Development of Apple Superficial Scald, Soft Scald, Core Flush, and Greasiness Is Reduced by MCP

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1-Methylcyclopropene (MCP) was used to evaluate the role of ethylene in development of apple (*Malus* × *domestica* Borkh.) physiological disorders during storage. Granny Smith, Red Chief Delicious, and Fuji apple fruit were treated with MCP at a concentration of 1 μL L^{-1} for 12 h at 20 °C. For all varieties stored at 0 °C, ethylene production and respiration rates were reduced for several months following MCP treatment, and firmness and titratable acidity of treated fruit were higher compared to controls. Apples treated with MCP did not develop superficial scald or peel greasiness through 6 months storage plus ripening at 20 °C for 7 days. Core flush was not observed in MCP-treated fruit until 6 months after treatment when the incidence was still lower compared to control fruit. MCP delayed the rise in production of α-farnesene and reduced accumulation of its oxidation products.

Keywords: *Apple; conjugated trienes; core flush; ethylene; α-farnesene; greasiness; 1-methylcyclopropene; 6-methyl-5-hepten-2-one, soft scald; superficial scald*

Ethylene regulates many aspects of fruit ripening (Yang and Hoffman, 1984; Brady, 1987); however, the role of ethylene in development of postharvest physiological disorders is not well defined. Many physiological disorders of apple fruit, including superficial scald, soft scald, core flush, and greasiness, appear as fruit ripen in storage and are considered to be associated with fruit senescence (Meheriuk et al., 1994). Ethylene inhibitors such as 2,5-norbornadiene, diazocyclopentadiene (DACP), and 1-methylcyclopropene (MCP) reduce ethylene action as well as synthesis and delay fruit senescence (Sisler and Serek, 1997). These compounds provide a means to investigate the role of ethylene in development of physiological disorders during apple fruit ripening.

Superficial scald (scald) is an important postharvest disorder of apple fruit. After several months cold storage, the disorder may appear as a darkened, diffuse area on the peel, and injury is localized primarily to cells in the hypodermis (Bain and Mercer, 1963). The specific mechanism of scald development is unknown although it is believed to be induced by autoxidation products of α-farnesene and formation of free radicals (Anet, 1969; Chen et al., 1990; Du and Bramlage, 1994). Although α-farnesene was the first compound suggested to be the scald-inducing factor in the apple cuticle (Murray et al., 1964; Huelin and Murray, 1966), accumulation of α-farnesene oxidation products, including conjugated trienes (CTs) (Huelin and Coggiola, 1968; 1970) and 6-methyl-5-hepten-2-one (MHO) (Anet, 1972; Mir et al., 1999), may be more directly associated with scald development.

Many factors affect scald development, including cultivar, maturity, seasonal environmental variation, cultural practices, and postharvest conditions (Huelin and Coggiola, 1968; Ingle and D'Souza, 1989). Apple fruit susceptibility to scald decreases with advanced fruit maturity. Ethylene is produced as apple fruit mature and ripen; however, whether ethylene plays a role in the diminished susceptibility to scald of mature fruit has not been clearly established. There are several lines of evidence supporting a role for ethylene in scald development. First, scald susceptibility decreases and ethylene production increases as apple fruit mature. Second, ethephon treatments that can advance fruit maturity decrease scald development in some apple cultivars (Couey and Williams, 1973; Lurie et al., 1989b; Curry, 1994). Third, scald development can be reduced by controlled atmosphere (CA) storage, a practice that also reduces ethylene biosynthesis (Little and Taylor, 1981; Lau, 1990). Fourth, diphenylamine (DPA), an anti-oxidant commercially used to prevent scald, also suppresses ethylene production (Lurie et al., 1989a) and Granny Smith apples treated with the ethylene action inhibitor DACP developed less scald during storage (Gong and Tian, 1998). DACP is reported to be a weaker ethylene inhibitor compared to MCP (Sisler and Serek, 1997).

