HORTSCIENCE 27(5):420-421. 1992.

Postharvest Carbon Dioxide Treatment Enhances Firmness of Several Cultivars of Strawberry

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Additional index words. firmness enhancement, oxygen, pH, Hunter color, *Fragaria ×ananassa*

Abstract. **Various cultivars of strawberry *(Fragaria ×ananassa* Duch.) were stored for 42 h under an atmosphere of 15% CO_2 to determine whether their firmness would be enhanced. Compared to initial samples and stored control samples, enhanced firmness was found in 21 of the 25 cultivars evaluated. The CO_2 had no effect on color, as measured by Hunter 'L', 'a' and 'b', or on soluble solids concentration (SSC) or pH. There were significant differences among cultivars in firmness; Hunter color 'L', 'a', and 'b'; SSC; and pH.**

Research conducted in Poland (Ptocharski, 1982) and in Canada (Smith, 1992) has shown that the firmness of some cultivars of strawberry is enhanced when they are stored in a modified atmosphere high in CO_2. The concentration of O_2 had no effect on firmness. Other researchers have indicated that CO_2 helps maintain firmness (Harris and Harvey, 1973; Li and Kader, 1989) or that fruit stored in a CO_2 atmosphere is firmer than berries not stored under CO_2. It is possible that enhancement of firmness has not been identified because comparisons between treated and nontreated fruit may only have been made at the end of the storage trial and because it has been assumed that the differences were due to firmness retention rather than firmness enhancement. The fruit of some cultivars of strawberry may not respond to a CO_2-enriched atmosphere.

The objective of this investigation was to test whether controlled-atmosphere (CA) storage enhances the firmness of various cultivars and selections of strawberry.

Twenty-five cultivars of strawberry were harvested from experimental plots (Horticultural Research Institute of Ontario, Vineland Station) as they became mature during the season. Within cultivars, berries of similar color were selected and then randomized among the three treatments (initial, air-stored, and CA-stored). The replicates consisted of three successive harvests from each cultivar. The fruit was forced-air-cooled to 0.5C and placed in polyethylene storage units (Smith and Reyes, 1988), and the atmospheres were adjusted with compressed gases and a Nova 305 portable CO_2-O_2 analyzer (Nova Analytical Systems, Hamilton, Ont). The CO_2 was maintained at 0% or 15% and O_2 at 18.5% for both. The berries were held under these atmospheres for 42 h. Trials conducted with 'Redcoat' have shown an increasing response throughout a 30- to 45-h exposure to CO_2; however, other trials with 'Redcoat' have shown no increase in response after 18 h (Smith, 1992).

Upon removal from the CA storage, the berries were evaluated for firmness. Firmness was measured as the force required to initiate cell shearing (Voisey et al., 1972) (generally referred to as the bioyield point or puncture test) when the berry was probed with a 0.64-cm flat-tip probe affixed to an Ottawa Texture Measuring System (Model D.1804.C; Canners Machinery, Simcoe, Ont.). Measurements were recorded on 15 berries from each treated sample.

A 200-g sample of fruit from each treatment was washed, blot dried, decapped, and frozen (–35C) for subsequent determinations of pH (model 811; Orion Research, Boston); soluble solids concentration (SSC) (AO Abbe refractometer model 10450; American Optical Corp., Buffalo, N.Y.); and Hunter color 'L', 'a', and 'b' (Hunterlab D25-3A Color Difference Meter; Hunter Associates Lab., Fairfax, Va.). The samples for color were blended under vacuum to provide uniform, bubble-free material. A 50-g sample was placed in an Agtron sample cup (#11595; Magnuson Engineers, San Jose, Calif.) and the color read through the bottom using reflected light. The final standardization of the Hunter meter was made on the red tile ('L' = 25.9, 'a' = 28.4, and 'b' = 12.9). [Hunter 'L' measures lightness/darkness (0 = black, 100 = white), 'a' measures red/green (+ = red, 0 = grey, – = green), 'b' measures blue/yellow (+ = yellow, 0 = grey, – = blue)].

