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Effects of 1-Methylcyclopropene on Firmness Loss and the Development of Rots in Apple Fruit Kept in Farm Markets or at Elevated Temperatures

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SUMMARY. **Many of the apples (*Malus×domestica*) grown in the southeastern United States are sold to consumers through direct farm markets and roadside stands. Fruit in these markets may be exposed to high temperatures (>68 °F), which cause the fruit to ripen quickly, limiting their shelf life and consumer appeal and increasing their susceptibility to decay pathogens. Studies were undertaken in 2009 and 2010 to determine the effects of a 1-μL·L^{-1} postharvest 1-methylcyclopropene (1-MCP) treatment on the maintenance of flesh firmness and the incidence of rots in fruit held at elevated temperatures for up to 8 weeks. 1-MCP-treated fruit of three apple cultivars (Ginger Gold, Gala, and Golden Delicious) held in three retail farm markets in the southeastern United States maintained their firmness for 3 to 5 weeks. The firmness of non-treated 'Ginger Gold' fruit declined to less than 12 lbf after 1 week in each market, whereas the firmness of treated fruit remained greater than 16 lbf after 3 weeks. Treated 'Gala' fruit maintained their firmness at 14 lbf during 4 weeks in each farm market, whereas the firmness of non-treated fruit declined to less than 12 lbf after 2 weeks. The firmness of non-treated 'Golden Delicious' fruit declined to less than 12 lbf after 1 week in each farm market, whereas treated fruit maintained their firmness for up to 4 weeks. 'Golden Delicious' fruit treated with 1-MCP exhibited almost no loss of firmness during 4 weeks at 32, 50, or 70 °F, or even up to 8 weeks at 32 or 50 °F. The incidence of fruit rots increased with temperature, and 1-MCP reduced the incidence of fruit rots after 4 weeks at 70 °F in 2009 or after 8 weeks at 70 °F in 2010. These data show that 1-MCP may be of great benefit to producers who sell their fruit directly to the consumer by delaying the loss in firmness and reducing the incidence of rots in fruit kept at elevated temperatures.**

Many apples grown by producers in the southeastern United States are sold directly to the consumer through farm markets. Fruit in these markets may be held at high temperatures (>68 °F) for prolonged periods before sale. Exposure to such high temperatures will cause fruit to ripen quickly, limiting their shelf life and consumer appeal and resulting in increased losses because of the development of fruit rots caused by pathogens, such as white rot (*Botryosphaeria dothidea*) and bitter rot (*Colletotrichum gleosporoides*). Overmature fruit are unsalable in retail outlets and are disposed of, usually at very low prices, representing a significant loss in fruit value.

Many of the changes that occur during apple fruit ripening, including increases in respiration, softening of the flesh, and production of volatile aroma compounds, are triggered by the autocatalytic rise in ethylene production (Schaffer et al., 2007). The ethylene action inhibitor 1-MCP (SmartFresh; AgroFresh, Spring House, PA) has been widely adopted in commercial practice as a postharvest treatment for delaying the loss of flesh firmness of apples held for long periods in either air or controlled atmosphere storage (Watkins and Miller, 2005).

Many factors can influence the response of apples to 1-MCP. DeEll et al. (2008) noted that cultivars tended to behave differently and that responses often varied with storage conditions. This variability may also be related to factors such as the internal ethylene concentration (IEC) of fruit at harvest or their rate of ripening (Jung and Lee, 2009) or the delay between harvest and treatment (DeEll et al., 2008; Parker et al., 2010; Watkins and Nock, 2005). The effects of 1-MCP on firmness after holding fruit for 7 d at temperatures around 68 °F following cold storage is frequently reported in the literature. However, only a handful of studies have examined the potential for 1-MCP to maintain the firmness of fruit held at elevated temperatures for prolonged periods (Fan et al., 1999; Jung and Lee, 2009; Mir et al., 2001; Toivonen and Lu, 2005). None have reported the effects on firmness of fruit held in uncontrolled environments such as those found in many farm markets.

