

Firmness Retention, and Prevention of Coreline Browning and Senescence in ‘Macoun’ Apples with 1-Methylcyclopropene

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Abstract. 1-Methylcyclopropene (1-MCP) maintained firmness of ‘Macoun’ apple (*Malus ×domestica* Borkh.) above 50 N after 90 to 100 days regular air storage when harvested at a starch index of 2.7 to 3.5, and after 50 days when harvested at a starch index past 4.0. Softening of ‘Macoun’ was slowed by 1-MCP in both preclimacteric and climacteric fruit, but for a shorter duration in climacteric fruit. 1-MCP reduced but did not eliminate the occurrence of senescent breakdown. The effect of 1-MCP on coreline browning was inconsistent, reducing its occurrence in 2002 and 2003, but increasing its occurrence in 2001 when fruit were harvested at an advanced maturity.

‘Macoun’ is a high-value apple cultivar in New England because of its high consumer appeal and limited production. It is popular because of its flavor, but loses its appeal within a few months of harvest because of rapid softening. In addition to softening, ‘Macoun’ is prone to senescent breakdown, typically succumbing after two to three months in regular air storage. As a result, production remains less than 10% of the total in New England.

The ethylene inhibitor, 1-methylcyclopropene (1-MCP), has the potential to slow softening and to prevent disorders of apple (Fan et al., 1999b), but the effect on firmness is short-lived with regular air storage (Watkins et al., 2000; Weis and Bramlage, 2002). Since most ‘Macoun’ are stored in regular air, efficacy may be short-lived with this cultivar. Additionally, 1-MCP can be less effective in fruit of more advanced maturity (Mir et al., 2001; Watkins and Nock, 2000), so it is not known when to harvest for maximum efficacy in delaying softening of ‘Macoun’ apple. The objective of this project was to evaluate effectiveness of 1-MCP on maintaining firmness and preventing disorders of ‘Macoun’ at different stages of maturity.

Materials and Methods

‘Macoun’ apples were harvested at different maturity stages, 24 Sept. and 4 Oct. 2001, 7 and 15 Oct. 2002, and 1 and 8 Oct. 2003. The orchards were located at the University of Maine Agricultural Experiment Station in Monmouth. In 2001 and 2002, fruit were har-

vested from trees on various dwarf rootstocks, part of a rootstock trial planted in 1995. In 2003, fruit were harvested from trees on B.9 rootstock planted in 1998. Flesh firmness and starch index were measured on 10 fruit at each date. The Cornell Starch Chart was used where 1 = all starch remaining and 8 = no starch (Blanpied and Silsby, 1992). Internal ethylene concentration (IEC) at harvest was measured in 10 fruit in 2002 and 2003.

In each year of the study, apples were exposed to 1-MCP (EthylBlocJ, Rhom and Haas in 2001; SmartFresh, AgroFresh in 2002 and 2003) within 24 h of harvest. Fruit were exposed to 1 $\mu\text{L}\cdot\text{L}^{-1}$ for 21 to 24 h in 45-L sealed portable coolers. Fruit temperature during exposure to 1-MCP ranged from 12 to 20 °C. In 2001, concentrated 1-MCP gas was injected with a syringe into sealed coolers through a rubber septum inserted into a hole on the side of the cooler. In 2002 and 2003, a vial containing 1-MCP dissolved in water was placed inside the cooler. The vial cap was removed just before closing the cooler. A portable fan circulated the air inside. Fruit were stored at 3 °C in regular air for 100 d in 2001. In 2002 and 2003, fruit were stored at 1 °C in regular air for 50 and 90 d. Following storage, fruit were held at 20 °C for 1 and 7 d when IEC was measured on five to six replications each containing five sound fruit in 2001, and ten fruit per replication in 2002 and 2003. Firmness was measured on 10 fruit per replication after 1 and 7 d at 20 °C. Senescent breakdown, stem end browning and coreline browning were measured on about 50 fruit per replication after 7 d at 20 °C.

