The Effectiveness of 0.7% Oxygen to Attenuate Scald Symptoms in ‘Delicious’ Apples is Influenced by Harvest Maturity and Cultivar Strain

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ABSTRACT. In a 3-year study, the effectiveness of 0.7% and 1.5% O₂ to attenuate scald was evaluated on three strains of ‘Delicious’ apples (*Malus × domestica* Borkh.)—‘Harrold Red’, ‘Starking’, and ‘Starkrimson’—harvested five times at weekly intervals from a wide range of orchards. Scald susceptibility of fruit held in air, 1.5% O₂ + 1.0% CO₂, and 0.7% O₂ + 1.0% CO₂ at 0 °C decreased sharply as the fruit matured on the tree (starch index 1.0 to 2.5 on a 0 to 9 scale). Later harvests (starch index >2.8) further reduced scald but the fruit had more watercore-induced breakdown and were 3 N softer than fruit picked at a less advanced maturity. Early picked ‘Starkrimson’ (starch index <2.0) scalded more than ‘Starking’ and ‘Harrold Red’ in air, 1.5% O₂, and 0.7% O₂ storage at 0 °C, and 0.7% O₂ was less effective than 1.5% O₂ in scald control. While 0.7% O₂ storage effectively reduced scald (less than 10%) for 8 months in ‘Starking’ and ‘Harrold Red’ picked over a wide range of maturity (starch index 0.7 to 4.3), it did not adequately control scald (up to 45%) in early picked ‘Starkrimson’ (starch index <2.0). Storage in 0.7% also reduced watercore-induced breakdown in ‘Starkrimson’ (starch index >3.0) and did not result in skin purpling or alcoholic taste in ‘Harrold Red’, ‘Starking’, and ‘Starkrimson’.

The storage potential of ‘Delicious’ apples in 2.5% O₂ controlled atmosphere (CA) storage is reduced because of scald, watercore-induced breakdown, and flesh softening. Retention of flesh firmness is improved by storing fruit in 1.0% O₂ established by a rapid CA procedure (Lau, 1985).

Scald development is an oxidative process, and the antioxidants diphenylamine (DPA) and ethoxyquin (Smock, 1955, 1957) or low O₂ atmospheres (Anderson, 1967; Chen et al., 1985; Fidler and North, 1961; Johnson et al., 1989; Lau, 1990a; Little and Pegg, 1987; Patterson and Workman, 1962; Roberts et al., 1963; Schouten and van Schaik, 1981; Smock, 1960) alleviate or control the disorder.

DPA reduces the incidence of scald but it does not always provide complete control (Anderson, 1967; Ingle et al., 1990; Lau, 1990a). Concerns about environmental and health effects of chemicals coupled with a global movement toward less chemical use may jeopardize the current use of DPA and ethoxyquin as measures to control scald in apples. DPA solutions are classified as “special waste” in British Columbia and are subject to a specific disposal protocol, which creates an expensive disposal procedure for packing houses. Ethoxyquin is not reregistered for use on apples but is registered for controlling scald in ‘Anjou’ pears.

British Columbia-grown ‘Delicious’ apples can benefit from low O₂ storage as an alternative means of controlling scald because the fruit is tolerant to 0.5% to 1.0% O₂ for extended periods (Lau, 1985, 1990b). Scald control is better with 0.7% O₂ than with 2000 mg·L⁻¹ of DPA in air or 1.5% O₂ storage or than with C₂H₄ scrubbing in 1.5% O₂ storage (Lau, 1990a). The latter research

