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Optimum O_2 or CO_2 Atmosphere for Storing Broccoli Florets at Various Temperatures

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Abstract. **'Marathon' broccoli *(Brassica oleracea* L. var. italica) florets were stored in air, low O_2 (0.25%, 0.5%, and 1 %) or high CO_2 (3%,6%, and 10%) at 0, 5, and 10C. Oxygen consumption and CO_2 production were reduced under low O_2 or high CO_2 atmosphere, the reduction being greater at lower O_2 and higher CO_2 levels. No *differences were* found in ethylene production among the different atmospheres. Low O_2 and high CO_2 retained color of broccoli florets to about the same extent at 10C but had no effect at 0 and 5C. Development of soft rot and browning was suppressed by low O_2 or high CO_2, but offensive off-odor occurred in 0.25%02 at all temperatures and 0.5% O_2 at 10C. These results indicate that the best O_2 and CO2 levels seem to be 0.5% O_2 and 10% CO_2 at 0 and 5C, and 1% O_2 and 10% CO_2 at 10C.**

A controlled atmosphere with reduced O_2 and/or elevated CO_2 reduces respiration (Kasmire et al., 1974; Lebermann et al., 1968), ethylene production (Wang, 1979), weight loss (Anelli et al., 1984; Makhlouf et al., 1989a), and decay (Lipton and Harris, 1974; Makhlouf et al., 1989a) and retards yellowing (Kasmire et al., 1974; Lebermann et al., 1968; Lipton and Harris, 1974; Wang, 1979; Makblouf et al., 1989a) of broccoli heads. Based on these results, lowering O_2 to 1% to 2% and/or increasing CO_2 to 5% to 10% is recommended for storing broccoli heads to maintain quality at 0 to 5C (Saltveit, 1993). With the increasing demand for lightly processed vegetables, controlled or modified atmosphere for broccoli florets also has been researched over the past few years (Ballantine et al., 1988; Barth et al., 1993; Bastrash et al., 1993; Berrang et al., 1990). However, these studies were conducted only at a single temperature, which differed among the studies.

Since the optimum storage atmosphere can differ with storage organ–commodity and storage temperature, our objective was to determine the optimum treatment atmosphere for storage of broccoli florets at 0, 5, and 10C. The 10C was included because the temperature of a few commercial holding rooms approaches 10C. Optimum atmosphere was based on physiological activity and visual quality of the florets. Oxygen levels below 1% were examined in this study because the internal O_2 content in broccoli heads probably drops substantially below 1% when using 1% to 2% O_2 atmosphere. In broccoli heads, compared to the florets, the gas diffusion is more limited, which causes a larger gradient in gas concentration from the external to internal tissue (Brecht, 1980).

Materials and Methods

Heads of 'Marathon' broccoli were obtained from the Wholesale distribution center in Jessup, Md., and separated with a knife into florets of about 15 g each. A 150-g sample was placed on an elevated screen in a 2-liter glass jar with 100 ml of distilled water in the bottom to maintain high relative humidity. Three replicated samples were stored at O, 5, and 10C under a continuous stream of