Two other disorders, core flush and soft scald, also develop during apple storage. Core flush, characterized by diffuse browning of cortex tissue adjacent to the carpels, can be induced by improper temperature management during storage (Bramlage and Meir, 1990). Core flush of Granny Smith apples can be reduced by slow cooling to 0 °C, by treating with an antioxidant such as diphenylamine (DPA) prior to air storage (Little and Taylor, 1981), by avoiding late harvest (Little and Taylor, 1981), and by low ethylene storage (Little et al.,

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1985). Soft scald is also a low-temperature-induced disorder, characterized by a sharply defined, irregularly shaped, smooth brown area of apple peel (Meheriuk et al., 1994). Unlike superficial scald, the susceptibility of apples to soft scald increases with advanced maturity (Gerhardt and Sainsbury, 1952). However, like superficial scald, soft scald can be controlled by a prestorage treatment with DPA (Wills et al., 1981). Although both core flush and soft scald can be induced by low temperature and are more likely to occur when apples are harvested late in the season, the actual mechanisms of these disorders are not clearly understood.

Peel greasiness developing during apple ripening is associated with an increase in the oil fraction of cuticle lipids (Mazliak and Pommier-Miard, 1963). Greasiness limits marketability of apples. Some cultivars, including Granny Smith, are more likely to develop greasiness during storage (Leake et al., 1989). Development of greasiness is associated with fruit maturity (Leake et al., 1989); the more mature fruit are at harvest, the greater the extent of greasiness occurring during storage.

A common factor in susceptibility to these disorders is fruit maturity stage at harvest, determined in part by ethylene production. The objective of this study was to examine the role of ethylene in development of the apple physiological disorders superficial scald, soft scald, core flush, and greasiness by modulating ethylene synthesis and action with MCP.

MATERIALS AND METHODS

Granny Smith, Red Chief Delicious, and Fuji apples (*Malus* × *domestica* Borkh.) were harvested from orchards in central Washington state. Internal ethylene concentration (IEC) was measured 1 day after harvest according to Williams and Patterson (1962). Fruit were treated on the day of harvest by sealing the fruit in a 230-L steel chamber and exposed for 12 h to approximately 1 $\mu L \cdot L^{-1}$ MCP. The headspace volume in the chamber was sufficient to prevent development of anaerobic respiration during treatment. Untreated controls were also held for 12 h in a similar steel chamber without MCP. MCP was quantified using butylene as a standard. MCP was obtained from BioTechnology for Horticulture Inc. (Burr Ridge, IL) and prepared according to instructions.

Granny Smith apples were stored at 0, 5, or 10 °C following treatment and evaluated after 3 and 6 months storage. Red Chief Delicious and Fuji apples were stored at 0 °C and evaluated after 3 and 6 months (Red Chief Delicious) or 6 months (Fuji). Fruit quality as well as incidence and severity of disorders was determined after removal from cold storage plus 1 or 7 days at 20 °C. Fruit firmness, soluble solids content, titratable acidity, and color were measured as previously described (Fan et al., 1998). There were 20 fruits per treatment. Color was measured once per apple on a scald-free area and recorded as CIE $L^*a^*b^*$ with a chromameter (Model CR200, Minolta, Japan) using CIE illuminant C and an 8-mm measuring aperture. Hue and chroma were calculated from a^* and b^* (Hunter and Harold, 1987). Superficial scald was visually assessed using a scale from 1 to 7 with consideration of both severity and area of surface affected: 1, no scald; 2, light scald, <33% of the surface area affected; 3, light scald, 33−66% of the surface affected; 4, light scald, >66% of the surface affected; 5, dark scald, <33% of the surface affected; 6, dark scald, 30−66% of the surface affected; 7, dark scald, >60% of the surface affected. Soft scald, core flush, and greasiness were visually assessed as clear (1) or affected (2).

Another group of Granny Smith apples treated with MCP was stored for 4 or 8 months at 0 °C. Disorders were recorded as described earlier, and ethylene production and respiration rate were also measured after removal from storage (Fan et al., 1998). Four replicate peel samples (5 apples/replicate) were frozen in liquid N_2 and stored at −20 °C for 0.5−3.5 months before extraction. Peel samples were subsequently extracted with HPLC-grade hexane for 3 h at 32 °C with shaking. UV absorbance (190−300 nm at 2 nm intervals) of diluted hexane extracts was measured using a spectrophotometer (HP8451A, Hewlett-Packard, Avondale, PA). The concentrations of CTs in the hexane extract were calculated from OD 280−290 (E = 25 000) (Anet, 1972)

