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Effects of a Pre-storage High CO_2 Treatment on British Columbia and Washington State 'Golden Delicious' Apples[1]

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Abstract. **Thirty-two lots of 'Golden Delicious' apples (*Malus domestica* Borkh.) from 22 British Columbia (B.C.) orchards varied in their susceptibility to injury from a 10-day 14 or 18% CO_2 treatment preceding controlled atmosphere storage. In general, the incidence of injury was much higher than in 25 lots of Washington State 'Golden Delicious' treated similarly in a commercial storage. A small improvement in firmness was observed in the B.C. fruit. Within the 32 B.C. lots, susceptibility to CO_2 injury was not related to fruit skin color, size, soluble solids or acidity, the N, K, Mg, Ca, Zn, Fe or B content of the leaves, or N, K, Mn, Mg, Ca or Zn content of the fruits. However, Washington 'Golden Delicious' were less green, were lower in N, Mn and Zn and higher in K, Mg and soluble solids than B.C. fruit which may provide a clue to their resistance to CO_2 injury.**

Softening of 'Golden Delicious' apples in commercial controlled atmosphere (CA) storage is the main impediment to successful storage of this cultivar beyond about 6 months. Soft fruits are not only undesirable from the consumers' viewpoint, but they are highly susceptible to bruising during packing and distribution.

Considerable improvement in the retention of firmness has been achieved with Washington State 'Golden Delicious' with a relatively short pre-storage CO_2 treatment (1, 2). This procedure extends the market season and fruits withstand the rigors of packing in Feb. and March with noticeably less bruising.

Visible injury to the fruits from this CO_2 treatment, however, is a serious concern. Couey and Olsen (2) reported very little injury but Bartram (1) observed injury (up to 30%) in several grower lots in commercial trials in Washington over several seasons but the quantity of fruits affected (less than 2% of all treated fruits) was not sufficient to generate serious concern. A substantial portion of the Washington 'Golden Delicious' crop is now being treated (1).

A 3-year study by Meheriuk (4) showed that treatments of 10-20% CO_2 for 10-14 days resulted in firmer British Columbia 'Golden Delicious' apples but injury often exceeded levels considered commercially acceptable. This present study of 32 fruit lots from 22 orchards in the southern Okanagan Valley, the principal 'Golden Delicious' growing area in B.C., was undertaken to determine the local applicability of this pre-storage procedure and to learn more about orchard factors influencing the responsiveness of fruits to CO_2 treatment. We also examined 25 grower lots of 'Golden Delicious' grown and treated commercially with CO_2 in Washington in an effort to explain their apparent greater resistance to CO_2 injury.

Materials and Methods

Thirty-two lots of 'Golden Delicious' apples were harvested between Sept. 20-22 and Oct. 4-5, 1976 (140 to 147 days after full bloom) from 22 orchards in Oliver, Osoyoos, Keremeos, Okanagan Falls, Naramata, and Westbank, B.C. A bushel of fruits (60-70 fruits) was picked from each of 16 randomly selected trees in each orchard block. These fruits were randomized among 16 boxes so that the fruits in each box came from 16 trees. The fruits were treated with CO_2 using levels and procedures approximating those used by commercial storages in Washington. One box of fruit from each orchard lot was used for the 'at harvest' assessment and of the remaining 15, 5 were treated with 2% CO_2 (control), 5 with 14% CO_2 and 5 with 18% CO_2 in the presence of 6% O_2 for 10 days starting 1-3 days after harvest. Each of the 3 atmosphere treatments was applied in a 2.5 × 2.5 × 2.5m polyethylene-lined cabinet in a cold storage room held at $0^{o}C$. Fruit temp was about 1^{o} at the time of the gassing treatment. Each cabinet, containing 160 bu of fruit, was sealed and flushed with nitrogen gas for several hours to establish an O_2 level of about 8%, and then CO_2 was introduced slowly into the top of the cabinet. Two fans were used to circulate the gas mixture inside each cabinet. Establishment of the specified CO_2 levels required about 24 hr and these levels were maintained within very close tolerances for the next 9 days. The fruits were then removed and placed in a commercial CA storage room with storage conditions of -1^{o}, 2% CO_2 plus 2.5% O_2, and about 90% RH.

A bushel box of fruit (60-70 apples) from each orchard lot and each CO_2 treatment was removed from storage in Dec., Feb., March and May. Every fruit was measured with calipers and assessed for color with a 'Golden Delicious Color Meter' (Model GD, Techwest Enterprises Ltd., Vancouver, B.C.) and firmness with a Ballauf pressure tester (2 punches/apple, 11.1 mm tip). The amount of external CO_2 injury was recorded using a scoring system previously described (3). A wedge from each fruit was used in a composite juice sample assessed for acidity by titration to pH 8.1 and soluble solids content by refractive index. The data from each examination from storage were subjected to an analysis of variance involving 3 treatments and 32 reps.

