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Tolerance of Three Apple Cultivars to Ultra-low Levels of Oxygen

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Abstract. **Tolerance of apples to low levels (0.5%) of O_2 was cultivar-dependent. 'Spartan' (SP), 'Delicious' (RD), and 'Golden Delicious' (GD) apples *(Malus domestica* Borkh.) held for 7 months in 1.0% O_2 (with 1.5% CO_2) at 0.5C, plus ≈2 months in air at 0C and 7 days in air at 20C, were similar to those held in 1.5% O_2. However, incidence of skin injury in fruit held in 0.5% O_2 was very high in SP (purple-brown discoloration), low in RD (purple-brown discoloration), but only negligible in GD (lesions). Skin discoloration in SP and RD developed rapidly in air at 20C. Holding in 0.5% O_2 improved retention of flesh firmness and juice acidity in GD and, under certain conditions, reduced scald in RD and SP, delayed yellowing in GD, but increased flesh breakdown in SP, flesh browning and alcohol flavor in SP and RD, and core browning in RD.**

British Columbia-grown 'Golden Delicious' (GD), 'Delicious' (RD), and 'Spartan' (SP) apples kept well at 0C in a rapidly established 1.0% O_2 + 1.0% to 1.5% CO_2 atmosphere (Lau, 1983, 1985). Anderson (1967) found that 'Delicious' apples stored for 6 months in 0% O_2 at 0C plus 7 days in air at 21C developed brown sunken skin injury, core browning, and fermented flavors. However, no fermented flavors and only negligible amounts of fruit injury occurred with atmospheres containing 1% or more O_2. With commercial adoption of storage in 1.0% to 1.2% O_2 in the Pacific Northwest of North America, determination of whether atmospheres as low as 0.5% O_2 could be tolerated by the above cultivars and thus provide a margin of safety for packinghouse operators appeared appropriate. Storage results with 0.5%, 1.0%, and 1.5% O_2 are discussed in this paper.

Box quantities (80 apples per box) of GD, RD, and SP apples (33 lots per cultivar per O_2 treatment per year, each one from a different grower, 1984 through 1986) were obtained randomly at controlled-atmosphere (CA) and air storage facilities in Oliver, Kelowna, and Winfield, B.C., Canada, throughout the entire commercial harvest period. Flesh firmness, starch index, and internal ethylene concentration (IEC) of each grower lot were determined before storage (Table 1) on a 10-fruit subsample using methods described previously (Lau, 1983; Lau et al., 1986). IEC values were used to calculate the percentage of fruit with IEC > 1 $\mu l \cdot liter^{-1}$, a value deemed indicative of the onset of fruit ripening.

The GD, RD (drenched in diphenylamine at 2000 $mg \cdot liter^{-1}$ before storage), and SP samples were cooled in 0C air for 1.5 days before storage in 0.5% O_2 (cabinets; 0.85 t) or in 1.0% or 1.5% O_2 (CA rooms; 420 t). The cabinets and rooms were maintained at 0.5 ± 0.5C, O_2 values within ± 0.2%, and CO_2 at 1.5% ± 0.2%. The desired O_2 and CO_2 levels were established within 2 to 4 days and 3 days of sealing, respectively, and maintained by venting and lime scrubbing.

After CA storage plus a period in air at 0C and 7 days in air at 20C, subsamples of 10 to 15 apples from each treatment were assessed for flesh firmness and alcohol flavor (by a team of 11 sensory panelists, two panelists per grower replicate) as described previously (Lau, 1983). Incidence and severity of storage disorders were determined on 10-fruit (first and second examinations, Fig. 1) or 40-fruit samples (third examination, Fig. 1 and Table 2). Scores (maximum = 300, Fig. 1) were derived by multiplying the severity ratings (slight = 1, moderate = 2, and severe = 3) of the disorder by the percentage of fruit affected. Storage data were subjected to analysis of variance, and main effects sums-of-squares for storage O_2 concentrations were partitioned into single-degrees-of-freedom polynomials. A quadratic response of quality characteristics to O_2 concentrations is indicative of a parabolic relationship between fruit response and O_2 concentrations.

