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Interaction of Daminozide, Harvesting Date, and Ethylene in CA Storage on 'McIntosh' Apple Quality[1]

F. W. Liu
Department of Pomology, Cornell University, Ithaca, NY 14853

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Abstract. **Daminozide (butanedioic acid mono-(2,2-dimethylhydrazide) -treated 'McIntosh' apples (*Malus domestica* Borkh.) harvested at the preclimacteric stage did not soften in 7-½ months of controlled-atmosphere (CA) storage with <1 ppm ethylene in the atmosphere. These apples were satisfactorily firm and of acceptable-to-good quality after storage plus 7 days at 21°C. Apples from all other treatments were softer and had inferior quality. Control fruit harvested at the preclimacteric stage and stored in CA with a low ethylene level (<2.6 ppm) was also slightly firmer than similar fruit stored in CA with high ethylene (10 or 500 ppm). With a high ethylene level (500 ppm) in CA, daminozide-treated fruit was not firmer than control fruit and had more 'McIntosh' breakdown during the 7-day holding period after storage.**

Several investigators (5, 6, 11) have found that minimizing ethylene in CA storage often resulted in firmer 'McIntosh' apples after storage. The best result was obtained when fruit was harvested several days before the onset of climacteric, and the ethylene in CA was kept close to or below 1 ppm (6, 7). However, early harvest often sacrificed red color (6, 7) because anthocyanin synthesis is favored by late season cool temperatures and maturation or ripening. A delayed onset of the climacteric would be desirable if the aim is to harvest fruit at its preclimacteric stage and yet to have acceptable red color. Daminozide, a growth retardant which is used extensively in 'McIntosh' orchards to prevent preharvest drop, does delay the onset of the climacteric (2, 4, 9, 10). However, daminozide has been suspected of aggravating 'McIntosh' breakdown (1, 3). The purpose of this study was to learn the extent to which the condition and quality of 'McIntosh' apples could be improved by using daminozide to delay the climacteric in the orchard, and by minimizing ethylene in CA to retard ripening.

Materials and Methods

There were 12 treatments: 2 levels of daminozide (0 and 1,000 ppm) × 2 harvest dates per daminozide level × 3 levels of ethylene (low, 10 ppm, and 500 ppm) in CA. Six mature 'McIntosh' trees at the Cornell University orchard at Ithaca were selected. Three control trees had never been sprayed with daminozide, and 3 others were sprayed to the drip with 1,000 ppm daminozide in mid-July, 1977, with paired trees as replicates. Control trees were harvested on September 15 and 21, 1977. Preharvest drop, the onset of the respiratory climacteric and the ethylene production upsurge (7) occurred in fruit on these trees between these dates (data not shown). Daminozide-treated fruit was harvested on September 22 and 28. Preharvest drop and the onset of the climacteric did not occur in these fruits on or before September 28. Besides harvesting on these dates mentioned above, small samples (15 apples/tree) were periodically gathered for respiration and ethylene production measurements to monitor the onset of the climacteric.

After harvest, 30 apples from each tree were examined for firmness, acidity, and soluble solids levels (first evaluation) with methods reported previously (6). Other apples were placed into 19-liter (5-gal) jars, with 60 fruits/jar, which were left unstoppered at 2.2°C for overnight cooling. Each jar was then stoppered and a gas mixture containing 3% O_2, 3% CO_2, and 94% N_2 passed through it continuously at about 200 ml/min. The gas mixture was humidified by bubbling 85% of it (measured by a flow meter) through H_2O and then remixing it with the other 15% before being distributed to each jar. Two Petri dishes of Purafil (ethylene absorbent) were placed in each low-ethylene jar before stoppering. While no ethylene was added to these low-ethylene jars, some diluted ethylene (2% ethylene + 98% nitrogen in steel cylinders) was added continuously to the gas stream for other jars to bring the ethylene levels to 10 and 500 ppm beginning October 1. Thirty-six jars (12 treatments × 3 replicates) of apples described above were stored at 2.2 to 3.3° from harvest to early May, 1978. Ethylene content in the effluent gas from each jar was measured periodically with a gas chromatograph. The last ethylene measurement for low-ethylene jars was made 2 days after removal of Purafil from each jar in May in order to estimate ethylene production rates of apples in these jars. The maximum ethylene concentration before the last measurement was 0.94 ppm in low-ethylene jars containing daminozide-treated apples and was 2.57 ppm in similar jars containing control fruit. The ethylene concentrations in other jars were always 10 or 500 ppm with <10% error.