Production of *a*-farnesene and HMO by intact fruit was measured 1 and 7 days at 20 °C after storage using dynamic headspace sampling of intact fruit. Approximately 1 kg of fruit (4−5 apples) was placed in 4 L glass jars, and the jars were closed with Teflon lids having two gas ports (Berghof/America, Concord, CA). Purified compressed air flowed at 6 $L \cdot h^{-1}$ through the jars and volatile compounds in the outlet gas were adsorbed onto 50 mg of 30−50 mesh Tenax (Alltech Associates, Deerfield, IL) packed in glass tubing (17.5 cm × 0.4 cm i.d.). Volatile compounds on the Tenax traps were desorbed at 250 °C for 3 min using a Tekmar 6000 aero trap desorber (Tekmar Co., Cincinnati, OH). After the desorbed sample compounds were condensed at −120 °C, the cryofocusing module was flash heated to 250 °C under a stream of He carrier gas which carried the analytes into a Hewlett-Packard 5890A/5971A GC-MSD equipped with a DB-Wax column (J&W Scientific, 60 m × 0.25 mm i.d., 0.25 μm film thickness). Compound identification was made by comparison of spectra of sample compounds with those contained in the Wiley-NBS library and by comparing retention indices of sample compounds and standards. Quantification was performed using selected ion monitoring for base peaks, and quantitative values were calculated using response factors generated with standards.

Statistical analyses were conducted using SAS (SAS Institute, Cary, NC). Data were subjected to analysis of variance. Treatment differences were identified using Fisher's least significant difference ($P < 0.05$); only significant results are discussed unless stated otherwise. Orthogonal comparisons were performed on the Granny Smith apples stored in different temperatures.

RESULTS

Mean IECs for Granny Smith and Red Chief Delicious apples at harvest were 0.04 and 0.07 $\mu L \cdot L^{-1}$, respectively, indicating the fruit were preclimacteric (data not shown). The mean IEC for Fuji apples was 3.01 $\mu L \cdot L^{-1}$ (data not shown). During storage of Granny Smith apples, MCP-treated fruit were firmer compared to controls regardless of storage temperature or storage duration (Table 1). Soluble solids content after 3 months of storage was not consistently affected by MCP treatment; however, MCP-treated fruit had higher soluble solids content compared to controls at all temperatures after 6 months of storage. MCP treatment also reduced titratable acidity loss at all storage temperatures and storage durations. Fruit color (L^*, hue, and chroma) was not consistently different between MCP and control fruit after 3 months. After 6 months, MCP-treated fruit had higher L^*, hue, and chroma values, indicating the fruit were greener than controls.

Scald developed on control Granny Smith apples after 3 and 6 months, while MCP treatment prevented scald development (Table 1). Nontreated fruit stored at 5 °C had less scald than fruit stored at 0 or 10 °C after 3 and 6 months of storage. MCP treatment also prevented core flush after 3 months of storage and reduced the incidence of core flush after 6 months of storage. Control fruit developed greasiness after 3 and 6 months storage. The only MCP-treated fruit that developed greasiness during the first 3 months after treatment were stored at 10 °C; however, all fruit stored for 6 months developed greasiness.