GD, RD, and SP apples obtained from a wide range of orchards and maturities (Table 1) and held in ≤1.0% O_2 (with 1.5% CO_2) plus additional days in air at 0C and 7 days in air at 20C, were firmer and mostly higher in titratable acidity than comparable fruit held in 1.5% O_2 (Table 2). No appreciable increase in fruit injury was found in these three cultivars held in 1.0% O_2. In 0.5% O_2, however, the incidence of skin injury was very high in SP (discoloration), low in RD (discoloration), and only negligible in GD (lesions resembling those caused by high CO_2) (Table 2). Post-CA storage of fruit for ≈2 months in air at 0C increased the incidence, but not the severity, of skin discoloration in SP (Fig. 1). However, subsequent incubation of fruit for 7 days in air at 20C markedly increased the incidence and severity of the disorder in both RD and SP. Incidence and

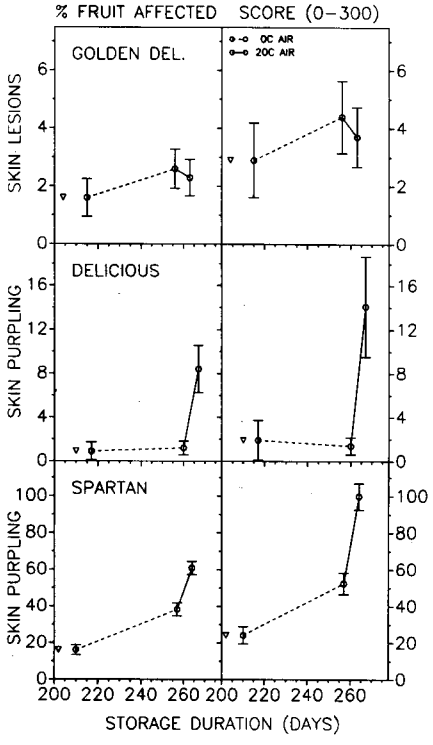

Fig. 1. Progression of skin lesions in 'Golden Delicious' and skin purple-brown discoloration in 'Delicious' and 'Spartan' apples after CA storage in air at 0C for 50 to 55 days (broken lines) and in air at 20C for 7 days (solid lines). Inverted triangles indicate the dates of fruit removal from storage at 0.5C in 0.5% O_2 + 1.5% CO_2. Vertical bars represent ± SE (n = 33 grower lots per year × 3 years; 1984 through 1986). Note that scales differ for skin defects on y axis.

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Table 1. Characteristics of 'Golden Delicious', 'Delicious', and 'Spartan' apples at harvest (n = 33 grower replicates per year).[z]

Fruit characteristics at harvest	Cultivar: Golden Delicious, Fruit sampling period: 21 Sept.–10 Oct. 1984	Golden Delicious, 17 Sept.–2 Oct. 1985	Golden Delicious, 16 Sept.–6 Oct. 1986	Delicious, 3–16 Oct. 1984	Delicious, 25 Sept.–16 Oct. 1985	Delicious, 27 Sept.–17 Oct. 1986	Spartan, 5–16 Oct. 1984	Spartan, 25 Sept.–10 Oct. 1985	Spartan, 24 Sept.–14 Oct. 1986
Flesh firmness (N)	71 ± 4	79 ± 6	76 ± 3	81 ± 4	83 ± 5	78 ± 3	73 ± 4	77 ± 5	73 ± 3
Internal ethylene concn (IEC, $\mu l \cdot liter^{-1}$)	6 ± 12	1 ± 3	1 ± 3	17 ± 15	16 ± 22	10 ± 16	134 ± 92	50 ± 65	38 ± 38
IEC > 1 $\mu l \cdot liter^{-1}$ (% of fruit)	17 ± 33	10 ± 16	3 ± 7	53 ± 27	46 ± 38	32 ± 29	93 ± 15	85 ± 25	75 ± 28
Starch index (0–9)	6.5 ± 1.6	4.1 ± 1.9	4.6 ± 2.0	2.2 ± 0.6	2.2 ± 1.0	2.4 ± 1.0	5.7 ± 1.2	3.7 ± 1.9	4.2 ± 1.7

[z]Mean ± SD.

Table 2. Effects of O_2 concentrations (with 1.0% CO_2 at 0.5C) on storage quality of 'Golden Delicious', 'Delicious', and 'Spartan' apples (n = 33 grower replicates per cultivar per year).