The effects of 1-MCP on the incidence of fruit rots either during or after storage in apple have been variable (Watkins, 2008). Several of these studies have involved wound inoculations with rot pathogens and storing the fruit at low temperatures (Janisiewicz et al., 2003; Leverentz et al., 2003; Saftner et al., 2003). Others have investigated the effects of 1-MCP on naturally occurring pathogens in fruit held in cold storage (DeEll et al., 2007) or continuously at 20 °C (Mir et al., 2001).

The objective of this research was to determine if 1-MCP could maintain the firmness of apple fruit and reduce losses because of fruit rots of apples held in uncontrolled environments or at elevated temperatures typical of many retail farm markets in the southeastern United States. The cultivars Ginger Gold, Gala, and Golden Delicious were chosen because of their importance to the fresh market apple industry in this region.

Materials and methods

Market study. Fruit of three apple cultivars (Ginger Gold, Gala, and Golden Delicious) were harvested at a stage of maturity that was within the guidelines for commercial 1-MCP treatment for each cultivar (AgroFresh, 2009). The harvest dates were 4 Aug. 2009 for 'Ginger Gold', 19 Aug. 2009 for 'Gala', and 10 Sept. 2009 for 'Golden Delicious'. 'Ginger Gold' fruit were harvested from a commercial orchard in Henderson County, NC, whereas 'Gala' and 'Golden Delicious' were harvested from mature trees in a uniform orchard on the Mountain Horticultural Crops Research and Extension Center, Mills River, NC. 'Ginger Gold' and 'Gala' trees were managed according to commercial production practices. 'Golden Delicious' trees were managed according to commercial production practices except that they did not receive foliar calcium sprays. Harvest maturity was evaluated on four 10-apple samples of each cultivar. Starch index (SI) was rated according to the Cornell starch chart (Blanpied and Silsby, 1992), where 1 = 100% staining and 8 = 0% staining. Fruit firmness was measured on opposite pared sides of each fruit using a fruit texture analyzer (model GS-14; Güss Manufacturing, Strand, South Africa) and expressed as pounds force. Soluble solids concentration (SSC) of a composite juice sample was measured using a digital refractometer (model PR-32 α; Atago U.S.A., Bellevue, WA) after extracting the juice from a vertical wedge taken from each apple in a juice extractor (model Big Mouth Pro; Hamilton Beach, Richmond, VA).

Fruit were placed into 24 wooden crates at harvest with ≈100 fruit in each crate (≈2400 fruit per cultivar) and immediately placed in cold storage at 32 °F. Half of the fruit samples (12 crates) were moved to an adjacent cold storage room at the same temperature and exposed to 1 $\mu L \cdot L^{-1}$ 1-MCP for 24 h either 1 d ('Golden Delicious') or 2 d ('Ginger Gold' and 'Gala') after harvest. Immediately after treatment, all samples were moved to the same cold storage room. Fruit were treated with 1-MCP by placing the wooden crates onto a pallet in the cooler and covering them with a polyethylene pallet cover fitted over a 4.0-m^3 polyvinyl chloride pipe frame and sealed to a linoleum floor cover with duct tape. 1-MCP was applied using a SmartFresh Research Tablet Generator [RTG (AgroFresh)]. The appropriate number of 1-MCP tablets was dissolved in 18 mL of activator solution together with an activator tablet. A battery-operated fan (model 2000001021; Coleman, Wichita, KS) was placed on the floor of the tent beside the RTG to facilitate circulation of 1-MCP throughout the tent. For each 1-MCP treatment, a sample of ≈10 tomato fruit at the breaker stage of maturity were placed in the treatment chamber and a second sample of 10 tomato fruit at the same maturity stage was placed in the cooler with the control fruit. After treatment, both tomato fruit samples were held at 70 °F to continue ripening. Observation of the progression of red color development in these samples provided quick confirmation of treatment efficacy.