used ‘Delicious’ of commercial maturity but the strains were not known. Since scald varies with season, harvest maturity and cultivar strain (Chen et al., 1985; Fidler and North, 1961; Hardenburg, 1965; Lau, 1990a; Little and Taylor, 1981; Smock, 1979), it is possible that the effectiveness of 0.7% O₂ as a means to control scald could also be influenced by the same factors. Two studies were therefore conducted with apples from many orchards in 1990–92 to compare the effectiveness of 0.7% O₂ with 1.5% O₂ and air storage on scald and other important quality attributes as influenced by harvest maturity and strain of ‘Delicious’. The first study evaluated the effect of harvest maturity (based on starch index) and storage O₂ on the development of scald, low O₂ injury, and watercore-induced breakdown in ‘Starkrimson’ (a spur strain). The second study compared scald susceptibility of ‘Starkrimson’ with ‘Starking’ (a bud mutation of ‘Delicious’) and ‘Starkrimson’ with ‘Harrold Red’ (a bud mutation of ‘Starking’) in relation to harvest maturity and storage O₂. This information is needed to ensure a scald-free and disorder-free 0.7% O₂ storage of ‘Delicious’ without the use of antioxidant chemicals.

Materials and Methods

HARVEST MATURITY AND O₂ TRIAL (‘STARKRIMSON’). Fruit from the same ‘Starkrimson’ orchards in the southern, central, and northern parts of the Okanagan region (five in Oliver-Osoyoos, five in Summerland, and five in Kelowna) were used in 1990–92. A 10-fruit maturity sample and two replicated storage samples (60 apples each) were harvested five times at weekly intervals from each orchard. Harvesting commenced on 23 Sept. 1990, 15 Sept. 1991, and 12 Sept. 1992, ≈2 weeks before commercial harvest. The 10 storage samples per orchard constituted a 5 × 2 factorial design: five harvests × two O₂ levels (1.5% O₂ + 1.0% CO₂ and 0.7% O₂ + 1.0% CO₂) at 0 °C.

‘DELICIOUS’ STRAIN TRIAL (‘HARROLD RED’ VS. ‘STARKRIMSON’ AND ‘STARKING’ VS. ‘STARKRIMSON’). The same four orchards in Summerland and Kelowna, each with ‘Starking’ and ‘Starkrimson’, and three other orchards in Oliver and Kelowna, each with

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'Harrold Red' and 'Starkrimson', were used each year during 1990–92. Each strain was harvested five times at weekly intervals from each collection site and randomized into 10-fruit samples for maturity determination and three 50-fruit samples for 4 months of air storage and 8 months of 1.5% and 0.7% O₂ storage at each harvest date. Fruit sampling commenced on 21 Sept. ('Harrold Red' and 'Starkrimson') and 26 Sept. ('Starking' and 'Starkrimson') 1990, 13 Sept. ('Harrold Red' and 'Starkrimson') and 18 Sept. ('Starking' and 'Starkrimson') 1991, and 10 Sept. ('Harrold Red' and 'Starkrimson') and 15 Sept. ('Starking' and 'Starkrimson') 1992, ≈2 weeks before commercial harvest. Ten air storage samples were used in a 5 × 2 factorial design: five harvests × two strains. Twenty CA storage samples were used in a 5 × 2 × 2 factorial design: five harvests × two strains × two O₂ levels (1.5% O₂ and 0.7% O₂).

MATURITY DETERMINATION. Starch index values, flesh firmness, and watercore incidence were determined on each 10-fruit maturity sample immediately after harvest using published methods (Lau, 1985, 1990a; Smith et al., 1979). Starch index values of 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9 represent (%) 0, 9, 20, 38, 51, 66, 81, 90, 96, and 100, respectively, of the cross-sectional area of fruit clear of starch.

STORAGE PROCEDURES. Air storage samples were held in a 0 °C room. All CA samples were cooled in 0 °C air for 36 h before storage in 1.7-m³ steel cabinets kept in a 0 °C room. The 1.5% and 0.7% O₂ atmospheres were established within 36 h of sealing by purging with N₂. Storage CO₂ was gradually increased to 1.0% within 5 to 9 d by fruit respiration and additions of CO₂ as required. Storage O₂ and CO₂ were monitored twice daily with a paramagnetic O₂ analyzer and infrared CO₂ analyzer, respectively. Atmospheres were maintained at the desired levels ±0.2% by scrubbing with hydrated lime, purging with N₂, or by adding air or CO₂. Storage temperature was maintained at 0 ± 0.3 °C for all samples.