A randomized complete-block design was used in this trial. Analysis of variance (ANOVA) was conducted using an IBM PST Model 50 computer with the Statistical Analysis System (SAS) program package (SAS Institute, Cary, N.C.). Means within cultivars were separated using Duncan's multiple range test. The firmness data was subjected to a $\log_{10}$ transformation to correct for lack of homogeneity of variances. The standard error was calculated for variables used to evaluate changes among cultivars. Correlation coefficients were calculated for various combinations of 'L', 'a', and 'b'.

After 42 h, the fruit exposed to CO_2 was significantly firmer than initial samples and the non-CO_2-treated control berries (Table 1). Comparison of means revealed that 21 of the 25 cultivars treated with CO_2 were firmer than the berries samples initially and 21 were firmer than the corresponding control samples. The CO_2-treated fruit of 'Chandler' and 'Vantage' were not significantly firmer than the initial or the stored control samples. Other CO_2-treated berries not significantly firmer than initial samples, but significantly firmer than the control, were 'Bounty' and 'V 7251-1'. The CO_2-treated fruit of 'Kent' and 'Midway' were significantly firmer than the initial samples, but not significantly firmer than the control. In initial trials, CO_2-treated fruit was firmer than the control for ≈60%

Table 1. Comparison of firmness within strawberry cultivars cooled to 0C but not stored (initial) or stored at 0C for 42 h either in air or controlled atmosphere (15% CO_2 and 18% O_2).

	Firmness (N)		
Cultivar	Initial	Control-stored	CA-stored
Allstar[z,y]	6.92 a	6.70 a	9.46 b
Bounty	4.34 ab	4.02 a	4.99 b
Chandler	6.31 a	6.47 a	7.29 a
Dana	4.16 a	4.59 a	5.41 b
Glooscap	5.05 a	4.86 a	6.03 b
Governor Simcoe	6.17 a	6.12 a	8.09 b
Guardian	5.09 a	4.71 a	6.12 b
GU62E55[x]	3.55 a	3.56 a	4.79 b
Kent	5.79 a	6.28 ab	7.28 b
Micmac	4.95 a	4.99 a	6.31 b
Midway	4.65 a	5.22 ab	5.94 b
Pajaro	6.71 a	6.82 a	8.28 b
Raritan	4.80 a	4.73 a	6.75 b
Redcoat	4.90 a	5.24 a	7.16 b
Selva	8.22 a	7.91 a	11.48 b
Settler	5.06 a	4.63 a	7.28 b
Sparkle	2.88 a	2.98 a	4.14 b
Tribute	6.15 a	6.50 a	8.04 b
Tristar	6.08 a	5.90 a	8.26 b
Vantage	6.31 a	6.24 a	6.90 a
Veestar	4.84 a	4.80 a	6.81 b
Vesper	3.41 a	3.24 a	4.19 b
Vibrant	4.58 a	4.69 a	6.21 b
Selkirk	9.40 a	8.83 a	12.65 b
Scotland	9.02 ab	8.34 a	10.30 b
Mean	5.57	5.53	7.21
SE	1.05	---	---
Error mean square	0.00124		
Error d.f.	48		

[z]Means within rows separated by Duncan's multiple range test, P = 0.05. Actual data are presented, analysis of variance conducted using $\log_{10}$ X.

[y]Firmness measured as the force required to initiate cell shearing (puncture test) using a 0.64-cm, flat-tip probe.

[x]A Univ. of Guelph selection.

Received for publication 18 Nov. 1991. Accepted for publication 2 Jan. 1992. We thank J. Nichols for technical assistance and Brian Allen (Univ. of Guelph) for statistical assistance and acknowledge the monetary support from The Ontario Berry Growers' Assn., Louth Niagara Orchards, and The Agriculture and Food Research Fund. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

Table 2. Hunter color 'L', 'a', and 'b'; pH; and soluble solids concentration (SSC) for various strawberry cultivars in production trials at the Horticultural Research Institute of Ontario.