After treatment, the fruit were transferred to one-bushel (42 lb) cardboard apple boxes without plastic liners and separated into three sets of four treated and non-treated boxes of each cultivar. The cardboard boxes were not ventilated apart from normal air movement through the ends (handle vents) and upper and lower seams. The cardboard boxes of each cultivar were stacked together on a wooden pallet and stored on the floor in a cold room at 32 °F for 21 d ('Ginger Gold') or 7 d ('Gala' and 'Golden Delicious') before they were transported in an unrefrigerated covered truck to three farm markets that were within 50 miles of the Mountain Horticultural Crops Research and Extension Center. The delay from treatment until placement in the retail markets was required because the markets had not yet opened for the season. Two of the farm markets were in Henderson County, NC (NC1, NC2), whereas the third market was in Greenville County, SC (SC). One of the farm markets (NC1) was an air-conditioned market, whereas the other two were open-air markets. Air temperatures (±1.0 °C) were recorded at 60-min intervals in each market by placing a temperature data logger (*i*Button model DS1921G; Maxim Integrated Products, Sunnyvale, CA) in the center of a box of fruit in each farm market. The relative humidity (RH) in each farm market was not recorded. Four replicate boxes of treated and non-treated fruit were placed in each market. A sample of 10 sound fruit was removed from each box when it was placed in each market and at 7-d intervals thereafter for the measurement of flesh firmness, SSC, and SI as previously described. The incidence of fruit rots was not recorded in the market study.

Storage temperature studies. Two additional wooden bins, each containing ≈18 bushels (756 lb) of 'Golden Delicious' apples, were harvested on the same day and from the same group of trees as those harvested for the market study in 2009. One of the bins was moved to a cooler at 32 °F and exposed to 1 $\mu L \cdot L^{-1}$ 1-MCP as described earlier for 24 h on the day of harvest (i.e., while the fruit were in the process of cooling). The second bin was held in an adjacent cooler at

The mention of trade names implies no endorsement of the products mentioned, nor criticism of similar products not mentioned.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.0352	bushel(s)	m^3	28.3776
29.5735	fl oz	mL	0.0338
0.0283	ft^3	m^3	35.3147
0.4536	lb	kg	2.2046
4.4482	lbf	N	0.2248
1.6093	mile (s)	km	0.6214
1	ppm	$\mu L \cdot L^{-1}$	1
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

32 °F. After treatment, the fruit were sorted into 12 one-bushel lots of treated and control fruit (each with ≈ 100 sound apples), and placed in cardboard apple boxes. The fruit were held in the same cooler for 27 d until 7 Oct. when four replicate bushels of treated and non-treated fruit were moved to each of three different storage temperatures (32, 50, and 70 °F). The fruit in each box that developed rots were counted and removed at weekly intervals until 4 weeks at each storage temperature. A subset of 10 sound fruit were removed from each replicate sample at weekly intervals, and maturity (flesh firmness, SSC, and SI) was measured after 24 h at 70 °F as described earlier. The incidence of fruit that developed rots each week during storage was calculated as a percentage of the sound fruit each week.

A similar study was conducted in 2010 using fruit from the same ‘Golden Delicious’ orchard. Twenty-four wooden crates, each containing ≈100 fruit, were harvested on Sept. 13, and maturity was determined on four replicate samples of 10 fruit as described earlier (firmness = 15.0 lbf, SI = 5.0, SSC = 12.8%). Internal ethylene concentration was also measured at harvest in 2010 by injecting a 1-mL gas sample drawn from the core cavity of each fruit onto a gas chromatograph (model GC-8A; Shimadzu Corp., Kyoto, Japan) fitted with an activated alumina stainless steel column and a flame ionization detector. The fruit were separated into two groups of 12 crates. One group was moved to a cooler at 32 °F and exposed to 1 $\mu L \cdot L^{-1}$ 1-MCP as described earlier for 24 h on the day of harvest, whereas the second group was held in an adjacent cooler at 32 °F. The fruit were transferred to cardboard boxes immediately after treatment and held at three storage temperatures (32, 50, and 70 °F) as described earlier. The number of fruit in each box that developed rots were counted and removed after 1, 2, 4, and 8 weeks of storage. Fruit maturity (flesh firmness, SSC, and SI) was measured at each removal time on a sample of 10 sound fruit per replicate after 24 h at 70 °F as described earlier. The incidence of fruit that developed rots was calculated as in the previous study.