POSTSTORAGE FRUIT EVALUATION. After 4 months in 0 °C air or 8 months in 0 °C CA, plus 7 d in 0 °C air and 7 d in 20 °C air, 10-fruit subsamples from each treatment were assessed for flesh firmness (by Magness-Taylor penetrometer with a 11.1-mm-diameter tip) and alcoholic taste and off flavors (by sensory panel). Incidence of scald and skin purpling were determined on 40-fruit subsamples by methods described previously (Lau, 1985, 1990a). Storage data were subjected to analysis of variance (SAS, Cary, N.C.) to test for harvest date, strain, and storage treatment interactions. Harvest means were partitioned into single-degree-of-freedom polynomials using the contrast option in SAS's GLM procedure. Percent values were arcsine transformed before variance analysis.

Results

Maturation of 'Starkrimson', 'Harrold Red', and 'Starking', based on starch index value and incidence of watercore, was earlier and more rapid in 1992 than in 1990 and 1991 (Tables 1 and 2).

Starch index value and flesh firmness at harvest were similar for 'Harrold Red' and 'Starkrimson' and for 'Starking' and 'Starkrimson' in 1990–92 (Table 2).

Scald susceptibility of 'Delicious' was negatively associated with harvest date, positively associated with storage O₂ (1.5% vs. 0.7%), and varied with orchard (data not shown) and strain (Tables 3 and 4).

HARVEST MATURITY. Scald susceptibility of 'Starkrimson' and 'Starking' held in air, 1.5% O₂, and 0.7% O₂ and of 'Harrold Red' held in air decreased sharply as the fruit matured on the tree (starch index 1.0 to 2.5; Tables 3 and 4). Later harvests (starch index >2.8) resulted in less scald, but the fruit had significantly more watercore-induced breakdown (Tables 3 and 5) and were, on the average, 3 N softer (data not shown) than earlier picked fruit. The effect of advanced harvest date on scald control was stronger for 1.5% than 0.7% O₂-stored fruit (Tables 3 and 4).

STORAGE O₂. Incidence of scald was high (average = 29%; range = 0% to 87% for all strains, maturities and years) in 'Delicious' held for 4 months in 0 °C air (Table 4). Storage in 1.5% O₂ did not adequately control scald after 8 months (average = 26%; range = 0% to 79%), while 0.7% O₂ markedly reduced the disorder (average = 8%; range = 0% to 45%; Table 4). The 0.7% O₂ storage was also more effective than 1.5% O₂ in reducing water-induced breakdown in 'Starkrimson' in 2 high-watercore years, 1990 and 1992 (Tables 1 and 3).

STRAIN. 'Starkrimson' scalded more readily than 'Starking' or 'Harrold Red' after 8 months in 1.5% or 0.7% O₂ (Table 4). Although 0.7% O₂ effectively reduced scald (0% to 10%) in 'Harrold Red' and 'Starking' picked over a wide range of maturity (starch index 0.7 to 4.3), it did not adequately reduce scald (20% to 45%) in early picked 'Starkrimson' (starch index 0.7 to 0.9). However, 'Harrold Red' (1991–92) and 'Starking' (1992) were more susceptible to watercore-induced breakdown than 'Starkrimson' (Table 5).

LOW O₂ INJURIES. Storage in 0.7% did not result in alcoholic taste or off-flavors in any of the three 'Delicious' strains after 8 months of storage (data not shown). Skin purpling was almost nil (0% to 0.3% in 1990; 0% to 0.5% in 1991; 0% in 1992) in all three strains picked at the correct maturity (data not shown). However, fruit picked 1 to 2 weeks after the optimal harvest date had some skin purpling (0% to 2% in 1990; 1% to 5% in 1991) in 0.7% O₂ storage.

FLESH FIRMNESS. 'Starkrimson' (Table 3), 'Harrold Red', and 'Starking' (data not shown) held in 0.7% O₂ were, on average, 2 to 3 N firmer than fruit held in 1.5% O₂.