Apples were transferred to 21°C air after storage for condition and quality evaluations 1 and 7 days later (referred to in Tables 1 and 2 as second and third evaluations, respectively). Each treatment had triplicate 30-apple samples (½ of 60 apples in each jar) for each of the 2 evaluations. Each sample was displayed for sensory evaluations by 6 or 7 experienced apple taste panelists. Each panelist evaluated the composite 30-apple sample for surface color, ground color, gloss, and overall appearance. Then each panelist tasted 3 apples in each sample to evaluate firmness, sweetness, acidity, overall flavor and aroma, overall ripeness, and overall eating quality ignoring the color and appearance factors. A 5-point sensory scale was used for each item of evaluation. After the sensory evaluation the fruit was objectively evaluated for firmness, soluble solids, and acidity with methods reported previously (6). Every fruit was cut longitudinally after firmness evaluation. Fruits which had 'McIntosh' breakdown (12) with flesh browning visible on a cut surface were excluded from further objective evaluations. The firmness data of these "breakdown" apples were also discarded.

Results and Discussion

Fruits not treated with daminozide (control fruit) softened markedly in CA storage (Table 1). However, control fruit harvested at the preclimacteric stage (September 15) softened less in low ethylene (<2.6 ppm) than in high ethylene (10 or 500 ppm) in CA. After 7-½ months of storage the firmness

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Table 1. Effects of daminozide, harvest date, and ethylene in CA storage on firmness, acidity, and breakdown of 'McIntosh' apples.[z]

Daminozide	Harvest date	Ethylene (ppm)	Firmness (kg) At harvest	Firmness (kg) 2nd evaluation[y]	Firmness (kg) 3rd evaluation[x]	Acids (as mg malate/100 ml juice) At harvest	Acids (as mg malate/100 ml juice) 2nd evaluation[y]	Acids (as mg malate/100 ml juice) 3rd evaluation[x]	Breakdown (%) 2nd evaluation[y]	Breakdown (%) 3rd evaluation[x]
–	Sept. 15	<2.6	6.6 a[w]	5.5 c	4.9 b	660 a	381 cd	337 b	0	0
		10	–	5.0 de	4.6 cd	–	381 cd	333 b	0	0
		500	–	4.7 e	4.5 cd	–	377 cd	339 b	0	0
–	Sept. 21	<2.1	6.3 a	4.8 de	4.7 bcd	660 a	361 cd	325 b	0	0
		10	–	4.7 de	4.5 cd	–	373 cd	317 b	1.1	0
		500	–	4.5 cd	4.5 e	–	349 d	310 b	2.2	0
+	Sept. 22	<1.0	6.6 a	6.9 a	5.4 a	678 a	493 a	424 a	0	0
		10	–	5.1 cd	4.9 b	–	440 abc	374 ab	0	2.2
		500	–	4.9 de	4.8 bc	–	427 abcd	374 ab	0	7.8
+	Sept. 28	<1.0	6.1 a	6.1 b	5.3 a	637 a	473 ab	380 ab	0	0
		10	–	4.7 de	4.6 cd	–	398 bcd	346 b	0	6.7
		500	–	4.5 e	4.3 d	–	392 bcd	338 b	1.1	13.3

[z]Avg of triplicates, 30 apples in each replicate.

[y,x]Second and third evaluation were made after storage and 1 and 7 days at 21°C, respectively.

[w]Mean separation within columns, by Duncan's multiple range test, 5% level.