STATISTICAL ANALYSIS. Data in the market study were analyzed separately for each cultivar and farm market. The effects of 1-MCP and storage time on fruit firmness and the development of rots were analyzed separately for each temperature using the mixed model procedure of SAS (version 9.1; SAS Institute, Cary, NC).

Results and discussion

The maturity of ‘Gala’ fruit harvested for the market study was within the recommended guidelines for 1-MCP treatment, whereas the SI of ‘Ginger Gold’ was 0.2 units higher than the upper limit (3.2 vs. 3.0). The firmness of ‘Golden Delicious’ had already declined below the recommended level but the SI was still relatively low (Table 1). ‘Ginger Gold’ fruit were treated 2 d after harvest and held in air storage at 32 °F for an additional 21 d after treatment before being sent to each farm market. The air temperatures to which fruit were exposed were only slightly different in each farm market (Fig. 1). However, the RH would have been significantly lower in NC1

Table 1. Recommended and actual harvest maturity parameters of ‘Ginger Gold’, ‘Gala’, and ‘Golden Delicious’ apples in the market study. Maturity parameters were determined on four replicate samples of 10 fruit.

	Recommended harvest maturity parameters[z]			Actual harvest maturity parameters		
Cultivar	SI (1–8 scale)[y]	Firmness (lbf)[x]	Harvest date (2009)	SI (1–8 scale)	Firmness (lbf)	SSC (%)
Gingergold	1.5–3.0	17.0	4 Aug.	3.2	17.9	11.5
Gala	3.0–6.0	16.0	19 Aug.	4.7	17.5	11.7
Golden Delicious	4.0–6.5	15.5	10 Sept.	3.7	14.2	11.9

[z]Based on AgroFresh (2009).
[y]1 = 100% staining, 8 = 0% staining.
[x]1 lbf = 4.4482 N.
SI = starch index; SSC = soluble solids concentration.

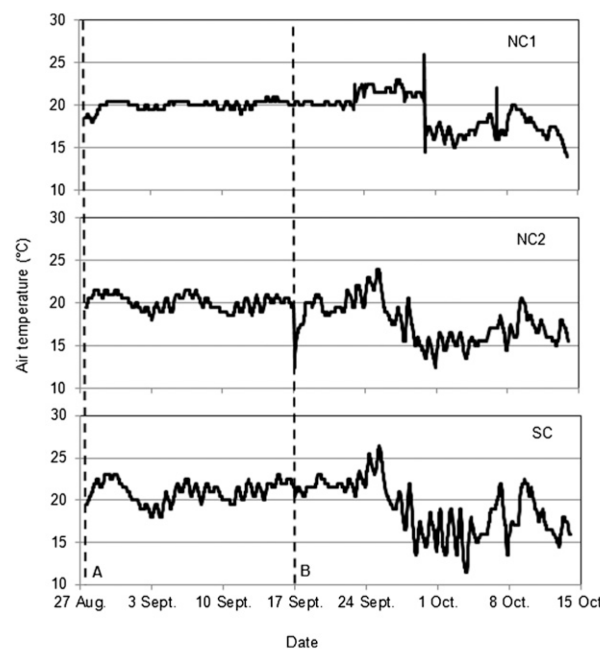

Fig. 1. Hourly air temperatures during the period when fruit of three apple cultivars were placed in three farm markets in the southeastern United States. Two of the farm markets (NC1 and NC2) were in Henderson County, NC, whereas the third farm market (SC) was in Greenville County, SC. NC1 was an enclosed air-conditioned market, whereas NC2 and SC were open-air markets. Temperature loggers were placed inside the cardboard boxes containing fruit samples at each location. Dashed lines indicate the date that ‘Ginger Gold’ and ‘Gala’ fruits (line A) and ‘Golden Delicious’ fruit (line B) were placed in each market. ‘Ginger Gold’ was held in the markets for 3 weeks, whereas ‘Gala’ and ‘Golden Delicious’ were kept in the markets for 4 weeks; (1.8 × °C) + 32 = °F.