O_2 concn (%)[z]	Golden Delicious, 1984	Golden Delicious, 1985	Golden Delicious, 1986	Delicious, 1984	Delicious, 1985	Delicious, 1986	Spartan, 1984	Spartan, 1985	Spartan, 1986
	Storage period (days)[y]								
	180 + 76	188 + 62	244 + 18	173 + 80	226 + 37	232 + 32	174 + 77	197 + 58	236 + 29
	Flesh firmness (N)								
1.5	60.7	64.9	59.3	66.0	67.0	67.1	51.8	57.2	51.4
1.0	63.0	66.8	62.8	68.0	69.2	70.4	54.6	59.7	57.4
0.5	64.5	70.9	67.9	67.4	67.2	69.5	53.2	60.4	50.7
Significance[x]	Q***	Q***	Q***	L**	L***	L***	L***	Q*	Q***
	Titratable acidity (mg malate/100 ml juice)								
1.5	272	320	275	240	229	219	274	278	259
1.0	288	348	314	242	227	230	281	290	286
0.5	325	381	340	241	233	224	283	307	267
Significance	Q***	Q***	Q***	NS	NS	L*	NS	Q***	L***
	Good fruit (%)[w]								
1.5	96	92	97	96	89	78	61	81	70
1.0	97	96	97	97	93	89	65	82	82
0.5	95	96	92	91	72	84	27	32	20
Significance	NS	L*	Q**	Q*	Q***	L***	Q***	Q***	Q***
	Skin lesions (%)[v]			*Skin discoloration (%)*[v]					
1.5	0.6	0	0	0.3	0.6	0.2	1.0	0	2.6
1.0	0.4	0.4	0.1	0	0.9	0	5.1	0.7	6.1
0.5	1.9	0.8	4.4	4.6	19.8	1.3	52.1	58.2	72.2
Significance	Q**	Q*	Q***	Q**	Q***	Q**	Q***	Q***	Q***
	Senescent scald (%)[v]			*Scald (%)*[v]					
1.5	0	4.8	0	1.3	7.0	9.9	8.3	2.8	1.8
1.0	0	1.4	0	1.3	2.5	3.3	1.8	0.2	0.2
0.5	0	0.3	0	0.8	0.7	0.1	3.0	0.3	0.1
Significance	NS	L*	NS	NS	Q**	Q***	L***	L***	L*
	Skin color (1–10)[u]						*Flesh breakdown (%)*[v]		
1.5	4.7	4.7	4.6	---	---	---	1.1	3.0	2.9
1.0	4.5	4.6	4.4	---	---	---	2.4	1.2	1.2
0.5	4.5	4.2	3.9	---	---	---	7.1	6.1	9.3
Significance	NS	Q***	Q***				Q***	Q***	Q***
	Flesh browning (%)[v]								
1.5	0.5	0.1	0.4	0.7	1.9	6.6	3.2	3.8	7.8
1.0	0.9	0.5	0.6	0.8	1.0	3.3	6.1	3.7	2.8
0.5	0.5	1.3	2.1	0.8	5.1	5.8	13.9	8.3	27.6
Significance	NS	Q**	Q**	NS	Q**	L*	Q***	Q***	Q***
	Core browning (%)[v]								
1.5	0	0.9	0	0.9	1.6	6.7	34.7	10.8	16.8
1.0	0.1	0.7	0.3	0.5	0.6	4.0	26.8	11.3	8.0
0.5	0.3	0.2	0.1	4.0	3.5	8.1	39.9	11.1	13.9
Significance	NS	NS	NS	Q**	Q***	L**	Q*	NS	L**
	Alcohol flavor (1–5)[t]								
1.5	1.3	1.2	1.7	1.3	1.5	1.6	1.5	1.3	2.3
1.0	1.3	1.2	1.7	1.5	1.4	1.6	1.5	1.2	2.2
0.5	1.2	1.2	1.6	1.4	1.7	2.1	1.9	1.9	2.6
Significance	NS	NS	NS	NS	NS	Q***	Q***	Q***	NS

[z]Held in 420-t rooms (1.5% and 1.0% O_2) or 0.85-t cabinets (0.5% O_2).
[y]Days in CA (first number) and air (second number) storage followed by a 7-day shelf life test in air at 20C.
[x]Linear (L), quadratic (Q), and significant at $P = 0.05$ (*), 0.01 (**), or 0.001 (***), or nonsignificant (NS).
[w]Expressed as percent of fruit without any fruit injury or storage disorder.
[v]Expressed as percent of fruit examined or affected (analysis of variance performed on arcsin square root of the percentage transformation).
[u]Higher values indicate less green pigment.
[t]Alcohol flavor: 1 = none, 3 = readily detectable, and 5 = strong.

severity of skin lesions in GD were not affected by the post-CA storage periods in air at 0 or 20C.

Holding in 0.5% O_2 markedly improved retention of flesh firmness and juice acidity in GD and, in some years, reduced scald in RD and SP, delayed yellowing in GD, but increased flesh breakdown in SP, flesh browning and alcohol flavor in SP and RD, and core browning in RD. Varying tolerance of apple cultivars to 0.5% O_2 could be due to differences in their skin's resistance to diffusion and in their respiration rates (Cameron and Reid, 1982; Solomos, 1986).

In conclusion, GD was slightly more tolerant to 0.5% O_2 atmosphere than was RD, which, in turn, was more tolerant than SP. While the margin of safety can be as much as –0.5% O_2 for GD held in 1.0% O_2, indications (Lau, 1990) (Table 2) are that it is only –0.3% O_2 for RD held in 1.0% O_2. Because of its low tolerance to 0.5% O_2, SP should be held at O_2 levels > 1.0% at all times, preferably at 1.1% ± 0.1% O_2.

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