Discussion

Scald susceptibility of 'Delicious' apples decreased with advanced harvest maturity (based on starch index) and low O₂ storage (1.5% vs. 0.7%) and was greater in 'Starkrimson' than 'Harrold Red' or 'Starking' (Tables 3 and 4). The results agree with earlier

Table 1. Characteristics of 'Starkrimson Delicious' apples at harvest (n = 15 orchards per year).

Harvest	Harvest date			Starch index (0–9)			Watercore (% fruit affected)			Flesh firmness (N)		
	1990	1991	1992	1990	1991	1992	1990	1991	1992	1990	1991	1992
1	23 Sept.	15 Sept.	12 Sept.	1.3 ± 0.6	1.0 ± 0.5	1.5 ± 0.4	0 ± 1	0 ± 0	1 ± 2	90 ± 4	90 ± 3	86 ± 4
2	30 Sept.	22 Sept.	19 Sept.	1.6 ± 0.6	1.2 ± 0.5	1.7 ± 0.6	0 ± 0	0 ± 0	23 ± 25	86 ± 4	87 ± 2	83 ± 5
3	7 Oct.	29 Sept.	26 Sept.	2.1 ± 0.8	1.5 ± 0.3	2.4 ± 0.5	3 ± 5	0 ± 0	39 ± 33	85 ± 3	86 ± 4	78 ± 4
4	14 Oct.	6 Oct.	3 Oct.	2.4 ± 0.8	1.7 ± 0.5	3.2 ± 0.6	19 ± 19	6 ± 7	64 ± 33	83 ± 4	82 ± 3	80 ± 5
5	21 Oct.	13 Oct.	10 Oct.	3.3 ± 1.0	2.1 ± 0.5	4.3 ± 0.5	56 ± 24	15 ± 18	80 ± 21	83 ± 4	81 ± 4	81 ± 5

studies relating harvest date (Hardenburg, 1965; Smock, 1979), starch index value (Little and Taylor, 1981), and storage O₂ (Fidler and North, 1961; Lau, 1990a; Patterson and Workman, 1962; Smock, 1960) to scald. 'Starkrimson' was also more susceptible to scald in studies by Smock (1979) and Chen et al. (1985).

The decrease in scald susceptibility associated with advanced maturity (starch index 1.0 to 2.5; Tables 3 and 4) and the lower scald susceptibility of 'Starking' and 'Harrold Red' than that of 'Starkrimson' (Table 4) could be the result of a smaller accumulation of α -farnesene, a higher level of naturally occurring antioxidants, or a more-efficient antioxidant system for protecting against auto-oxidation of α -farnesene in the fruit. Accumulation of α -farnesene and its subsequent oxidation to conjugated trienes have been implicated in scald development (Huelin and Coggiola, 1968; Huelin and Murray, 1966). Concentration of α -farnesene differs greatly between cultivars (Huelin and Coggiola, 1968; Meigh and Filmer, 1969). Scald does not occur if antioxidants in the cuticular layer remain adequate to prevent or sufficiently limit the extent of α -farnesene auto-oxidation (Anet, 1974). Antioxidant concentration at harvest is inversely related to scald development (Barden and Bramlage, 1994). Increased scald susceptibility of less-mature fruit has also been attributed to a less-efficient antioxidant system (Anet, 1972). Late harvests (starch index >2.8) reduced or eliminated scald (Tables 3 and 4), but the fruit were, on average, 3 N softer (data not shown) and had more watercore-induced breakdown than fruit picked at a less-advanced maturity (Tables 4 and 5). Consequently, delayed harvesting is not an advisable means to overcome scald problems.

Since auto-oxidation of α -farnesene into harmful alkyl peroxy requires O₂ (Anet, 1974), it is not surprising that 0.7% O₂ was more effective than 1.5% O₂ in reducing scald (Tables 3 and 4). Harvest date $\times$ O₂ level interactions were significant for scald (1992) and watercore-induced breakdown (1990) in 'Starkrimson' in 1 of 3 years (Table 3). These interactions were due to a stronger effect of harvest date on scald and watercore-induced breakdown in 1.5%

than 0.7% O₂-stored fruit. Early picked 'Starkrimson' scalded more readily than 'Harrold Red' (1992) or 'Starking' (1990 and 1992) in CA storage (Table 4). This probably accounted for the significant interactions (harvest $\times$ strain) for scald on 'Harrold Red' vs. 'Starkrimson' in 1992 and on 'Starking' vs. 'Starkrimson' in 1990 and 1992. The statistical interactions (harvest $\times$ O₂ level) for scald on the 1992 'Delicious' samples (Table 4) were likely the results of a weaker harvest date effect on scald in 0.7% than in 1.5% O₂-stored fruit. Since these interactions occurred in 1 of 3 years (Tables 3 and 4), their implications are not clear.