Table 1. Effect of Temperature and MCP on Granny Smith Quality

	firmness (N)		SS (%)		TA (%)		scald		core flush		greasiness		*L**		hue		chroma	
temp °C	CK	MCP	CK	MCP	CK	MCP	CK	MCP	CK	MCP	CK	MCP	CK	MCP	CK	MCP	CK	MCP
3 Months of Storage																		
0	67	88	12.2	12.0	0.564	0.656	3.2	1.0	1.4	1.0	2.0	1.0	64.1	61.0	112.6	113.4	46.3	43.3
5	68	88	11.8	12.3	0.532	0.649	1.0	1.0	1.9	1.0	2.0	1.0	60.7	67.7	113.2	112.5	44.1	48.7
10	71	85	12.3	11.9	0.481	0.518	1.7	1.0	1.3	1.0	2.0	2.0	73.5	70.2	102.3	104.0	52.6	51.6
significance[b]																		
MCP (*M*)	***		NS		***		***		***		***		NS		NS		NS	
temp (*T*)																		
linear	*	NS	NS	NS	***	***	***	NS	NS	NS	NS	NS	***	***	***	***	***	***
quadratic	NS	NS	***	***	NS	***	***	NS	***	NS	NS	NS	***	*	***	NS	***	NS
M × *T*	*		***		***		***		***		***		***		NS		***	
6 Months of Storage																		
0	58	90	11.6	12.1	0.436	0.603	3.8	1.0	2.0	1.1	1.0	1.0	60.7	64.4	108.6	113.5	42.7	46.4
5	57	86	11.1	11.9	0.402	0.503	2.2	1.0	1.9	1.2	2.0	2.0	64.9	66.5	102.3	107.2	44.7	48.3
10	51	79	10.7	11.5	0.238	0.409	4.5	1.0	2.0	1.5	1.1	2.0	71.1	76.2	90.7	91.3	50.7	56.7
significance[b]																		
MCP (*M*)	**		***		***		***		***		***		***		***		***	
temp (*T*)																		
linear	*	***	***	***	***	***	NS	NS	NS	**	NS	***	***	***	***	***	***	***
quadratic	NS	NS	NS	NS	***	NS	***	NS	NS	NS	***	***	NS	***	NS	***	NS	***
M × *T*	NS		NS		***		***		*		***		NS		*		NS	

[a] The fruit were treated with 1 $\mu L \cdot L^{-1}$ MCP or air (CK) for 12 h at 20 °C before storage at 0, 5, or 10 °C for 3 or 6 months. Firmness, soluble solids (SS), titratable acidity (TA), scald, core flush, and greasiness were then measured after ripening at 20 °C for 7 days. [b] NS, *, **, or *** indicate Nonsignificant or significant at $P < 0.05$, 0.01, or 0.001, respectively.

Table 2. Effect of MCP on Internal Ethylene Concentration (IEC), Respiration Rate, Scald, Core Flush, α-Farnesene, 6-Methyl-5-hepten-2-one (MHO), and Conjugated Triene (CT) of Granny Smith Apples[a]

days at 20 °C	treatment	IEC ($\mu L \cdot L^{-1}$)	respiration rate (mmol of $CO_2 \cdot kg^{-1} \cdot h^{-1}$)	α-farnesene ($\mu mol \cdot kg^{-1} \cdot h^{-1}$)	MHO ($\mu mol \cdot kg^{-1} \cdot h^{-1}$)	CT ($\mu mol \cdot g^{-1}$)	core flush (1−2)	scald (1−7)
4 Months of Storage								
1	CK	309.9 a[b]	0.70 a	139 a	4.0 a	0.52 a	1.0 a	4.8 a
1	MCP	0.5 b	0.34 b	109 a	0.8 b	0.07 b	1.0 b	1.0 a
7	CK	169.9 a	0.72 a	168 a	2.5 a	0.21 a	1.5 a	5.7 a
7	MCP	0.6 b	0.44 b	203 a	1.3 b	0.07 b	1.0 b	1.0 b
8 Months of Storage								
1	CK	38.3 a	1.37 a	59 a	2.6 a	0.17 a	2.0 a	5.7 a
1	MCP	1.2 b	0.57 b	146 b	1.3 b	0.07 b	1.4 b	1.0 b
7	CK	120.4 a	0.90 a	145 b	2.6 a	0.12 a	2.0 a	4.9 a
7	MCP	10.5 b	0.46 a	69 a	1.2 b	0.07b	1.5 b	1.3 b

[a] The fruit were treated with 1 $\mu L \cdot L^{-1}$ MCP or air (CK) for 12 h at 20 °C before stored at 0 °C for 4 and 8 months with an additional 1 or 7 days ripening at 20 °C. [b] Numbers with same letter are not significantly different ($P < 0.05$). Comparison made between CK and MCP in same month and ripening date.

