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Efficacy of Diphenylamine, Ultra-low Oxygen, and Ethylene Scrubbing on Scald Control in 'Delicious' Apples

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Abstract. **Incidence of scald in nontreated and DPA (2000 mg·liter^{-1})-treated 'Delicious' apples (*Malus domestics* Borkh.) was assessed after 8.5 months in 1.5% or 0.7% O_2 plus 1.5% CO_2 at 0.2C, with and without C_2H_4 scrubbing. Incidence of scald was high in non-DPA fruit held in 1.5% O_2, and DPA treatment reduced scald in fruit held in 1.5% or 0.7% O_2. Scald control was better with 0.7% O_2 and no DPA 'treatment than with 1.5% O_2 and a DPA dip. Ethylene scrubbing had no effect on scald in fruit held in 0.7% or 1.5% 0_2. Susceptibility of fruit to scald-and flesh browning exhibited seasonal variation, which was related to the differences in fruit maturity and the amount of watercore at harvest, respectively. Chemical name used: diphenylamine (DPA).**

Control of scald in sensitive apple cultivars, such as 'Delicious', is achieved by treating the fruit with DPA or 6-ethoxy-l,2,-dihydro-2,2,4-trimethyl quinoline (ethoxyquin) immediately following harvest (Hardenburg, 1965; Smock, 1955, 1957). Recent concerns about the effects of chemicals on human health and the environment are creating uncertainty over the long-term future use of DPA and ethoxyquin. Therefore, a search for non-chemical control of apple scald is required. One approach has been low O_2 (Chen et al., 1985; Little and Taylor, 1981; Patterson and Workman, 1962; Roberts et al., 1963), another low C_2H_4 (Dover, 1985; Knee and Hatfield, 1981; Liu, 1977).

British Columbian-grown 'Delicious' could benefit from the use of low O_2 for controlling scald because it does not develop much purple-brown skin discoloration in low-O_2 atmospheres (Lau, 1990). 'Delicious' apples stored in 0.5% O_2 plus 1.5% CO_2 at 0.5C for 7 months followed by 2 months in air at 0C and 7 days in air at 20C had a skin discoloration incidence of 8% compared to 61% in 'Spartan' and 44% in 'McIntosh'.

The purpose of the present study was to determine the efficacy and potential problems associated with the use of low-O_2 atmospheres (1.5% or 0.7%), DPA treatment (2000 mg·liter^{-1}), and C_2H_4 scrubbing to control scald of 'Delicious' apples.

Materials and Methods

Eight replicates (80 fruit each; 10 fruit for prestorage fruit maturity measurement and 70 fruit for storage study) of 'Delicious' apples were obtained each year (1986 and 1987) from each of eight random grower lots at a commercial controlled-atmosphere (CA) storage facility. The eight (2 x 2 x 2) treatments were: ± DPA (2000 mg·liter^{-1}), 0.7% or 1.5% O_2 plus 1.5% CO_2, and ± C_2H_4 scrubbing.

Fruit grade, flesh firmness, internal C_2H_4, concentration (IEC), starch index, and incidence of watercore of each grower lot were determined before storage on a 10-fruit sample using methods described by Lau (1985, 1989). The IEC values were used to calculate the percentage of fruit with IEC > 1 µl·liter^{-1}, a value generally deemed indicative of the onset of fruit ripening.