Late-picked fruit had some skin purpling (0% to 2% in 1990; 1% to 5% in 1991), while fruit picked at the correct maturity had no skin purpling, alcoholic taste, or off-flavors after 0.7% O₂ storage (data not shown). These results indicate that 0.7% O₂ was sufficient to meet the respiratory needs of the fruit. These results also agree with those of Chen et al. (1985) and Lau (1985, 1990b) that 'Delicious' tolerate 0.5% to 1.0% O₂ for extended periods.

Storage in 0.7% O₂ decreased watercore-induced breakdown in 'Starkrimson' in 2 high-watercore years (0% to 56% watercore in 1990; 1% to 80% watercore at harvest in 1992), possibly by suppressing cell wall and cell membrane degradation in watercored tissues (Marlow and Loescher, 1984) or oxidative metabolism in general. It is not known why 'Harrold Red' (1991 and 1992) and 'Starking' (1992) had more watercore-induced breakdown than 'Starkrimson' (Table 5). Lord and Southwick (1964) have reported that the development of internal breakdown in storage is associated with the severity of watercore at harvest, is reduced by CA storage, and is also strain dependent.

In summary, harvesting 'Delicious' apples at the correct maturity was the key factor in achieving good scald control and minimizing watercore-induced breakdown in 0.7% O₂ storage. Since early picked 'Starkrimson' (starch index <2.0) were more scald susceptible than 'Harrold Red' and 'Starking', they should be picked at a slightly more mature stage (starch index 2.5 to 3.0) or 5 to 7 d later than 'Harrold Red' and 'Starking' (starch index 2.0

Table 2. Characteristics of three 'Delicious' strains at harvest (n = 3 to 4 orchards per year).