Ethylene production by Granny Smith apples was reduced following MCP treatment (Table 2). The IEC of MCP-treated fruit was below 1 $\mu L \cdot L^{-1}$ after 4 months storage plus 1 or 7 days ripening at 20 °C. Respiration rate of MCP-treated fruit was reduced to approximately half that of control fruit. Scald did not develop on MCP-treated fruit after 4 months of storage; however, some light scald developed on treated fruit after 8 months of cold storage plus 7 days at 20 °C. No core flush developed in MCP-treated fruit through 4 months of storage. After 8 months, core flush was present in MCP-treated fruit but the incidence was lower compared to control fruit. The α-farnesene emission by MCP-treated fruit was lower compared to controls after 3 months of storage (data not shown); however, no difference was detected after 4 months of storage. MCP treated fruit had lower α-farnesene production after 8 months of storage plus 1 day ripening at 20 °C. MHO production was reduced following MCP treatment throughout the 8 month storage period. The accumulation of CTs was reduced by MCP treatment although the difference between control and MCP-treated fruit was less after 8 months of storage.

MCP treatment produced similar responses by Red Chief Delicious apples (Table 3). IEC of MCP-treated fruit was lower compared to control fruit after 3 months of storage as well as 1 day after removal from 6 months of storage. However, no difference was present after 7 days ripening at 20 °C. The respiration rate of MCP-treated fruit was lower than that of controls after both 3 and 6 months of storage plus 1 or 7 days at 20 °C. MCP-treated fruit had lower α-farnesene emission after 3 months of storage, but no difference was detected after 6 months of storage. MCP treatment reduced MHO emission throughout the 6 month storage period.

IEC and respiration rate were lower in MCP-treated Fuji apples through 6 months of storage plus 1 or 7 days ripening at 20 °C (Table 4). Scald was not observed on either control or MCP-treated fruit. Control fruit developed soft scald and core flush, but these disorders were prevented by MCP treatment through 6 months of storage plus 1 or 7 days at 20 °C. MCP reduced production of α-farnesene and MHO through 6 months of storage except at 6 months plus 7 days ripening when there was no difference in α-farnesene production between control and MCP treated fruit.

DISCUSSION

A role for ethylene in scald development is suggested in the literature although the specific mode of action is

Table 3. Effect of MCP on Internal Ethylene Concentration (IEC), Respiration Rate, Scald, α-Farnesene, and 6-Methyl-5-hepten-2-one of Red Chief Delicious Apples[a]

days at 20 °C	treatment	IEC ($\mu L \cdot L^{-1}$)	respiration rate (mmol of $CO_2 \cdot kg^{-1} \cdot h^{-1}$)	α-farnesene ($\mu mol \cdot kg^{-1} \cdot h^{-1}$)	MHO ($\mu mol \cdot kg^{-1} \cdot h^{-1}$)	scald (1−7)
			3 Months of Storage			
1	CK	219.8 a[b]	0.53 a	292 a	3.8 a	1.0 a
1	MCP	0.1 b	0.28 b	66 b	1.0 b	1.0 a
7	CK	170.1 a	0.56 a	296 a	2.7 a	1.0 a
7	MCP	22.5 b	0.27 b	144 b	0.7 b	1.0 a
			6 Months of Storage			
1	CK	274.4 a	0.82 a	145 a	7.5 a	3.2 a
1	MCP	13.3 b	0.45 b	246 a	3.2 b	1.0 b
7	CK	197.4 a	0.71 a	153 a	4.9 a	2.9 a
7	MCP	148.7 a	0.50 b	261 a	2.0 b	1.0 b

[a] The fruit were treated with 1 $\mu L \cdot L^{-1}$ MCP or air (CK) for 12 h at 20 °C before stored at 0 °C for 3 and 6 months with an additional 1 or 7 days ripening at 20 °C. [b] Numbers with same letter are not significantly different ($P < 0.05$). Comparison made between CK and MCP in same month and ripening date.