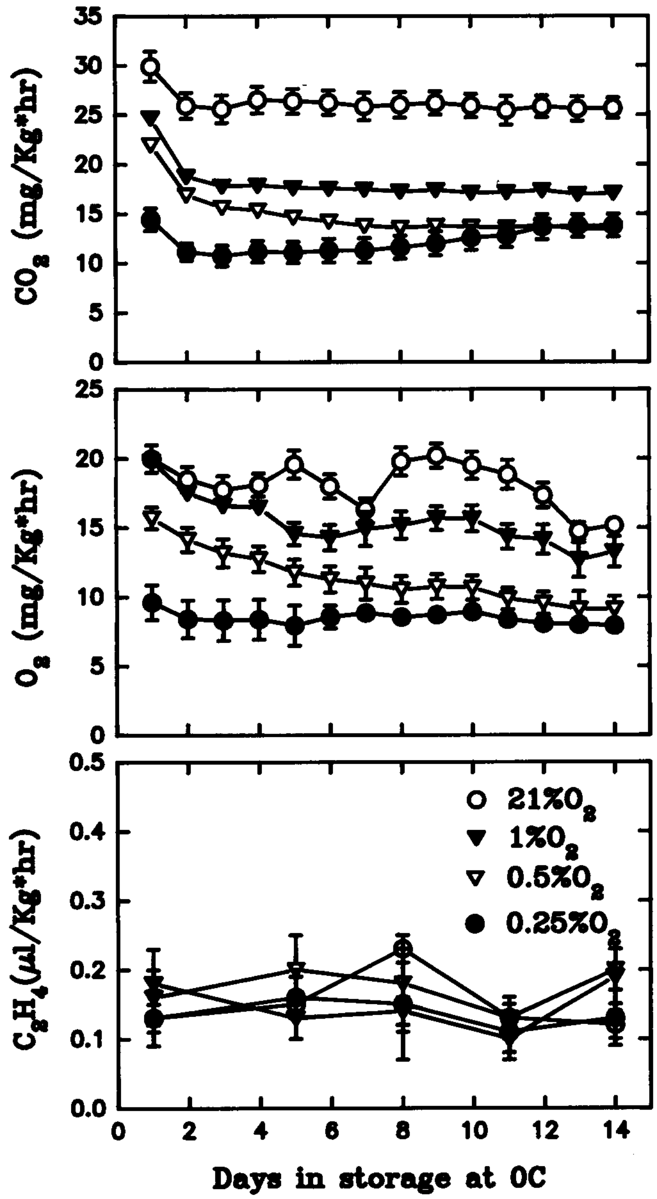

Fig. 1. Rates of CO_2 production, O_2 consumption, and ethylene production of broccoli florets during storage at 0C under air or low O_2 atmospheres. Vertical lines represent SE. SE bars not shown when within symbols.

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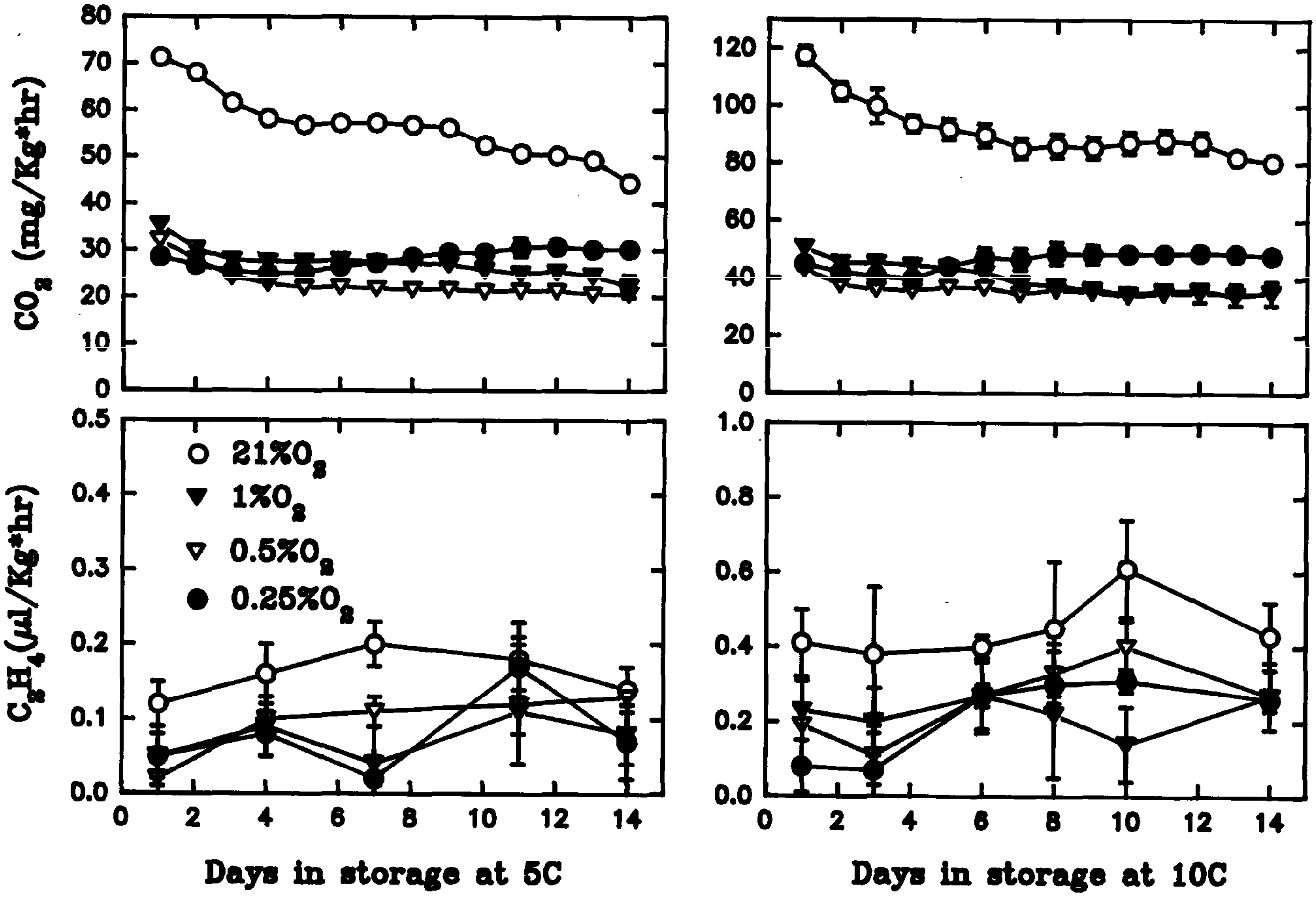