Harvest date	Harrold Red (HR) vs. Starkrimson (SN) (n = 3)						Harvest date	Starking (SK) vs. Starkrimson (SN) (n = 4)					
	Starch index (0–9)		Flesh firmness (N)		Watercore (% fruit affected)			Starch index (0–9)		Flesh firmness (N)		Watercore (% fruit affected)	
	HR	SN	HR	SN	HR	SN		SK	SN	SK	SN	SK	SN
1990													
21 Sept.	1.4 ± 0.5	1.2 ± 0.6	88 ± 1	91 ± 2	0 ± 0	0 ± 0	26 Sept.	1.2 ± 0.4	0.9 ± 0.3	89 ± 2	88 ± 3	0 ± 0	0 ± 0
28 Sept.	1.5 ± 0.1	1.4 ± 0.4	84 ± 3	88 ± 2	0 ± 0	0 ± 0	3 Oct.	1.2 ± 0.7	1.3 ± 0.6	89 ± 3	86 ± 4	1 ± 3	0 ± 0
5 Oct.	2.1 ± 0.3	2.1 ± 1.0	84 ± 1	86 ± 2	10 ± 5	5 ± 9	10 Oct.	1.7 ± 0.6	1.6 ± 0.5	84 ± 2	84 ± 1	14 ± 6	1 ± 3
12 Oct.	2.3 ± 1.0	2.4 ± 0.5	81 ± 3	84 ± 2	23 ± 16	37 ± 26	17 Oct.	2.0 ± 0.7	2.0 ± 0.6	83 ± 2	82 ± 4	28 ± 21	15 ± 16
19 Oct.	3.2 ± 0.7	3.1 ± 1.1	81 ± 4	84 ± 4	70 ± 30	63 ± 10	23 Oct.	2.1 ± 0.7	2.7 ± 0.6	84 ± 5	83 ± 3	78 ± 12	61 ± 19
1991													
13 Sept.	0.9 ± 0.2	0.7 ± 0.4	92 ± 2	92 ± 2	0 ± 0	0 ± 0	18 Sept.	0.7 ± 0.1	0.9 ± 0.4	92 ± 6	90 ± 1	0 ± 0	0 ± 0
20 Sept.	1.1 ± 0.3	0.8 ± 0.1	86 ± 2	89 ± 2	0 ± 0	0 ± 0	25 Sept.	1.2 ± 0.3	1.0 ± 0.4	87 ± 4	88 ± 2	0 ± 0	0 ± 0
27 Sept.	1.9 ± 0.5	1.4 ± 0.4	85 ± 2	89 ± 2	0 ± 0	0 ± 0	2 Oct.	1.8 ± 0.4	1.4 ± 0.2	89 ± 4	88 ± 2	1 ± 3	0 ± 0
4 Oct.	2.1 ± 0.2	1.7 ± 0.4	84 ± 2	86 ± 4	18 ± 15	2 ± 3	9 Oct.	1.8 ± 0.3	1.4 ± 0.4	83 ± 1	82 ± 4	19 ± 21	8 ± 6
11 Oct.	2.4 ± 0.4	2.2 ± 0.4	84 ± 2	84 ± 3	35 ± 31	5 ± 0	16 Oct.	2.1 ± 0.5	1.8 ± 0.6	83 ± 3	83 ± 2	38 ± 35	30 ± 26
1992													
10 Sept.	1.1 ± 0.3	1.1 ± 0.1	91 ± 3	88 ± 2	2 ± 3	3 ± 3	15 Sept.	1.5 ± 0.3	1.5 ± 0.2	88 ± 0	85 ± 3	8 ± 15	1 ± 3
17 Sept.	1.7 ± 0.5	1.6 ± 0.2	86 ± 3	85 ± 3	25 ± 17	10 ± 0	22 Sept.	1.7 ± 0.3	1.5 ± 0.3	84 ± 5	85 ± 5	35 ± 41	41 ± 30
24 Sept.	2.5 ± 0.0 ^c	2.3 ± 0.6	80 ± 4 ^c	77 ± 3	45 ± 0 ^c	43 ± 18	29 Sept.	2.3 ± 0.2	2.2 ± 0.3	81 ± 2	79 ± 3	48 ± 36	48 ± 49
1 Oct.	3.6 ± 0.4 ^c	2.9 ± 0.1	78 ± 3 ^c	76 ± 3	90 ± 14 ^c	80 ± 21	6 Oct.	3.2 ± 0.3	3.6 ± 0.6	84 ± 4	80 ± 3	77 ± 12	70 ± 38
8 Oct.	4.3 ± 0.9 ^c	4.6 ± 0.3	79 ± 2 ^c	75 ± 1	98 ± 4 ^c	90 ± 7	13 Oct.	4.0 ± 0.7	4.1 ± 0.6	84 ± 6	82 ± 4	85 ± 18	78 ± 37

^cn = 2.

Table 3. Effect of harvest maturity and storage O₂ concentration on

Harvest	Starch index (0–9)		
	1990	1991	1992
1	1.3	1.0	1.5
2	1.6	1.2	1.8
3	2.1	1.5	2.4
4	2.4	1.7	3.2
5	3.3	2.1	4.3
Significance			
Harvest date (H)			
O ₂			
H × O ₂			

Table 4. Effect of 'Delicious' strain, harvest maturity, and storage O₂ concentration on incidence of scald.