Table 4. Effect of MCP on Internal Ethylene Concentration (IEC), Respiration Rate, Scald, Core Flush, α-Farnesene, and 5-Methyl-5-hepten-2-one (MHO) of Fuji Apples[a]

days at 20 °C	treatment	IEC ($\mu L \cdot L^{-1}$)	respiration rate (mmol of $CO_2 \cdot kg^{-1} \cdot h^{-1}$)	α-farnesene ($\mu mol \cdot kg^{-1} \cdot h^{-1}$)	MHO ($\mu mol \cdot kg^{-1} \cdot h^{-1}$)	soft scald (1−2)	core flush (1−2)	scald (1−7)
				3 Months of Storage				
1	CK	144.1 a[b]	0.88 a	224 a	3.1 a	1.2 a	1.0 a	1.0 a
1	MCP	1.6 b	0.48 b	98 b	1.4 a	1.0 b	1.0 a	1.0 a
7	CK	178.6 a	0.66 a	214 a	3.4 a	1.2 a	1.0 a	1.0 a
7	MCP	3.4 b	0.27 b	71 b	2.3 b	1.0 b	1.0 a	1.0 a
				6 Months of Storage				
1	CK	144.0 a	0.81 a	358 a	3.3 a	1.2 a	1.0 a	1.0 a
1	MCP	3.4 b	0.46 b	189 b	1.0 b	1.0 b	1.0 a	1.0 a
7	CK	173.4 a	0.95 a	163 a	5.9 a	1.4 a	1.4 a	1.0 a
7	MCP	4.1 b	0.53 b	155 a	2.9 b	1.0 b	1.0 b	1.0 a

[a] The fruit were treated with 1 $\mu L \cdot L^{-1}$ MCP or air (CK) for 12 h at 20 °C before stored at 0 °C for 3 and 6 months with an additional 1 or 7 days ripening at 20 °C. [b] Numbers with same letter are not significantly different ($P < 0.05$). Comparison made between CK and MCP in same month and ripening date.

unclear. Mature fruit that have relatively high rates of ethylene production at harvest have low superficial scald susceptibility (Anet, 1972) suggesting ethylene production is related to the reduction in superficial scald potential. Rising ethylene production during storage is also accompanied by the accumulation of α-farnesene (Watkins et al., 1993), the compound considered to be critical to scald development (Huelin and Coggiola, 1968). Scald can be reduced by CA storage and/or prestorage treatment with DPA, and both treatments reduce ethylene production (Lau, 1990; Lurie et al., 1989b). Our results showed that inhibiting ethylene action using MCP reduces ethylene production as well as scald, and scald develops only on fruit producing ethylene. Light scald was observed on MCP-treated Granny Smith fruit only after 8 months of storage plus 7 days ripening at 20 °C, where IEC was about 10 $\mu L \cdot L^{-1}$ (Table 2). These results indicate that development of superficial scald requires ethylene production and action.

Fruit maturity at harvest has been considered to be an important factor determining scald susceptibility (Brooks et al., 1919). Although riper fruit are less scald susceptible, evidence to support ripening per se as a factor influencing scald susceptibility is lacking. Preharvest ethephon treatments that advance ripening do not significantly enhance scald resistance in the absence of preharvest low temperatures (Barden and Bramlage, 1994). Postharvest practices that slow fruit ripening, such as CA storage and/or the use of DPA, also decrease superficial scald development (Lau, 1990; Lurie et al., 1989b). MCP treatment of Granny Smith and Delicious apples also slows fruit ripening, and MCP treatment prevents or reduces the incidence of superficial scald.

α-Farnesene and its oxidation products are correlated to scald development (Murray et al., 1964; Huelin and Murray, 1966; Huelin and Coggiola, 1968, Mir and Beaudry, 1999). Ethephon stimulates α-farnesene and CT accumulation in fruit peel (Du and Bramlage, 1994). MCP only delayed the onset of α-farnesene production while accumulation of CT and production of MHO were inhibited throughout the investigation period in all apples tested. These results suggest both production and oxidation of α-farnesene may require ethylene action. During cold storage, α-farnesene typically increases rapidly after harvest and then declines (Huelin and Coggiola, 1968; Huelin and Murray 1966), similar to our results in control fruit (Table 1). The greater amount of α-farnesene produced by MCP-treated fruit after 6−8 months of storage indicates the climacteric-like pattern of α-farnesene production is delayed following MCP treatment. The α-farnesene in control Granny Smith fruit decreased after more than 4 months of storage while production by MCP-treated fruit increased, resulting in a higher α-farnesene production in MCP-treated fruit than controls after 8 months of storage. Production of CT is more correlated to scald development, supporting a role for the α-farnesene oxidative products in scald development (Huelin and Coggiola, 1968). In control fruit, Granny Smith apples developed more severe scald than Red Chief Delicious apples while scald was not observed on Fuji apples; the production rate of MHO was, however, the highest in Fuji apples, suggesting that a high rate of MHO production is by itself insufficient to cause scald development. The inherent resistance to scald development also appears to be a critical factor determining whether scald develops.