compared with the other two markets since it was air conditioned. Fruit in the NC1 market were held at ≈20 °C until 30 Sept., when the air conditioning in this market was turned off and temperatures fluctuated between 15 and 20 °C during the remainder of the study. Air temperatures in the NC2 market fluctuated slightly more than the NC1 market, but overall were very similar. Average air temperatures in the SC market were higher than that in the two NC markets during September.

Non-treated 'Ginger Gold' fruit were already 0.9 lbf softer than treated fruit when they were sent to the markets (Fig. 2), after 21 d storage at 32 °F. 'Gala' fruit were treated with 1-MCP 2 d after harvest and held in air storage at 32 °F for an additional 7 d before being sent to the markets. Firmness of treated and non-treated 'Gala' fruit was similar when they were sent to the farm markets. 'Golden Delicious' fruit were treated with 1-MCP on the day of harvest and held in regular air storage at 32 °F for 7 d before they were sent to the markets. Non-treated 'Golden Delicious' fruit declined in firmness by 0.9 lbf during this time in cold storage, whereas fruit treated with 1-MCP did not exhibit any loss in flesh firmness before they were sent to the farm markets.

Non-treated fruit exhibited rapid softening in each market regardless of cultivar (Fig. 2), although the rate of firmness decline of 'Ginger Gold' during the first week in each market (≈6 lbf) was greater than 'Gala' (≈4 lbf) or 'Golden Delicious' (≈3 lbf). The firmness of non-treated 'Ginger Gold' fruit declined to 10 lbf during the first week and remained at 10 lbf until the final measurement time, 3 weeks later. No firmness measurements of 'Ginger Gold' were taken after this time because there were insufficient numbers of sound fruit across both treatments. The firmness of non-treated 'Gala' fruit continued to decline until the final measurement, 4 weeks later. Non-treated 'Golden Delicious' fruit declined in firmness by ≈1.5 lbf during the 2nd week in the markets but remained at ≈9 lbf after this time. 1-MCP dramatically slowed, and in the case of 'Golden Delicious' effectively inhibited, the loss of fruit firmness in each market (Fig. 2). The minimum firmness difference in apple fruit evoking a sensory response in a trained taste panelist was found to be 6 N (Harker et al., 2002), equivalent to 1.3 lbf. Because the firmness loss of all three cultivars during the first week in each market was at least double this amount, it is likely that most consumers would detect a firmness difference between 1-MCP-treated and non-treated fruit at this time, and probably much earlier in the case of 'Ginger Gold'.

The positive effects of 1-MCP on maintaining flesh firmness in apple fruit held in farm markets must be weighed against any negative effects on other quality attributes, including a reduction in production of the volatile aroma compounds that help define the unique characteristics of a cultivar. Moya-Leon et al. (2007) reported that while exposure to 1-MCP depressed the aromatic volatile production in 'Royal Gala' fruit after storage, treated fruit were in fact preferred by untrained sensory panelists. Marin et al. (2009) reported that while consumers were able to distinguish 1-MCP-treated 'Gala' fruit from non-treated fruit that were matched for firmness, similar number of consumers preferred non-treated fruit as those preferring 1-MCP-treated apples. The results of these studies would suggest that the reduced production of aroma volatiles resulting from 1-MCP treatment is probably of less importance to most consumers than the maintenance of fruit firmness. In the case of cultivars that soften rapidly (e.g., 'Ginger Gold'), it is reasonable to speculate that the majority of consumers would prefer 1-MCP-treated fruit with a firmness of 16 lbf to non-treated fruit that had a firmness of only 10 lbf after 7 d in the market. Even in the case of cultivars that exhibit a strong characteristic aroma when ripe (e.g., 'Gala'), consumers did not prefer non-treated fruit over 1-MCP-treated fruit of the same firmness (Marin et al., 2009).