Leaf mineral (N, Zn, Mg, Mn, K, Ca, B, Fe) were analyzed by the B. C. Ministry of Agriculture Leaf Analysis Laboratory in Kelowna, B.C., using standard procedures. Mid-shoot leaves from each tree of each grower lot were collected in July 1976. Fruit cortical tissue was sampled from 200 fruits of each lot about 2 months after harvest and analyzed for K, Mn, Mg, Ca and Zn after freeze-drying, grinding, oven-drying, and ashing. Atomic absorption spectrophotometry was used for measuring K, Mn, Mg, Ca, and Zn and N was determined by the micro-Kjeldahl method using dried ground samples.

Twenty-five grower lots of CO_2-treated 'Golden Delicious' apples (process grade) were obtained from Skookum Inc., Entiat, Washington on March 16, 1977 by arrangement with Dr. M. Couey, USDA, Wenatchee. The decision to examine

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process grade fruit was in part based upon expediency but was also attractive in that the grading operation would direct most of the CO_2-injured fruits into this category. Thus, susceptible and resistant lots would be easier to identify. These fruits were harvested between Sept. 18 and 22, 1976 (about 141 days after full bloom) by orchardists in north-central Washington. The CO_2 gassing program was started within 1 to 5 days of harvest. The O_2 level in the CA room was reduced to about 10% and CO_2 increased to 6% within 48 hr using a catalytic O_2 burner. An atmosphere of about 4-5% O_2 and about 14% CO_2 was established withn the next 2½ days and maintained for another 8 days by introducing CO_2 gas behind the fan of the refrigeration coil into the room. The room was then flushed to remove CO_2 and the atmosphere in the CA room was established and maintained at about 1% CO_2 and 2.5% O_2 by using a catalytic O_2 burner and a lime scrubber. The CA room was opened on Feb. 16 and the fruits were sized and graded at Entiat, Washington between Feb. 25 and March 10 and the sample of process grade fruits was assessed on March 17, 1977 at the Summerland Research Station. Firmness, acidity, soluble solids, size, and color were determined using the same techniques and sample sizes as for the B.C. fruit. The extent of CO_2 injury was assessed and converted to percentage by factoring in the amount of process grade fruits in each grower lot. Mineral analysis of the fruit cortex was described above.

Table 1. Effect of a pre-storage CO_2 treatment on fruit firmness, soluble solids, and titratable acidity of 'Golden Delicious' apples grown in British Columbia (1976 crop). Each number in the table is the mean of 32 different grower lots with 60-70 fruits per lot.

CO_2 treatment	At harvest Sept. 20-22	Examination from CA storage^y Dec. 8-24	Feb. 1-7	March 22-25	May 17-20
			Firmness (kg)		
2%	7.55	7.00 b^z	6.77 c^z	6.27 b^z	6.00 c^z
14%		7.14 a	6.91 b	6.36 a	6.14 b
18%		7.18 a	7.09 a	6.41 a	6.32 a
			Soluble solids (%)		
2%	11.3	12.0	12.1	12.0	11.9
14%		12.1	12.0	12.0	11.9
18%		12.1	12.0	11.8	12.0
			Titratable acidity (%)		
2%	0.526	0.445	0.413	0.381	0.322
14%		0.443	0.416	0.381	0.325
18%		0.445	0.413	0.384	0.319

^{y}Storage was at -1^oC with 2% CO_2 plus 2.5% O_2 and 90% RH.

^{z}Mean separation, within columns, by Duncan's multiple range test, 5% level. The differences in soluble solids or titratable acidity, within columns, are not statistically significant.

Results and Discussion

The 14% and 18% CO_2 treatment marginally increased the firmness of B.C.-grown 'Golden Delicious' apples and this benefit was apparent at all examination dates from Dec. to May (Table 1). However, fruit from individual orchard lots varied considerably in the extent to which firmness was improved by high CO_2 (Table 2). Fruit from different blocks operated by one grower also responded differently to the high CO_2 treatment. The overall effect on fruit firmness retention is considered insufficient to warrant commercials application of the treatment and supports the conclusion of Meheriuk (4) that B.C. 'Golden Delicious' appear to benefit less than Washington fruit.