Firmness of peeled flesh was measured on the green and red side of each fruit with an electronic pressure tester (model EPT-1; Lake City Technical Products, Kelowna, Canada). Soluble solids was measured from a composite juice sample of five fruit using a temperature-compensated digital hand-held refractometer (PR-101; Atago, Japan). To measure IEC, a 25-mm-long stainless steel needle with syringe was inserted through the calyx end to remove

1 mL of gas. This gas was injected into a gas chromatograph with a flame ionization detector (GC-8A; Shimadzu, Kyoto, Japan). The gas chromatograph was fitted with a 450 × 3-mm stainless-steel column packed with activated alumina. Flame ionization detector temperature was 200 °C and column temperature 80 °C. Peak area was integrated with an integrator (model 3395; Agilent Technologies, Wilmington, Del.). Ethylene concentration was calculated using a standard of 9.5 $\mu\text{L}\cdot\text{L}^{-1}$.

The study had a randomized complete block design with a two-way factorial arrangement of harvest and 1-MCP treatment. The treatments were replicated six times in 2001 and 2002 with ten trees in each replication. In 2003, there were five replications with four trees within each replication. Data were analyzed by ANOVA with mean separation by LSD (SAS, Inst., Inc., 2000). Percent incidence of each disorder was arcsine-transformed for analysis.

Results

In 2001, starch index was 3.0 at the first harvest and 5.6 at the second. In 2002, starch index was 3.1 at the first harvest and 4.9 at the second. Mean IEC was undetectable at the first harvest and 29 $\mu\text{L}\cdot\text{L}^{-1}$ at the second. In 2003, starch index was 2.7 at the first harvest and 3.5 at the second. Mean IEC was 4.1 $\mu\text{L}\cdot\text{L}^{-1}$ at the first harvest and 1.1 $\mu\text{L}\cdot\text{L}^{-1}$ at the second.

Internal ethylene after storage was not affected by harvest date or by 1-MCP in 2001 (Table 1). In 2002, IEC was reduced by MCP at 50 and 90 d. At 90 d there was an interaction with harvest date when IEC was greater in fruit from the first harvest, but only in untreated fruit. In 1-MCP fruit, there was no difference in IEC. Internal ethylene followed a similar pattern in 2003 with an interaction of 1-MCP and harvest date. In 1-MCP-treated fruit, IEC remained at an undetectable level in fruit from both harvests, but in untreated fruit was greater with the first harvest compared to the second.

In 2001, after 4 months storage and 1 d at 20 °C, firmness was not affected by harvest date or by 1-MCP (data not shown). After 7 d at 20 °C, however, there was a significant effect of 1-MCP and harvest date with an interaction between these two factors (Table 1). At this time, 1-MCP-treated fruit were firmer than untreated with the first harvest, but not the second. 1-MCP-treated fruit from the second harvest softened in storage as much as untreated fruit. In 2002, both harvest date and 1-MCP affected firmness with a significant interaction between these two factors. The effect on firmness in 2002 and 2003 was similar after both 1 and 7 d at 20 °C, so only data from 7 d is shown. 1-MCP maintained firmness above that of untreated fruit after 50 and 90 d, but appeared to be more effective on fruit from the first harvest. After 50 d, firmness was greater by 17 N in first harvest fruit, but only by 8 N in second harvest fruit. After 90 d, firmness of first harvest fruit was greater by 7 N, but only by 4 N in second harvest fruit. After 50 and 90 d in 2003, both 1-MCP and harvest date affected firmness with an interaction between these two

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factors. As in 2002, untreated fruit were softer than 1-MCP-treated fruit, and this effect was more pronounced with the first harvest.

In 2001, post storage loss of firmness was reduced by 1-MCP (0.0N) in fruit from the first harvest ($P=0.0507$) compared to untreated fruit (5.0), but not from the second harvest when fruit softened by 4.2 N in both treatments. In 2002, poststorage loss of firmness was not affected by harvest date or by 1-MCP treatment. Fruit softened by 5 to 6 N after 50 d storage and by 1 to 4 N after 90 d storage. In 2003, 1-MCP reduced post storage loss of firmness in fruit from both harvests after 50 ($P = 0.0026$) and 90 d ($P = 0.0145$) with no harvest date interaction. Fruit softened by 7 to 9 N after 50 d storage in 1-MCP fruit compared to 2 to 6 N in untreated fruit. After 90 d, a similar pattern in softening occurred.

There was an interaction between harvest date and 1-MCP on soluble solids ($P = 0.0231$, data not shown) in 2001. Soluble solids was greater in 1-MCP-treated fruit from first harvest, but no difference occurred with the second harvest. Soluble solids in 2002 was not affected by harvest date or by 1-MCP following 50 d of storage (data not shown). After 90 d in storage, soluble solids was greater in 1-MCP-treated fruit ($P=0.0197$) with no effect of harvest date. In 2003, 1-MCP did not affect soluble solids after 50 or 90 d (data not shown).