'Golden Delicious' fruit used in the 2009 storage temperature study were treated with 1-MCP at 32 °F on the day of harvest and held for an additional 27 d at 32 °F before being moved to each storage temperature. In contrast, fruit in the 2010 storage temperature study were transferred to each storage temperature immediately after 1-MCP treatment. Fruit treated with 1-MCP were firmer than non-treated fruit [14.7 lbf for treated fruit, 13.4 lbf for non-treated fruit ($P = 0.03$)] when they were transferred to the different temperatures at the beginning of the 2009 study, but the SI values were not statistically different (SI of treated fruit was 4.2 and SI of non-treated fruit was 4.9). Treated fruit were firmer than non-treated

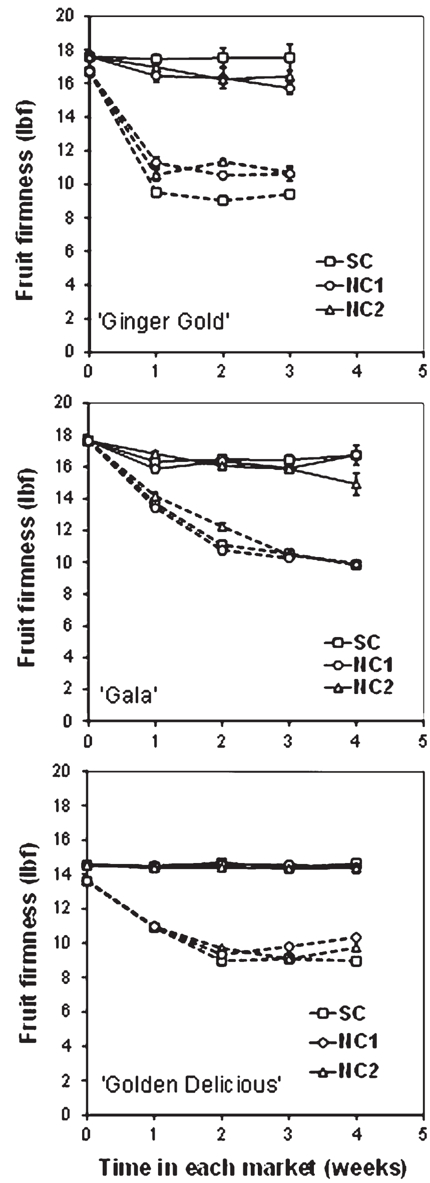

Fig. 2. Effects of a 24-h postharvest exposure to 1 μL·L^{-1} (ppm) 1-methylcyclopropene (1-MCP) at 32 °F on firmness of 'Ginger Gold', 'Gala', and 'Golden Delicious' apple fruit in three different farm markets in the southeastern United States. Two of the farm markets were in Henderson County, NC (NC1 and NC2), whereas the third farm market (SC) was in Greenville County, SC. Solid lines represent 1-MCP-treated fruit and dashed lines represent non-treated fruit. Error bars represent ± SE; 1 lbf = 4.4482 N, (°F − 32) ÷ 1.8 = °C.

fruit at all measurement times regardless of storage temperature in the 2009 study (Fig. 3). The firmness of non-treated fruit was inversely related to storage temperature, while storage temperature had no effect on the firmness of 1-MCP-treated fruit. As in the market study, there was no apparent loss of firmness in 'Golden Delicious' fruit that were treated with 1-MCP and held for up to 4 weeks at high temperatures (70 °F).