Fig. 2. Rates of CO_2 production and ethylene production of broccoli florets during storage at 5 and 10C under air or low O_2 atmospheres. Vertical lines represent SE. SE bars not shown when within symbols

air, low O_2 (0.25%, 0.5%, and 1%) or high CO_2 (3%, 6%, and 10%) atmosphere at 10, 20, and 40 ml·min^{-1}, respectively. The balance of the mixture was N_2 for the low O_2 atmosphere, and N_2 and air to give a minimum of 19% O_2 for the high CO_2 atmosphere. Different lots of broccoli were used for the low O_2 and the high CO_2 studies.

Oxygen and CO_2 contents of inlet and outlet streams of each jar were monitored with an oxygen analyzer and carbon dioxide analyzer (model S-3A/I and model CD-3A; Ametek, Pittsburgh). Ethylene levels in 5-ml gas samples taken from each jar were measured with an analytical gas chromatography (Model AGC-211; Carle, Tulsa, Okla.), equipped with a flame ionization detector. Color, decay, and odor were evaluated after storage. The color [hue angle, $\tan^{-1}(b^*/a^*)$] of the central part of the inflorescence was determined using a chroma meter (model CR-300; Minolta, Japan), with a 1-cm aperture. Incidence of soft rot and browning were expressed as a percentage of the total number of florets inspected. Raw and cooked odor of florets that had been placed in a microwave oven for 2 min were rated on a scale of 0 to 4, with 0 = normal and 4 = severely objectionable.

Results

Carbon dioxide production and O_2 consumption of florets held at 0C were lower with decreasing O_2 revels (Fig. 1). However, CO_2 production of florets at 0.25% O_2 decreased on day 2, and then increased gradually thereafter and approached the rate of those held at 0.5% O_2 by day 10, with samples held at 0C. In comparison, the CO_2 production rates of samples in 0.25% and 1% O_2 merged on day 7 at 5C and day 5 at 10C (Fig. 2). Carbon dioxide production of samples held in 0.25% O_2 was higher than those held in 0.5%, and 1% O_2 after day 11 at 5C, and day 8 at 10C (Fig. 2). No major differences were found in ethylene production between samples in air and low O_2 atmospheres at all temperatures (Figs. 1 and 2).