1-MCP increased the occurrence of coreline browning in 2001, but this was slight and insignificant in fruit from the first harvest. 1-MCP more than doubled its occurrence in fruit from the second harvest. In 2002, coreline browning

was prevalent in fruit from both harvests and did not appear to worsen between 50 and 90 d. Unlike the previous season, 1-MCP reduced its occurrence with no difference between the two harvest dates. In 2003, coreline browning was less prevalent than in the previous year, and 1-MCP reduced its occurrence.

Senescent breakdown was not affected by harvest date or by 1-MCP in 2001. Occurrence of senescent breakdown in 2002 was slight in fruit from the first harvest, so 1-MCP had no effect. In fruit from the second harvest, senescent breakdown was more prevalent, and this was reduced by 1-MCP after both 50 and 90 d storage. In 2003, there was almost no senescent breakdown in either treatment after 50 d, so 1-MCP had no effect on its occurrence. After 90 d, when senescent breakdown was more prevalent, 1-MCP reduced its occurrence.

In 2002, stem-end browning did not occur until 90 d when 1-MCP reduced its occurrence from 7% to <1% in the first harvest, and from 4% to 2% in the second harvest ($P = 0.0073$). Harvest date did not affect stem-end browning. In 2003, stem-end browning did not occur.

Discussion

Although 'Macoun' is a popular and profitable apple cultivar in New England, production is limited to <10% of total because this cultivar softens quickly and is prone to senescent breakdown. Sales of 'Macoun' generally decrease after firmness softens to about 50 N. In this study, untreated fruit softened to 50 N or less as early as 50 d in regular air storage. 1-MCP

delayed softening in 'Macoun' as it does in other varieties (Fan et al., 1999b; Rupasinghe et al., 2000; Watkins et al., 2000). 1-MCP slowed softening so that firmness remained above 50 N for a period of 90 to 100 d when fruit were harvested at a starch index of 2.7 to 3.5. When fruit were harvested at a starch index past 4.0, firmness with 1-MCP remained above 50 N for >50 d, but <90 d. Previous reports with other varieties indicate that the effect of 1-MCP on firmness is temporary and becomes undetectable after several months in regular air storage (Dauny and Joyce, 2002; Watkins et al., 2001). This occurred in 2001 in fruit from the second harvest, but fruit from the first harvest were not stored long enough for this to occur. There was still a measurable effect of 1-MCP after 100 d in storage. For 'Delicious', there is a small decrease in 1-MCP effectiveness with advancing maturity from the preclimacteric to climacteric stage (Fan et al., 1999a; Mir et al., 2001), but once 'McIntosh' fruit are climacteric, there is little effect on firmness (Watkins et al., 2001). A delay in harvest of 1 week reduced but did not eliminate effectiveness of 1-MCP in maintaining firmness of 'Macoun' in each year of the study. In 2002, when mean IEC was above $0.1 \mu\text{L}\cdot\text{L}^{-1}$ and 75% of the fruit had detectable ethylene at harvest, fruit responded to 1-MCP, but softened more in storage than preclimacteric fruit. Although there was little difference in flesh firmness or IEC at harvest in 2003, 1-MCP was more effective with the first harvest. Fruit had $\text{IEC} > 0.1 \mu\text{L}\cdot\text{L}^{-1}$ at each harvest, but 1-MCP was very effective in maintaining firmness. However, only 10%

Table 1. Internal ethylene (IEC), fruit firmness and occurrence of disorders in 1-MCP-treated 'Macoun' at two harvest dates after 100 d regular air storage in 2001, and 50 and 90 d storage in 2002 and 2003. Measured after 7 d at 20 °C.