		4 month 0 °C Air storage + 7 d 20 °C air					
		Scald (% fruit affected)					
Harvest		1990	1991		1992		
		Harrold Red (HR) vs. Starkrimson (SN) (n = 3)					
		HR	SN	HR	SN	HR	SN
1		59	67	56	87	39	84
2		45	44	34	53	10	35
3		19	12	33	62	1	24
4		6	2	10	27	0	0
5		1	5	1	10	0	1
Significance							
Harvest date (H)		L***	L***	L***	L***	L*	L***
Strain (S)	Harrold Red	26		27		12	
	Starkrimson	26 ^{NS}		48***		34***	
O ₂	1.5%						
	0.7%						
H × S		NS		NS		*	
H × O ₂		---		---		---	
S × O ₂		---		---		---	
		Starking (SK) vs. Starkrimson (SN) (n = 4)					
		SK	SN	SK	SN	SK	SN
1		72	84	67	74	45	62
2		57	63	54	65	20	41
3		26	28	41	46	5	7
4		6	10	11	17	1	5
5		4	4	0	3	0	1
Significance							
Harvest date (H)		L***	L***	L***	L***	L***	L***
Strain (S)	Starking	33		34		14	
	Starkrimson	38*		41 ^{NS}		23*	
O ₂	1.5%						
	0.7%						
H × S		NS		NS		NS	
H × O ₂							
S × O ₂							

^{NS}, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; L = linear, Q = quadratic.

The H × S × O₂ interaction was nonsignificant.

incidence of storage scald, watercore-induced breakdown and flesh firmness of 'Starkrimson Delicious' apples (n = 15 orchards per year)².

Storage O ₂ (%)																	
1990						1991						1992					
Storage scald (% fruit affected)						Watercore breakdown (% fruit affected)						Flesh firmness (N)					
1.5	0.7	1.5	0.7	1.5	0.7	1.5	0.7	1.5	0.7	1.5	0.7	1.5	0.7	1.5	0.7	1.5	0.7
56	35	55	23	66	20	0	0	0	0	0	0	76	77	78	79	73	74
50	28	62	30	55	14	0	0	0	0	1	0	74	77	76	77	72	74
28	14	61	21	30	8	0	0	0	0	3	1	72	74	73	76	69	71
18	10	44	16	11	3	5	0	0	1	12	7	69	72	71	75	66	70
12	6	25	7	3	2	20	5	1	0	31	18	68	71	69	74	66	68
L***	L***	Q***	Q*	L***	L***	Q***	Q***	L**	L*	Q***	Q**	L***	L***	L***	L***	L***	L***
***		***		***		***		NS		*		***		***		***	
NS		NS		***		***		NS		NS		NS		NS		NS	

²Examined after 245 d (1990), 265 d (1991), and 257 d (1992) in 0 °C controlled atmosphere, 7 d in 0 °C air, plus 7 d in 20 °C air.

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; L = linear, Q = quadratic.

8 month 0 °C CA storage + 7 d 20 °C air											
Scald (% fruit affected)											
1.5% O ₂		0.7% O ₂		1.5% O ₂		0.7% O ₂		1.5% O ₂		0.7% O ₂	
1990				1991				1992			
Harrold Red (HR) vs. Starkrimson (SN) (n = 3)											
HR	SN	HR	SN	HR	SN	HR	SN	HR	SN	HR	SN
19	62	5	18	20	59	4	20	21	79	3	21
5	49	5	25	17	73	3	24	19	63	7	13
7	24	7	10	22	72	1	18	13	31	2	2
5	15	3	1	23	51	1	19	0	2	0	1
1	9	0	2	13	31	2	6	0	0	0	0
NS	L**	NS	L**	NS	L*	NS	NS	L**	L***	NS	L***
	6				11				7		
	22***				37***				25***		
	20				38				26		
	8***				10***				6***		
	NS				NS				**		
	NS				NS				**		
	*				NS				*		
Starking (SK) vs. Starkrimson (SN) (n = 4)											
SK	SN	SK	SN	SK	SN	SK	SN	SK	SN	SK	SN
16	56	7	45	18	52	6	19	52	71	5	28
14	45	3	26	32	46	7	21	32	41	2	11
12	32	4	15	24	53	10	21	19	9	2	6
2	15	6	12	19	33	8	7	5	6	0	1
1	8	1	4	6	12	1	0	1	2	0	1
L*	L***	NS	L***	NS	L**	NS	L*	L***	L***	L*	L**
	6				13				12		
	26***				26***				17*		
	20				29				24		
	12**				10***				5***		
	**				NS				*		
	NS				NS				***		
	NS				NS				NS		