Furthermore, the B. C.-grown 'Golden Delicious' apples proved to be very susceptible to CO_2 injury (Tables 2 and 3). A varying degree of external CO_2 injury, characterized by irregular, sunken, dry and often pebbly brown patches confined to the skin, was observed in most of the CO_2-treated lots. The incidence and severity of injury varied greatly among lots and even among lots from different parts of a single orchard (Table

Table 2. Some differences in firmness benefit (relative to the 2% CO_2 treatment) and injury among 18 selected lots of 'Golden Delicious' apples treated with 18% CO_2 for 10 days. Because some orchardists operate several 'Golden Delicious' blocks these 18 lots represent 9 orchard operations (column 2).

Lot no.	Orchard no.	Firmness benefit (kg) Dec.	Feb.	Mar.	May	Mean	External injury (%) Slight	Moderate	Severe	Internal injury (%)	Total injury (%)
1	1	0.18	0.27	0.23	0.59	0.32 abcd^y	0	0	0	1.2	1.2 m^z
2	2	0.23	0.41	0.36	0.27	0.32 abcd	2.3	0.8	0	6.6	9.2 klm
3	2	0.09	0.50	0.09	0.23	0.23 abcd	0.4	0.4	0	9.4	10.7 klm
4	2	−0.41	0.55	−0.05	0.27	0.09 abcd	16.9	7.6	1.1	14.6	37.3 fg
5	3	−0.09	0.45	0.27	0.05	0.17 abcd	5.7	2.7	0.4	1.7	10.0 klm
6	3	0.18	0.45	0.55	0.82	0.50 a	13.4	9.8	2.5	3.5	30.8 ghi
7	4	0.36	−0.27	−0.14	0.05	0.00 d	5.3	2.5	0	4.6	10.9 kl
8	4	0.14	0.36	0.64	0.32	0.37 abcd	12.4	6.8	0.8	12.4	29.7 ghi
9	5	0.09	0.14	0.32	0.55	0.28 abcd	7.5	3.9	1.7	2.7	13.7 kl
10	5	−0.05	0.18	0.14	0.64	0.23 abcd	19.6	12.3	2.5	1.8	35.8 fgh
11	6	0.64	0.36	0.05	0.45	0.38 abcd	7.1	5.4	2.1	0	14.9 jkl
12	6	0.55	0.41	−0.27	0.14	0.21 abcd	11.3	10.0	1.3	9.4	29.0 ghi
13	7	0.00	−0.23	0.05	0.23	0.01 cd	8.3	5.7	0	3.2	16.1 jk
14	8	0.00	0.86	0.55	0.32	0.43 abc	14.7	13.4	11.9	3.0	40.4 ef
15	8	0.05	0.45	0.27	0.32	0.27 abcd	21.4	15.4	12.7	5.3	48.4 cde
16	9	0.68	0.68	0.36	0.23	0.49 ab	16.4	19.0	10.7	7.2	48.7 cde
17	9	0.68	0.41	0.09	0.55	0.43 abc	22.1	18.9	18.3	10.2	61.7 b
18	9	0.23	0.59	0.36	0.50	0.42 abcd	23.5	14.8	13.1	40.2	71.6 a

^{y}Mean separation by Duncan's multiple range test 5% level, based on an analysis of variance of 'benefit' values for 32 treatments and 4 replications (dates).

^{z}Mean separation by Duncan's multiple range test at the 5% level, based on an analysis of variance of 'injury' values for 32 treatments and 4 replications (dates).

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Table 3. A summary of the susceptibility of British Columbia 'Golden Delicious' apples to CO_2 injury from pre-storage high CO_2 treatments applied in 1976.

CO_2 treatment	% of fruits showing external and/or internal CO_2 injury			
	Dec. 8-24	Feb. 1-7	March 22-25	May 17-20
2%	0.8 c[z] (0–5.3)[y]	1.0 c (0–4.2)[y]	1.1 c (0–6.2)[y]	0.4 c (0–2.9)[y]
14%	16.2 b (1.3–42.4)	15.4 b (0–35.6)	13.7 b (0–41.5)	15.4 b (1.3–43.1)
18%	29.5 a (0–74.6)	29.3 a (1.3–75.8)	29.7 a (1.4–71.4)	32.0 a (2.1–68.6)

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

[y]Bracketed values are the range of values within the 32 lots examined.