Green color, expressed as hue angle, was retained in florets stored in all atmospheres at 0 and 5C (127.1 ± 1.1), whereas it decreased by 80% from the initial value for florets in air at 10C (104.7 ± 1.6). Low O_2 levels suppressed the development of soft rot on flower buds and browning of cut surfaces at 0C (Table 1). Browning was only suppressed at 5 and 10C. Soft rot incidence was not affected at 5C, but increased when florets were held in 0.25% and 0.5% O_2 atmospheres at 10C. An offensive off-odor was produced by raw florets held in low O_2 at all temperatures except 1% O_2 at 0C. After cooking, however, the odor was not detected with samples held at 0 and 5C in 0.5% and 1% O_2 and was minimal with samples at 10C in 1% O_2.

High CO_2 atmosphere inhibited CO_2 production of florets held at 0C, with the inhibition being greater in 10% or 6% CO_2 (Fig. 3). This pattern of differences among treatments was also observed at 5 and 10C (Fig. 4). Oxygen consumption tended to be lower in high CO, atmosphere than in air at 0C, although the difference was not as defined as that in CO_2 production (Fig. 3). There were no significant differences in ethylene production between air and high CO, atmospheres at all temperatures, except for the initial day at 0C (Figs. 3 and 4).

High CO_2 had no effect on retention of green color at 0 and 5C, but did retard its loss at 10C, as noted with low O_2 atmosphere (data

Table 1. Incidence of soft rot and browning and development of objectionable odor during storage of broccoli florets at 0, 5, and 10C under air or low 0_2 atmospheres.

Storage (°C)	Treatment	Soft rot[z]	Browning[z]	Odor[y] Raw	Odor[y] Cooked
0	21% O_2	20 a[x]	15a	0 c	0b
	1 % O_2	4 b	0 b	0 c	0b
	0.5% O_2	0 b	0 b	1.5b	0b
	0.25% O_2	0 b	0 b	2.0 a	3.0 a
5	21% O_2	17a	44a	1.0d	0 b
	1% O_2	21 a	15b	1.7C	0.7 b
	0.5% O_2	21a	10b	2.0 b	0.7 b
	0.25% O_2	11a	0 b	3.0 a	3.0 a
10	21% O_2	37 b	33 a	1.0c	0d
	1% O_2	45 ab	19b	1.0c	1.0c
	0.5% O_2	59a	13b	2.3 b	2.0 b
	0.25% O_2	61 a	0 c	3.0 a	3.0 a

[z](Number of injured florets/ 100 number of observed florets) × 100.
[y]Rated on a scale of 0 to 4, with 0 = normal and 4 = severely objectionable.
[x]Mean separation within each temperature by Duncan's multiple range test, P = 0.05.

not shown). Soft rot, browning, and off-odor were minimal in high CO_2 atmosphere at all temperatures, while the incidence of soft rot in air at 10C was about five times greater than that in high CO_2 at 10C (Table 2). No off-odor occurred after cooking samples held in high CO_2 atmospheres at all temperatures.

Discussion

Respiration rate of broccoli florets was reduced by both low O_2 and elevated CO_2. The effect was greater at 5 and 10C when florets were held in O_2 levels of 1% or less compared to CO_2 levels of up to 10%. Lebermann (1968) reported that respiration of broccoli heads was reduced when held in 2% O_2 or 20% CO_2 at 7C, but the reduction was similar in both atmospheres. With florets in our study, the greater effect of O_2 relative to CO_2 may have been due to a change in the mechanism by which low O_2 reduced the respiration rate, because respiratory quotient (RQ) was higher in florets held in 0.25% O_2 than in air, but lower in those held in high CO_2 atmospheres (data not shown). As the O_2 level was reduced to 0.25%, respiration may have changed from the aerobic to anaerobic pathway, and this shift would occur more readily at 5 and 10C than at 0C. High CO_2 has been shown to reduce respiration rate, the mechanism of action is unknown, but may be associated with changes in the Krebs cycle (Kader, 1986).