Table 2. Effects of daminozide, harvest date, and ethylene in CA storage on sensory evaluations of firmness, acidity, ripeness, flavor and aroma, and overall eating quality of 'McIntosh' apples.[z]

Evaluation time	Treatment: Daminozide	Treatment: Harvest date	Treatment: Ethylene (ppm)	Score: Firmness[y]	Score: Acidity[x]	Score: Ripeness[w]	Score: Flavor and aroma[v]	Score: Overall quality[v]
Second evaluation (made after storage and 1 day at 21°C)	–	Sept. 15	<2.6	2.96 bc[u]	2.91 ab	2.98 bc	2.59 abcd	2.57 abc
			10	2.48 cde	2.96 ab	3.42 cde	2.53 abcd	2.56 abc
			500	2.41 cde	2.72 bc	3.50 cde	2.22 d	2.23 c
	–	Sept. 21	<2.1	2.57 bcd	2.97 ab	3.17 bcd	2.94 a	2.94 ab
			10	2.61 bcd	2.89 ab	3.33 bcde	2.94 a	3.00 a
			500	2.29 cde	2.80 abc	3.57 cde	2.80 ab	2.76 abc
	+	Sept. 22	<1.0	3.61 a	3.07 a	2.36 a	2.72 abc	2.83 ab
			10	2.26 de	2.76 bc	3.68 de	2.62 abcd	2.51 abc
			500	2.17 de	2.84 abc	3.68 de	2.62 abcd	2.48 abc
	+	Sept. 28	<1.0	3.16 ab	2.81 abc	2.76 ab	2.85 ab	3.02 a
			10	2.19 de	2.68 bc	3.81 e	2.46 bcd	2.41 bc
			500	1.89 e	2.57 c	3.85 e	2.35 cd	2.17 c
Third evaluation (made after storage and 7 days at 21°C)	–	Sept. 15	<2.6	2.41 abc	2.70 ab	3.35 abc	2.52 bcd	2.49 bcd
			10	2.30 bcd	2.74 ab	3.54 abcd	2.50 bcd	2.54 bcd
			500	2.07 cd	2.58 abc	3.96 cde	2.40 cd	2.15 cde
	–	Sept. 21	<2.1	2.36 abc	2.71 ab	3.50 abcd	2.61 abc	2.59 bcd
			10	2.17 bcd	2.59 abc	3.70 bcd	2.57 bc	2.55 bcd
			500	2.06 cd	2.59 abc	3.95 cde	2.33 cd	2.19 cde
	+	Sept. 22	<1.0	2.91 a	2.96 a	3.04 a	3.11 a	3.22 a
			10	2.34 abc	2.72 ab	3.62 abcd	2.67 abc	2.67 abc
			500	1.96 cd	2.48 bc	4.04 de	2.32 cd	2.28 cd
	+	Sept. 28	<1.0	2.78 ab	2.89 a	3.27 ab	2.97 ab	3.02 ab
			10	1.97 cd	2.27 cd	3.97 cde	2.03 de	2.00 de
			500	1.70 d	1.95 d	4.40 e	1.72 e	1.74 e

[z]Avg of triplicate samples; each of 6 or 7 panelists evaluated 3 apples for each sample.

[y]5-point sensory scale: too hard=5, hard=4, crisp=3, melting=2, mealy=1.

[x]5-point sensory scale: too acid=5, slightly excessive=4, adequate=3, slightly deficient=2, definitely deficient=1.

[w]5-point sensory scale: overripe=5, ripe=4, firm ripe=3, hard ripe=2, unripe=1.

[v]5-point sensory scale: very good=5, good=4, acceptable=3, borderline=2, poor=1.

[u]Mean separation within columns within each evaluation by Duncan's multiple range test, 5% level.

difference between low and high ethylene treatments was <1 kg, similar to the results reported previously (6, 7).

Daminozide-treated fruit did not soften in CA with low (<1 ppm) ethylene levels, but softened in CA with high (10 or 500 ppm) ethylene levels (Table 1). The post-storage firmness difference between low and high ethylene CA was 1.4 to 2.0 kg. Daminozide-treated fruit stored in CA with low ethylene levels had average firmness values of 6.1 to 6.9 kg with a minimum

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Table 3. Effects of daminozide and harvest date on surface color of 'McIntosh' apples.[z]

Daminozide	Harvest date	Surface color[y]
–	Sept. 15	2.09 c[x]
–	Sept. 21	2.61 b
+	Sept. 22	2.94 a
+	Sept. 28	3.09 a

[z]Avg of 9 replicates with 30 fruits in each replicate evaluated by 6 or 7 panelists.

[y]5-point subjective scale: very good=5, good=4, acceptable=3, borderline=2, poor=1.