The 'Golden Delicious' fruit used in the 2010 storage temperature study were harvested on 13 Sept. (firmness was 15.0 lbf, SI was 5.0, and SSC was 12.8). The average IEC of fruit at harvest was 0.53 $\mu L \cdot L^{-1}$, with only 10% of fruit having an IEC >1.0 $\mu L \cdot L^{-1}$. These parameters indicate that the fruit were at an ideal stage of maturity for 1-MCP treatment. The fruit in this study were treated on the day of harvest and moved to the different storage temperatures immediately after treatment. As in the 2009 study, there was again no effect of storage temperature on the firmness of treated fruit during the first 4 weeks in storage (Fig. 3). However, 1-MCP-treated fruit held for 8 weeks at 70 °F were softer than treated fruit held at either 32 or 50 °F. Thus, 1-MCP-treated fruit could be held for up to 4 weeks at 70 °F or for at least 8 weeks at 32 or 50 °F without significant loss of fruit firmness. In contrast, non-treated fruit started to lose firmness after only 2 weeks at 32 or 50 °F or less than 1 week at 70 °F (Fig. 3).

White rot and black rot were the only two rot pathogens that were observed on fruit in the storage temperature studies. The total incidence of fruit rots were analyzed regardless of the causal pathogen. The incidence of fruit that developed rots was highest during the 2nd week of storage in the 2009 'Golden Delicious' study, where fruit were held for 28 d at 32 °C before being moved to the different storage temperatures. The 4-week storage delay between treatment and moving the fruit to the different temperatures may have resulted in the higher levels of decay in 2009 compared with 2010. There was a significant interaction between 1-MCP treatment and storage time on the incidence of rots in fruit stored at 32 °F (Table 2); rots developed earlier in 1-MCP-treated fruit compared with non-treated fruit. Although there was no effect of 1-MCP on rots in fruit stored at 50 °F (P = 0.08), 1-MCP significantly reduced the rot incidence in fruit stored at 70 °F in the 2009 study (Table 2). The overall incidence of fruit rots was much lower in 2010 with fewer than 10% of non-treated fruit and 2% of treated fruit developing rot after 4 weeks of storage regardless of temperature (Table 3). A high incidence of rot developed in fruit stored at 70 °F for 8 weeks, and 1-MCP reduced the incidence of rots in fruit stored at this temperature. These data show that 1-MCP greatly reduced, but did not eliminate, the incidence of rot when fruit were stored at high temperatures for long periods. However, keeping fruit at high temperatures should not be contemplated in years when the likelihood of fruit rots might be high. This could occur in years with warm, wet summers where