Four of the eight replicates from each grower were dipped into a DPA suspension before storage in 0.7% or 1.5% O_2 plus 1.5% CO_2 ± C_2H_4 scrubbing. The samples were held in 0C air for 24 hr and then sealed in 0.2C steel cabinets (1.7 m^3) equipped with a blower fan (2.8 m^3·min^{-1}). The desired 1.5% or 0.7% 0_2 levels were established within 24 or 32 hr after sealing by purging with N_2, and the 1,5% CO_2 levels were established within 4.5 days by fruit respiration and additions of CO_2 as required. Each low-C_2H_4 cabinet was equipped with an internal C_2H_4 scrubber containing 10 kg of Purafil beads (potassium permanganate-alumina; Circul-Aire, Montreal, Canada) spread evenly over four trays (25 x 70 x 3 cm). The volume of air movement and amount of Purafil used exceeded those suggested by Blanpied (1985). Ethylene in the low-C_2H_4 cabinets was below 1.0 µl·liter^{-1} during the first 3 (1986) or 6 (1987) months of storage and never exceeded 3.7 (1986) or 4.7 (1987) µl·liter^{-1} during subsequent months of storage. Content in the high-C_2H_4 cabinets (1986 = 397 µl.liter^{-1}, with a range of O to 819 µl.liter^{-1}; 1987 = 345 µl.liter^{-1}, with a range of O to 772 µl.liter^{-1}) was increased gradually by adding C_2H_4 at a rate of =100 µl·liter^{-1}·month^{-1} to simulate accumulation of C_2H_4 in non-C_2H_4-scrubbed CA storage. Storage C_2H_4 was monitored by gas chromatography and adjusted weekly. Storage 0_2 and CO_2 were monitored daily with a paramagnetic O_2 analyzer and infrared CO_2 analyzer, respectively. Atmospheres were maintained at the desired levels, ± 0.2%, by scrubbing with hydrated lime (10 to 15 g·kg^{-1} of fruit) to remove CO_2, purging with N_2 to remove excess O_2, or adding air or CO_2. Storage temperature was maintained at 0.2 ± 0.3C.

Table 1. Characteristics of 'Delicious' apples before storage (n = 8 grower replicates per year).

Fruit characteristics before storage	27 Sept. 1986	26 Sept. 1987
Extra-fancy and fancy grade (% of fruit)	86 ± 11[z]	81 ± 7
Flesh firmness (N)	76 ± 4	72 ± 2
Internal C_2H_4 concn (IEC, µl·liter^{-1})	4.5 ± 5.4	7.7 ± 9.2
IEC > 1 µl·liter^{-1} (% of fruit)	15 ± 14	54 ± 33
Starch index (0–9)	2.2 ± 1.0	2.9 ± 0.4
Watercore (% of fruit)	24 ± 27	2.5 ± 4.6

[z]Mean ± SD.

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After CA storage and also after a period in air at 0C (specified in each table) plus 7 days in air at 20C, subsamples of 10 apples from each storage treatment were assessed for flesh firmness, alcohol flavor, and storage disorders by methods described by Lau (1985, 1989). Evaluation of alcohol flavor was performed by 16 panelists for each storage treatment, using a 1 to 5 scale, where 1 = none, 3 = detectable, and 5 = strong. Storage disorders were determined on 10-fruit (first examination) or 40-fruit (second examination) samples. Data were subjected to analysis of variance and means separated by an F test.

Table 2. Percent of scald in DPA (2000 mg·liter^{-1})-treated and non-treated "Delicious' apples held for 8.5 months in 1.5% O_2 or 0.7% O_2 plus 1.5% CO_2 at 0.2C, with and without C_2H_4 scrubbing (n = 8 orchard replicates per year).

Treatment		Fruit affected with scald (%)							
		1986-87				1987-88			
		Post-storage holding[z]							
		7+0		31+7		1+0		25+7	
		O_2 concn during storage (%)							
C_2H_4 scrubbing	DPA	1.5	0.7	1.5	0.7	1.5	0.7	1.5	0.7
No	No	73	4	84	12	20	3	30	5
	Yes	29	0	41	3	8	6	9	3
Yes	No	66	6	64	10	25	11	21	5
	Yes	36	0	44	10	13	0	10	3
Main effects									
DPA	No	37		42		15		15	
	Yes	16		24		7		6	
		***		***		*		***	
O_2 concn	1.5%	51		58		16		17	
	0.7%	3		9		5		4	
		***		***		***		***	
Scrubbing	No	26		35		9		11	
	Yes	27		32		12		10	
		NS		NS		NS		NS	
Interactions[y]									
DPA × O_2		**		***		NS		**	

[z]Days in air at 0C (first number) and 20C (second number) after 253 days (1986–87) or 257 days (1987–88) in CA at 0.2C.
[y]DPA × scrubbing, O_2 × scrubbing, and DPA × O_2 × scrubbing are all nonsignificant.
*,**,***,NSSignificant at P = 0.05, 0.01, or 0.001, or not significant, respectively.