[x]Mean separation by Duncan's multiple range test, 5% level.

individual fruit firmness of 5.5 kg (12 lb.) after storage plus 1 day holding at 21°C (second evaluation), and had average firmness values of 5.3 to 5.4 kg with a minimum individual fruit firmness of 4.6 kg (10 lb.) after 7 days holding (3rd evaluation). At each of these 2 evaluations, apples in all other combinations of the 12 treatments were significantly softer (Table 1).

With a low ethylene level in CA, daminozide-treated fruit was firmer than control fruit, but with a high ethylene level in CA the firmness of daminozide-treated fruit and control fruit were equal (Table 1). Furthermore, some daminozide-treated fruit developed breakdown during the 7-day holding period after CA storage with high ethylene. Similar fruit did not develop breakdown during the same period after CA storage with low ethylene. It seemed, therefore, that there was an interaction between daminozide and ethylene in CA storage on fruit softening and breakdown. An interaction between fruit maturity at harvest and ethylene concentration in CA storage on fruit softening has been reported previously (6, 7).

Sensory evaluations also indicated that daminozide-treated fruit harvested at the preclimacteric stage and stored in CA with low ethylene was firmer and less ripe than fruit in other treatments after storage plus 1 day warming at 21°C (2nd evaluation, Table 2). Many apples in this treatment were considered "hard" or "too hard" rather than "crisp" by the taste panel. Possible due to the somewhat hard texture and/or unripe flavor, the overall eating quality of the fruit in this treatment was not significantly better than the overall eating quality of fruit from other treatments. Although the titratable acidity of daminozide-treated fruit was slightly higher than control fruit (Table 1), sensory evaluation of acidity did not detect the difference (Table 2). There was no significant difference in soluble solids content among treatments (data not shown).

After storage plus 7 days holding at 21°C daminozide-treated fruit stored in CA with low ethylene had significantly better eating quality than fruit in most of the other treatments (3rd evaluation, Table 2). These daminozide-treated low-ethylene fruit had adequate firmness and desirable ripeness while the fruit in all other treatments tended to be too soft and overripe. Among daminozide-treated fruit from the last harvest, those stored in CA with a low level of ethylene were significantly firmner, more acid, less ripe, and had better flavor and aroma and better overall eating quality than those stored in CA with high levels of ethylene (3rd evaluation, Table 2).

Daminozide delayed the onset of the climacteric of 'McIntosh' apples for at least 10 days in this study; this result is in agreement with previous reports (2, 9). A combination of daminozide and delayed harvest significantly improved fruit surface color (Table 3). Daminozide therefore made it possible to harvest preclimacteric 'McIntosh' apples with acceptable red color. Compared to those harvested on later dates, apples harvested on September 15 had slightly greener ground color, poorer overall appearance, but comparable gloss (data not shown).

Daminozide treatment has been reported to reduce ethylene production (10). Daminozide-treated fruit had an average ethylene production rate of 0.47 μl/kg·hr in low-ethylene jars compared to 2.33 μl/kg·hr for control fruit under similar condition measured in May, 1978 in this study.

After storage in CA with 500 ppm ethylene, a level comparable to those of commercial CA storage, more breakdown occurred to daminozide-treated fruit than to control fruit harvested on 2 consecutive dates, September 21 and 22 (Table 1). This result supports the suggestion that daminozide may contribute to 'McIntosh' breakdown in commercial storage (1, 3). When daminozide treatment was combined with late harvest and stored at a high ethylene level, even more breakdown occurred. On the other hand, daminozide-treated fruit was firmer than control fruit and had no breakdown after storage in CA with low ethylene. After storage and 1 week holding, daminozide-treated fruit had acceptable color, excellent condition, and a firmness of 5.4 kg (12 lb.), which is highly desirable to consumers (8). These results strongly suggest the possibility of applying a combined treatment of a daminozide spray, harvesting before the onset of climacteric, and ethylene removal in CA, for 'McIntosh' apples held in long term storage. An economically feasible scrubbing system capable of reducing ethylene to very low levels must be developed before this method can be applied commercially. The upper limit of tolerable ethylene level is yet to be identified. Current results indicated < 1 ppm to be desirable and 10 ppm to be undesirable. Lougheed et al. (11) found that reducing ethylene levels to 5-16 ppm often but not always resulted in firmer apples.

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