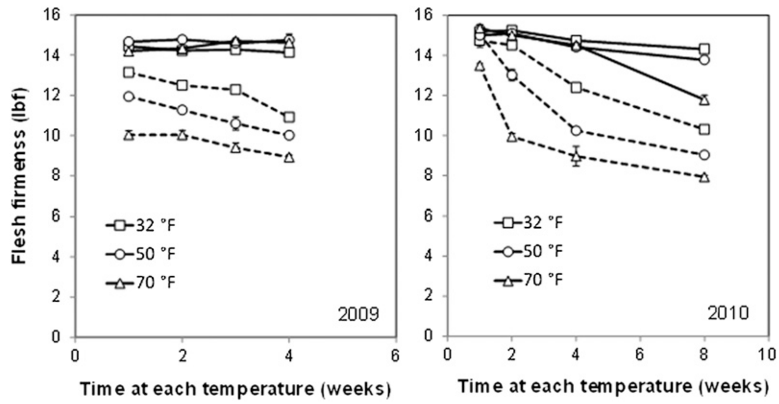

Fig. 3. Effects of a 24-h postharvest exposure to 1 $\mu L \cdot L^{-1}$ (ppm) 1-methylcyclopropene (1-MCP) at 32 °F on the firmness of 'Golden Delicious' apple fruit held in air at three different storage temperatures in 2009 and 2010. Solid lines represent 1-MCP-treated fruit; dashed lines represent non-treated fruit. Fruit were exposed to 1-MCP on the day of harvest and held at 32 °F for 28 d before being moved to each storage temperature in 2009. Fruit were exposed to 1-MCP on the day of harvest and moved to each storage temperature immediately after treatment in 2010. Treated and non-treated fruit were 14.7 and 13.4 lbf, respectively, when placed in each storage temperature in 2009. Treated and non-treated fruit were both 15.0 lbf when placed in each storage temperature in 2010. Error bars represent ± SE; 1 lbf = 4.4482 N, (°F − 32) ÷ 1.8 = °C.

Table 2. Effects of a 24-h postharvest exposure to 1 $\mu L \cdot L^{-1}$ (ppm) 1-methylcyclopropene (1-MCP) at 32 °F on the incidence of 'Golden Delicious' apple fruit that developed rots each week during storage at three different temperatures in 2009. Fruit were exposed to 1-MCP on the day of harvest and held at 32 °F for 28 d before being moved to each storage temperature.

Treatment	Time in storage (weeks)	Rot incidence (%)		
		32 °F[z]	50 °F	70 °F
Control	1	0.0	3.0	7.1
	2	1.2	7.0	21.9
	3	1.5	1.7	7.7
	4	6.9	6.6	11.2
1-MCP	1	0.0	8.0	7.9
	2	8.7	12.5	10.1
	3	4.6	4.4	6.8
	4	1.6	5.5	9.7
Significance[y]				
1-MCP		NS	NS	*
Time in storage		NS	**	**
Interaction		**	NS	NS

[z](°F − 32) ÷ 1.8 = °C.

[y]NS, *, **Nonsignificant or significant at P < 0.05 or 0.01, respectively, via the type 3 test of fixed effects using an autoregressive covariance structure.

Table 3. Effects of a 24-h postharvest exposure to 1 $\mu L \cdot L^{-1}$ (ppm) 1-methylcyclopropene (1-MCP) at 32 °F on the incidence of 'Golden Delicious' apple fruit that developed rots each week during storage at three different temperatures in 2010. Fruit were exposed to 1-MCP on the day of harvest and moved to each storage temperature immediately after treatment.

Treatment	Time in storage (weeks)	Rot incidence (%)		
		32 °F[z]	50 °F	70 °F
Control	4	0.0	0.0	8.7
	8	0.0	0.5	34.1
1-MCP	4	0.0	0.0	1.5
	8	0.0	0.0	11.3
Significance[y]				
1-MCP		—	NS	*
Time in storage		—	NS	**
Interaction		—	NS	NS

[z](°F − 32) ÷ 1.8 = °C.
[y]NS, *, **Nonsignificant or significant at $P < 0.05$ or 0.01, respectively, via the type 3 test of fixed effects using an autoregressive covariance structure.

greater inoculum pressure from summer rot pathogens would be expected.

1-MCP reduced ('Ginger Gold', 'Gala') or even eliminated ('Golden Delicious') the loss of firmness that occurred in fruit held in retail farm markets or at temperatures up to 70 °F. The flesh firmness of treated fruit was still acceptable after 3 or 4 weeks in each market, whereas the firmness of non-treated fruit declined to unacceptable levels (<12 lbf) within 1 week ('Ginger Gold', 'Golden Delicious') or 2 weeks ('Gala'). Postharvest 1-MCP treatment eliminated the negative effects of high temperatures (70 °F) on softening for up to 4 weeks. Significant fruit rots developed in non-treated fruit after 2 weeks at 70 °F in 2009 but not until after 4 weeks at the same temperature in 2010. 1-MCP significantly reduced the incidence of rots in fruit held at 70 °F. Storing 1-MCP-treated fruit under high temperatures should not be considered in years when the likelihood of fruit rots is high. 1-MCP may provide significant benefits for the many apple growers in the southeastern United States who sell their fruit directly to the consumer through retail farm markets.

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