Table 5. Effect of 'Delicious' strain, harvest maturity, and controlled atmosphere (CA) storage O₂

Watercore at harvest (% fruit affected)						
Harvest	1990		1991		1992	
Harrold Red (HR) vs. Starkrimson (SN) (n = 3)						
	HR	SN	HR	SN	HR	SN
1	0	0	0	0	2	3
2	0	0	0	0	25	10
3	10	5	0	0	45	43
4	23	37	18	2	90	80
5	70	63	35	5	98	90
Significance						
Harvest date (H)						
Strain (S)	Harrold Red					
	Starkrimson					
O ₂	1.5%					
	0.7%					
H × S						
Starking (SK) vs. Starkrimson (SN) (n = 4)						
	SK	SN	SK	SN	SK	SN
1	0	0	0	0	8	1
2	1	0	0	0	35	41
3	14	1	1	0	48	48
4	28	15	19	8	77	70
5	78	61	38	30	89	84
Significance						
Harvest date (H)						
Strain (S)	Starking					
	Starkrimson					
O ₂	1.5%					
	0.7%					
H × S						

ns,*,**,*Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively;
L = linear, Q = quadratic, C = cubic. Other interactions ($H \times O_2$, $S \times O_2$, and $H \times S \times O_2$) were nonsignificant.

ns, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively;

L = linear, Q = quadratic, C = cubic. Other interactions ($H \times O_2$, $S \times O_2$, and $H \times S \times O_2$) were nonsignificant.

to 2.5) to increase scald resistance and minimize the risks of watercore-induced breakdown in the fruit if stored in 0.7% O₂. Storage in 0.7% O₂ + 1.0% CO₂ at 0 °C is a viable alternative to DPA for controlling scald in 'Harrold Red', 'Starking', and 'Starkrimson' in British Columbia. Scald control is better with 0.7% O₂ than with 2000 mg·L⁻¹ of DPA in air or 1.5% O₂ storage (Lau, 1990a; Lau and Yastremski, 1993).

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Watercore-induced breakdown (% fruit affected)											
4 month 0 °C air storage + 7 d 20 °C air						8 month 0 °C CA storage + 7 d 20 °C air					
1990		1991		1992		1990		1991		1992	
Harrold Red (HR) vs. Starkrimson (SN) (n = 3)											
HR	SN	HR	SN	HR	SN	HR	SN	HR	SN	HR	SN
0	0	0	0	1	0	0	0	0	0	0	0
1	0	0	0	2	0	0	0	0	0	0	0
1	1	1	0	19	0	0	1	0	0	7	1
4	2	2	0	42	4	2	2	2	0	38	6
15	7	4	0	67	13	30	11	10	1	41	17
L*	L*	NS	NS	L**	Q*	Q***	Q**	Q*	NS	L***	Q**
4		3		22		6		3		14	
2 ^{NS}		0*		3**		3 ^{NS}		0**		4**	
						5		2		10	
						4 ^{NS}		1 ^{NS}		8 ^{NS}	
NS		NS		NS		NS		*		*	
Starking (SK) vs. Starkrimson (SN) (n = 4)											
SK	SN	SK	SN	SK	SN	SK	SN	SK	SN	SK	SN
1	0	0	0	2	1	0	0	0	0	1	1
2	1	0	0	7	4	0	0	0	0	2	2
0	0	0	0	15	6	0	0	0	0	10	4
4	12	3	0	25	22	2	5	0	1	21	19
8	13	10	4	41	36	19	22	3	1	61	35
L**	L**	NS	NS	L**	L**	C**	Q**	Q*	L*	Q**	Q*
3		3		18		4		1		19	
5 ^{NS}		1 ^{NS}		14 ^{NS}		5 ^{NS}		0 ^{NS}		12*	
						7		1		17	
						3*		0 ^{NS}		14 ^{NS}	
NS		NS		NS		NS		NS		*	

attenuate scald symptoms in 'Delicious' apples: Effect of apple strain and harvest maturity. *Acta Hort.* 326:183–189.

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