Although treatment of susceptible fruit with the antioxidant DPA effectively reduces scald development (Smock, 1957), the role of endogenous antioxidants in scald prevention is unclear. Ethephon treatment increases the concentrations of α-tocopherol, carotenoids, and ascorbic acid in apple peel, but accumulation of these compounds is not always accompanied by a reduction in scald development (Barden and Bramlage, 1994; Anet, 1974). Application of antioxidants does not always reduce incidence of scald (Bauchot and John, 1996). Whether or not MCP treatment influences the development of endogenous anti-oxidants is unknown.

CTs have three absorbance peaks at 258, 269, and 281 nm (Anet, 1972; Whitaker, 1998). Many compounds that are extractable in hexane may absorb in the UV range, including phenolic fatty acid esters identified in hexane extracts from apple fruit (Whitaker, 1998). Measurement of CT in hexane extracts by UV spectroscopy tends to overestimate the CT concentration (Rowan et al., 1995); therefore, the CT values presented here are probably higher than actual values. The relative difference between control and MCP treated fruit should still be real, however, as the same method was used for both treatments.

Scald has been reported to be a chilling injury (Watkins et al., 1995). Our results indicate that scald developed on Granny Smith apples stored at 10 °C, similar to other observations (Huelin and Coggiola, 1970). Granny Smith apples stored at 5 °C had the lowest incidence of superficial scald. Scald developing at higher temperatures (10 °C) may be the result of a different mechanism from that occurring in lower temperatures (0 and 5 °C).

MCP prevented or reduced the incidence of soft scald, core flush, and greasiness. Soft scald can also be prevented by prestorage treatment with antioxidants (Wills et al., 1981). The incidence of soft scald and greasiness increases with fruit maturity and appears to be related to fruit senescence (Leake et al., 1989; Meheriuk et al., 1994). The reduction in soft scald and greasiness following MCP treatment may be a result of delayed senescence (Meheriuk et al., 1994). Both soft scald and core flush have been suggested to be symptoms of chilling injury. Low-temperature stress enhances ethylene production of chilling-sensitive plant tissues although it is unclear whether ethylene is directly involved in the development of chilling injury (Wang, 1989). Our results indicate that inhibition of ethylene action in apple fruit reduces development of the chilling induced disorders soft scald, core flush, and superficial scald. Incidence of these disorders can also be reduced by the use of antioxidant chemicals; however, it is unclear whether ethylene plays any role in development of endogenous free radical scavenging systems during fruit ripening.

MCP treatment reduces ripening of several fruits (Abdi et al., 1998; Fan et al., 1999; Golding et al., 1998; Sisler and Serek, 1997). MCP treatment of apple fruit also results in enhanced firmness, titratable acidity, and soluble solids content through 6 months of cold storage. The retention of titratable acidity and soluble solids content by MCP may result from the lower respiration rate of MCP-treated fruit. Scald is an important storage disorder for many apple cultivars, and current methods for scald control rely on the use of antioxidants such as DPA and ethoxyquin, CA storage, or a combination of CA and antioxidant treatment. MCP not only controls scald but also results in improved fruit storage quality (firmness, acidity, and soluble solids content). MCP, however, reduces production of volatile compounds by apple fruit (Fan and Mattheis, 1999)

In summary, MCP treatment of Granny Smith, Red Chief Delicious, and Fuji apples results in higher firmness and acidity and reduced respiration rate and ethylene production. MCP eliminates or significantly reduces development of superficial scald, soft scald, core flush, and greasiness during cold storage and subsequent ripening at 20 °C. Development of these physiological disorders of apples appears to be regulated by ethylene. MCP delays production of α-farnesene and reduces production of its oxidative products—CT and MHO. As no evidence for a direct role for ethylene in the oxidation of α-farnesene exists, ethylene may regulate synthesis of enzyme(s) involved in the production and/or oxidation of α-farnesene. MCP has not yet been approved for use on food crops.

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