Results and Discussion

Harvesting was delayed in 1987 because of poor color development; thus, the 'Delicious' apples were more mature than in 1986 (Table 1). This difference could explain, at least in part, why non-DPA fruit had less scald in 1987 than in 1986 (Table 2). Scald susceptibility is negatively related to harvest maturity (Chen et al., 1985; Hardenburg, 1965; Little and Taylor, 1981). Dry and hot weather before harvest may also predispose the fruit to scald (Fidler, 1956; Little and Taylor, 1981). I (unpublished data) found a high incidence of scald in non-DPA, air-stored 'Delicious' apples picked at a starch index of ≤2.3. The high incidence of watercore in the 1986 crop predisposed the fruit to flesh browning during storage (Table 3). Kopec and Masek (1970) found that the creation of anaerobic conditions in watercore-affected tissues increased susceptibility of fruit to browning.

Incidence of scald in fruit stored in 1.5"% O_2 + 1.5% CO_2 was reduced markedly, but not always eliminated, by the post-harvest DPA dips in both years (Table 2).

Fruit not treated with DPA showed a mean scald value of 48% (1986 and 1987 combined) in 1.5% O_2, compared with a mean value of 7% in 0.7% O_2. Scald control was better with 0.7% O_2 and no DPA treatment than with 1.5% O_2 and a DPA dip. The effect of DPA was not as pronounced in 0.7% O_2 as in 1.5% O_2 because scald incidence was very low in 0.7% O_2 (Table 2). Low-O_2 injury (purple-brown skin discoloration) was negligible in non-DPA fruit held in 0.7% O_2; ≈ 0.6% of the fruit was affected in 1986 and none in 1987. Alcohol flavor rating of the fruit was not adversely affected by storage in 1.5% O_2 or 0.7% O_2 (1.5% O_2 vs. 0.7% O_2 = 1.3 vs. 1.4 in 1986 and 1.7 vs. 1.6 in 1987. Thus, the benefit of storage at 0.7% outweighs the risk of low-O_2 injury.

A low-C_2H_4 atmosphere reduced scald in 'Bramley's Seedlings' (Knee and Hatfield, 1981) and 'Delicious' (Liu, 1977) apples held in a 2.5% to 3.0% O_2 atmosphere. However, in the present study, C_2H_4 scrubbing was ineffective in reducing scald in 'Delicious' apples held in a static 1.5% or 0.7% O_2 atmosphere (Table 2). Patterson and Workman (1962) found that high C_2H_4 did not increase scald in 'Gallia Beauty' apples over that obtained from constantly renewed air. Dover (1985) found inconsistency in C_2H_4 scrubbing and scald reduction in 'Bramley's Seedling' apples. He obtained the best results when the fruit was harvested 1 week before the onset of autocatalytic C_2H_4 production and when storage C_2H_4 concentrations were maintained below 1 µl·liter^{-1} for most of the storage period.

Table 3. Incidence and severity of and correlation coefficients between watercore at harvest and flesh browning after storage.

Expression of physiological disorder	Watercore at harvest		Flesh browning				Correlation coefficient			
			1986		1987		1986		1986 + 1987	
			253 + 31 + 7[z]		257 + 25 + 7[z]		253 + 31 + 7[z]		255 + 28 + 7[z]	
			O_2 concn during storage (%)							
	1986	1987	1.5	0.7	1.5	0.7	1.5	0.7	1.5	0.7
Fruit affected (%)	24	2.5	11	10	0	0	0.90***	0.86**	0.92***	0.89***
Score (300 max.)[y]	52	3.8	18	13	0	0	0.91***	0.90***	0.91***	0.92***

[z]Days in 1.5% O_2, or 0.7% O_2 plus 1.5% CO_2 at 0.2C (first number), in air at 0C (second number), and in air at 20C (third number).
[y]Based on assigned values of 0 for free from disorder, 1 for slight, 2 for moderate, and 3 for severe disorder, multiplied by the percentage of fruit affected by the disorder.
,*Significant at P = 0.01 or 0.001, respectively.

In conclusion, 0.7% O_2 is a viable alternative to DPA for scald control in 'Delicious' apples harvested at commercial maturity (i.e., with an adequate proportion of the skin being red) (Table 1, extra-fancy and fancy grade). Ethylene scrubbing does not appear to serve a useful function in control of the disorder in 1.5% or 0.7% O_2 CA storage.

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