Cultivar	Hunter color[z] 'L'	'a'	'b'	pH	SSC (%)
Allstar	26.14	34.24	13.40	3.48	7.07
Bounty	20.42	30.44	10.35	3.55	7.93
Chandler	20.86	32.70	11.33	3.21	6.54
Dana	26.95	34.92	12.74	3.40	7.93
Glooscap	20.53	31.25	10.86	3.52	6.80
Governor Simcoe	28.46	33.93	13.72	3.51	7.57
Guardian	27.07	33.42	12.64	3.49	7.60
GU62E55[y]	19.48	31.17	10.55	3.33	7.40
Kent	20.83	30.16	10.63	3.39	7.07
Micmac	25.68	33.08	12.48	3.50	7.67
Midway	24.06	34.36	12.81	3.26	6.20
Pajaro	25.60	34.45	12.97	3.37	6.33
Raritan	23.18	32.84	12.12	3.57	6.33
Redcoat	27.65	34.20	13.16	3.34	6.73
Selva	25.11	31.49	11.95	3.51	5.67
Settler	24.27	33.88	12.84	3.43	6.70
Sparkle	22.90	32.39	11.63	3.51	8.10
Tribute	24.04	32.73	11.82	3.52	6.50
Tristar	21.30	32.66	11.47	3.27	7.23
Vantage	26.85	35.42	13.44	3.33	8.83
Veestar	25.17	34.54	13.08	3.30	6.63
Vesper	21.20	31.81	11.35	3.56	7.13
Vibrant	22.28	33.95	12.26	3.22	6.97
Selkirk	22.95	33.70	12.39	3.38	6.57
Scotland	28.01	33.85	12.73	3.50	8.30
SE	0.82	0.71	0.45	0.04	0.15
Error mean square	2.021	1.531	0.604	0.0056	0.066
Error d.f.	48	48	48	48	48

[z]'L' (light/dark; 0 = black and 100 = white), 'a' (red/green; + = red, 0 = grey, − = green), 'b' (blue/yellow; − = blue, 0 = grey, + = yellow).
[y]A Univ. of Guelph selection.

of the cultivars evaluated (R.B.S., unpublished data). The initial trials were conducted using 10 fruit for firmness tests. Sample size was increased to 15 fruit, resulting in less variation among replicates and, thus, more cultivars exhibiting a significant difference between treated and nontreated fruit. It is possible that if 20 fruit had been used, there would have been a significant difference exhibited for all cultivars. Ptocharski (1982) noted that the berries' response to CO_2 was affected by stage of development. This could have been another factor having an influence on whether the CO_2 significantly increased the firmness of the various cultivars. In this investigation, fruit not fully colored or overripe was discarded, whereas in the initial trials, fruit representing a wider range of development was used.

On average, the treated fruit was 29.5% firmer than the initial and the nontreated control samples. The exposure interval required for maximum increase in firmness has changed among trials (Smith, 1992); thus, a longer exposure interval could have resulted in a greater response. The enhancement in firmness was attributed to a change in pectins by Ptocharski (1982), but this could not be verified by Smith (1992).

Firmness is not enhanced by CO_2 in all cultivars. In the initial trials, one cultivar (not available for this investigation) became slightly, but not significantly, softer when exposed to CO_2 (R.B.S., unpublished data).

The ANOVA conducted on the various Hunter color values, pH, and SSC for the various cultivars indicated that the CO_2 treatments had no significant effect on these variables. However, the ANOVA indicated that there were significant differences among cultivars for these variables (Table 2) and also for firmness (Table 1). Correlations between the various Hunter readings were all highly significant. As Hunter 'L' decreased, Hunter 'a' increased (r = 0.68) and Hunter 'b' decreased (r = 0.83). As Hunter 'a' increased, Hunter 'b' decreased (r = 0.93). Morris et al. (1985), using a Gardner Color Difference Meter (CDM), indicated that lower CDM 'L' values were accompanied by higher CDM 'a' values and higher anthocyanin content.

Enhancement in firmness of strawberries treated with CO_2 provides further justification for the practice of subjecting berries to high levels of CO_2 during marketing. If the sole purpose of applying CO_2 were for enhancing firmness, then the procedure could be done in a cold room designed for that purpose, rather than applying the CO_2 under a pallet wrap as is presently practiced in some production areas of the world. Before any strawberry cultivar is subjected to high levels of CO_2 for the sole purpose of enhancing firmness, its response to high levels of CO_2 should be evaluated to determine whether there is a benefit. When firmness is enhanced, in soft fruit in particular, the consumer would be the beneficiary of a superior-quality fresh-market berry.

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