2) and was significantly higher for the 18% CO_2 than for the 14% CO_2 treatment (Table 3). The injury was apparent as early as 1 to 2 weeks after the CO_2 treatment and persisted through storage. All parts of the fruit surface were subject to injury but more injury occurred near the calyx end. A varying degree of internal CO_2 injury was occasionally observed in certain orchard lots (Table 2). It is characterized by small, elliptical, double-convex lens-shaped cavities (as large as 5 × 15 × 30 mm) surrounded by patches of dry, collapsed and discolored tissues in the core or the mid-cortex region of the fruit and often more prevalent near the calyx end. The long dimension of these cavities parallels the fruit axis. Internal injury was found in fruits sampled in December and there was very little further development during CA storage (Table 3). This within-orchard and between-orchard variability in susceptibility to injury agrees with the reports of Bartram (1) and Couey and Olsen (2). Certainly the extent of injury in the B.C. fruit would limit commercial application of the CO_2 treatment.

Soluble solids and titratable acidity of fruits were unaffected by any of the pre-storage CO_2 treatments (Table 1).

An important aspect of our study was to look for the relationships between responsiveness to CO_2 and the physical and chemical characteristics of the fruit and leaves. Mineral content of leaf and fruit, skin color, size, soluble solids, titratable acidity, and firmness of fruits of each orchard lot all appear unrelated to susceptibility to CO_2 injury (Table 4). The apparent relationship between leaf Mn and internal CO_2 injury is considered an anomaly. Mineral analyses of selected individual fruits, either

Table 4. Correlations (r) between CO_2 injury and various parameters of British Columbia 'Golden Delicious' leaf and fruit samples from 32 orchard lots.

Parameters examined[z]	CO_2 injury[y]	
	External	Internal
Leaf N	0.178	–0.028
Fruit N	–0.143	0.258
Leaf K	–0.027	–0.060
Fruit K	–0.007	–0.087
Leaf Ca	–0.152	–0.013
Fruit Ca	–0.189	–0.169
Leaf Mg	0.237	–0.135
Fruit Mg	–0.157	0.144
Leaf Mn	–0.091	0.455**
Fruit Mn	–0.297	0.103
Leaf Zn	0.010	–0.190
Fruit Zn[x]	–0.177	–0.389
Leaf Fe	–0.040	–0.207
Leaf B	0.092	0.231
Skin color	–0.075	–0.071
Fruit size	–0.173	0.118
Flesh firmness	–0.276	0.175
Soluble solids	–0.125	0.010
Titratable acidity	–0.045	0.150

[z]Leaf mineral analyses were completed in July, 1976 and fruit mineral analyses in Dec., 1976. Flesh firmness in Dec., 1976. and skin color, fruit size, soluble solids, and titratable acidity in Feb., 1977 were used to calculate the correlation coefficients.

[y]The average of external and internal CO_2 injury values observed in Feb., March, and May, 1977 were used in the calculation of the correlation coefficient.

[x]Only 15 orchard lots were included in the calculation of this correlation coefficient. All others involve 32 orchard lots.

**Significant at the 1% level.

Table 5. Some comparisons between British Columbia (32 lots) and Washington (25 lots) 'Golden Delicious' apples (1976 Crop).

Fruit parameter examined	Source of fruits	Range	Mean	t[x]
Flesh firmness (kg)	B.C.	5.59–7.18	6.41	1.015
	WA	5.27–7.41	6.55	
Size (unit)[z]	B.C.	1.69–2.67	2.12	1.967
	WA	1.59–2.28	2.01	
Skin color (unit)[y]	B.C.	2.07–4.37	2.84	3.084**
	WA	2.20–4.37	3.27	
Titratable acidity (%)	B.C.	0.31–0.52	0.38	1.158
	WA	0.30–0.43	0.37	
Soluble solids (%)	B.C.	10.2–14.1	11.8	3.509**
	WA	11.0–14.7	12.6	
Nitrogen (ppm)	B.C.	1090–3010	2030	3.441**
	WA	1250–2240	1720	
Potassium (ppm)	B.C.	4118–6799	5095	7.575**
	WA	5527-8865	6425	
Calcium (ppm)	B.C.	158–366	230	0.517
	WA	171-317	235	
Magnesium (ppm)	B.C.	198–286	239	6.403**
	WA	240–307	267	
Manganese (ppm)	B.C.	1.13–3.22	1.80	7.219**
	WA	0.83–1.74	1.17	
Zinc (ppm)	B.C.	1.74–4.88	3.10	2.397*
	WA	2.00–3.00	2.47	

[z]Apples with a diam <6.4 cm; <6.9 cm but >6.4 cm; <7.55 cm but >6.9 cm; <8.2 cm but >7.55 cm; and >8.2 cm were assigned a size rating of 1, 1.5, 2, 2.5, and 3, respectively.

[y]Upper scale reading of the 'Golden Delicious Color Meter' (see text). Higher values indicate less green color.