Harvest	Treatment	IEC ($\mu\text{L}\cdot\text{L}^{-1}$)		Firmness (N)		Senescent breakdown (%)		Coreline browning (%)	
		50 d	90 d	50 d	90 d	50 d	90 d	50 d	90 d
2001									
First	None	---	81	---	47 b ^y	---	10 b	---	14
	1-MCP	---	66	---	54 a	---	12 b	---	3
Second	None	---	85	---	46 b	---	10 b	---	10
	1-MCP	---	71	---	46 b	---	26 a	---	10
Analysis of variance									
Harvest			NS		**		NS		NS
1-MCP			NS		**		*		NS
1-MCP × harvest			NS		**		NS		NS
2002									
First	None	158 a	236 a	48 c	45 c	35 a	38 a	3 b	8 bc
	1-MCP	2 b	1 c	65 a	58 a	2 b	1 c	0 b	0 c
Second	None	164 a	105 b	45 d	42 d	24 a	26 b	24 a	39 a
	1-MCP	16 b	13 c	53 b	48 b	2 b	2 c	3 b	12 b
Analysis of variance									
Harvest			NS		***		NS		**
1-MCP			***		***		***		***
1-MCP × harvest			NS		***		NS		*
2003									
First	None	372 a	244 a	50 c	43 c	2 ab	---	2	9 ab
	1-MCP	0 c	0 c	73 a	64 a	0 b	---	0	4 b
Second	None	245 b	184 b	50 c	44 c	6 a	---	1	15 a
	1-MCP	0 c	1 c	64 b	56 b	0 b	---	0	3 b
Analysis of variance									
Harvest			*		**		NS		NS
1-MCP			***		***		*		**
1-MCP × harvest			*		**		NS		NS

^zNot measured at that time.

^yWithin a column, means followed by the same letter do not differ (LSD, 5% level).

NS,***,** Nonsignificant or significant at $P \leq 0.05, 0.01, \text{ or } 0.001$, respectively. Data for senescent breakdown and coreline browning were arcsine transformed for analysis, but actual means are presented.

of the fruit had detectable levels of ethylene at each harvest, so mean IEC was not the best measure of maturity in 2003.

The effect of 1-MCP on softening during post-storage ripening at 20 °C was inconsistent from year to year. In two years of the study, 1-MCP reduced poststorage softening, but in 1 year 1-MCP had no effect. In previous reports, 1-MCP resulted in less poststorage softening (Fan et al., 1999a; Watkins et al., 2001), but in another report (Rupasinghe et al., 2000) 1-MCP had an inconsistent effect. In this study, we compared the effect of 1-MCP over several years and found that it was inconsistent from year to year in slowing poststorage softening.

1-MCP reduced IEC of 'Macoun' after storage as previously reported for several other cultivars (Weis and Bramlage, 2002). Internal ethylene in 1-MCP-treated 'Macoun' was much lower than in untreated fruit after 50 and 90 d storage. However, in 2001, after 100 d in storage, there was no significant difference in IEC between 1-MCP-treated and untreated fruit. Fruit were stored at 3 °C in 2001, compared to 1 °C in the later years. This warmer storage temperature may have caused earlier loss of quality and hastened senescence in both treated and untreated fruit. 1-MCP-treated fruit eventually recover the ability to synthesize ethylene after several months in storage, particularly when stored in regular air (Rupasinghe et al., 2000; Watkins et al., 2000). This occurred by 100 d in 2001 when fruit were stored at an above optimum temperature.

1-MCP reduces or delays the occurrence of postharvest disorders such as senescent breakdown in 'Empire' and brown core in 'McIntosh'

(Watkins et al., 2000). 'Macoun' is very prone to senescent breakdown, which occurred in each year of the study, but was most severe in 2002. It began to develop in untreated fruit as early as 50 d in storage. 1-MCP reduced the occurrence of senescent breakdown, but did not completely prevent it since 1-MCP-treated fruit eventually developed it, as well. The occurrence of coreline browning varied from year to year, being very prevalent in 2001 and 2002, and much less prevalent in 2003. Symptoms were partial or complete browning of the coreline and resembled coreline browning that occurs with core browning of 'McIntosh' (Meheriuk et al., 1994). However, browning of the flesh adjacent to the seed cavity was rare in this study. The effect of 1-MCP on coreline browning was inconsistent, being increased by 1-MCP in 2001, and decreased by 1-MCP in 2002 and 2003. It is not clear why coreline browning was increased by 1-MCP in 2001, but could have been due to the advanced maturity with the second harvest since these fruit were harvested more mature than in later years.

Softening of 'Macoun' was slowed by 1-MCP in both preclimacteric and climacteric fruit, but for a shorter duration in climacteric fruit. For 'Macoun', 1-MCP has the potential to maintain optimum firmness during the normal two-month marketing window. 1-MCP did not completely prevent senescent breakdown or coreline browning, but in most instances these disorders were reduced to a very low level by 1-MCP.

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