[x]Unpaired "t" test was used to test differences between the B.C. and WA means; ** = significant at the 1% level; * = significant at the 5% level.

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completely free of injury or severely injured externally and/or internally, also failed to indicate any clear relationship between any of these parameters and CO_2 injury (data not shown).

An examination of the 25 lots of CO_2-treated 'Golden Delicious' apples obtained from Washington State suggests that these fruits were less susceptible to CO_2 injury. External injury averaged 1.5% (range: 0–13.5% and internal injury 0.1% (range: 0–1.4%). The incidence of external and internal CO_2 injury was, as in B.C. apples, not related to size, skin color, soluble solids, titratable acidity, firmness, and mineral (N, K, Ca, Mn, Mg, and Zn) content of the fruits (data not shown).

The reason why B.C. 'Golden Delicious' behave differently from those grown in Washington remains unknown. Analyses of the Washington and B.C. apples revealed little difference in fruit firmness, size, titratable acidity, and Ca content but Washington fruits were less green and were lower in N, Mn, and Zn and higher in soluble solids, in K, and Mg (Table 5). The fruit color and soluble solids data would suggest that the Washington fruits were of somewhat better quality but whether any of these differences could account for the disparity in CO_2 response is still open to question. High tree vigor with a light crop, immature fruits, spring frost damage, large fruit size, and excessive levels of CO_2 and duration of the CO_2 treatment have been suggested by R. D. Bartram (personal communication, 1977) to be factors associated with CO_2 injury. Meheriuk (4) observed that CO_2 injury to the skin was likely to be more severe in the earlier harvested fruit whereas internal injury tended to be more extensive in more mature fruit. Recently, we showed that moisture on fruit surfaces resulted in a high incidence of CO_2-associated skin injury (3). A similar but less direct observation was also noted by Bartram (personal communication).

In conclusion, CO_2 treatment before CA storage of 'Golden Delicious' apples in Washington State appears to be a commercially successful innovation. It does not presently appear promising for B.C. because the levels of CO_2 injury are excessive and results to date show the firmness retention response to be very marginal.

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Early Root Growth of Carrots in Organic Soil[1]

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Abstract. **Early root growth of carrots (*Daucus carota* L.) was studied in specially constructed pots containing organic soil under controlled environments at 16°, 20°, 24°, and 28°C. Carrot tops produced greater amounts of bio-mass on a fresh or dry weight basis than did roots, whereas taproots demonstrated faster rates of linear growth than did the tops throughout the 24-day sampling period at all temperatures. The optimum range of temperatures for carrot root growth was 20-24°C. Taproots reached the potential length for market-acceptable storage roots (15.2 cm) between 12 and 16 days after planting at 20°, 24°, and 28°C and after 20 days at 16°C. Average taproot lengths after 24 days at 16°, 20°, 24°, and 28°C were 23.6, 38.5, 35.6, and 16.7 cm, respectively. Secondary roots had developed by the 8th day and tertiary roots by the 20th day. Tertiary roots were confined to the upper 5 cm of the root system at this early date.**

The quality of bunched and topped carrots produced for fresh market depends heavily upon the configuration of the storage root. Grading standards as well as consumer acceptance have dictated criteria for root length, diameter, and the variability of these factors, as well as freedom from defects such as crooking and forking (4). The anatomical changes during development of the carrot have been described by Esau (2) and Havis (3). Recent reports by Phan and Hsu (5) and Slinger (6) are in good agreement with earlier descriptions of root growth in carrots. However, none of these workers studied in detail the early stages of taproot growth.

Reported effects of temperature and moisture on carrot root development are mostly a result of field observations and impressions (7). Barnes (1) has provided some experimental work which supports many of these observations. However, he investigated carrot root development after secondary thickening of the storage root had begun.

As part of an in-depth study of physical and biological factors affecting carrot root configuration and disorders, we report herein results describing the early stages of root growth of fresh market type carrots under controlled environment conditions.

Materials and Methods

Early carrot root growth was studied using specially constructed pots made of 10.2 cm inside diam polyvinyl chloride pipe. Sections of pipe 38 cm long were cut longitudinally into halves and rejoined with weatherproof tape. To facilitate removal of the soil and roots, the tape was removed and pots split apart for examination. Pots were filled within 2 cm of the top with an organic soil (Everglades mucky-peat) which had been steamed for 6 hr and sieved through a 0.64 cm mesh screen. The soil in each pot was packed to provide a medium soil compaction. A penetrometer (Model CL-700, Soil Test, Inc.) was used to measure soil compaction and each pot was

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