Ethylene production was minimal and green color was retained with florets held in low O_2 at 10C. Others have reported that the rate of ethylene production is correlated positively with the rate of chlorophyll degradation (Aharoni et al., 1985; Makhlouf et al., 1989b; Wang, 1979). However, in our study with the high CO_2 atmosphere at 10C, ethylene production had increased but the green color was retained. High CO_2 probably caused a stress condition which induced ethylene production but did not have a deteriorative effect on color (Aharoni et al., 1985). However, with extended storage, ethylene can cause degradation of chlorophyll (Makhlouf et al., 1989b). We found that high CO_2 and low O_2 retained the green color of florets to about the same degree at 10C. However, others have indicated that elevated CO_2 was more effective than reduced O_2 in retarding the yellowing of broccoli (Kasmire et al., 1974; Lebermann et al., 1968; Makhlouf et al., 1989a). The differences in the results maybe due to the differences in the temperature and length of storage periods.

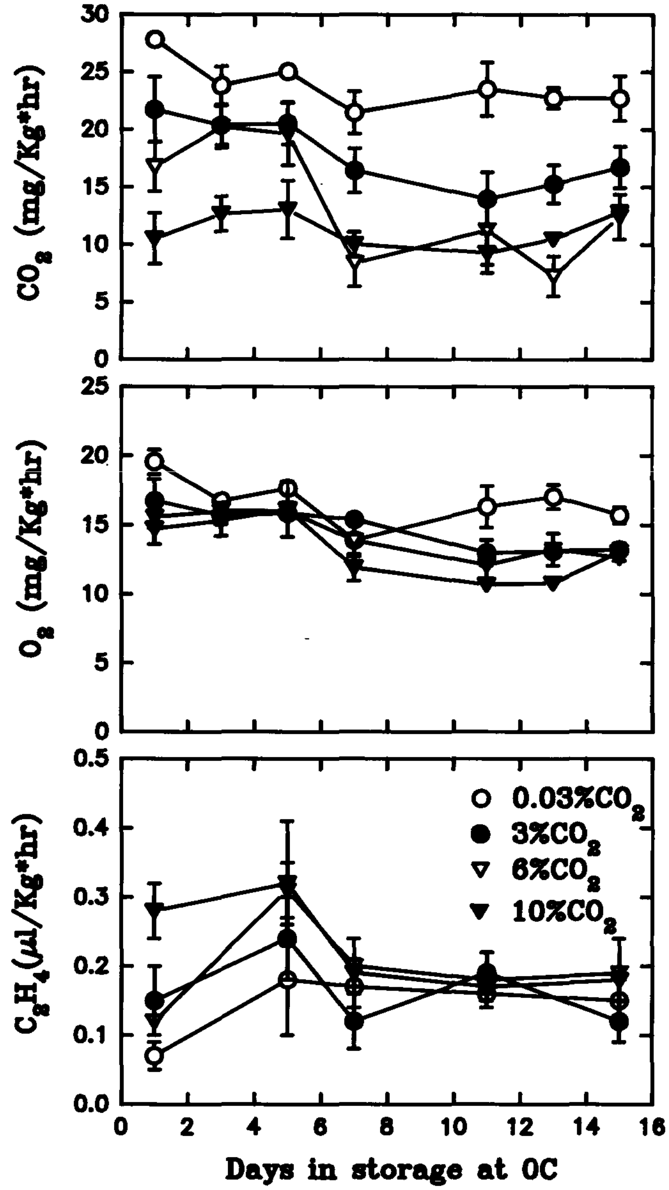

Fig. 3. Rates of CO_2 production, O_2 consumption, and ethylene production of broccoli florets during storage at 0C under air or high CO_2 atmospheres. Vertical lines represent SE. SE bars not shown when within symbols.

High CO, was more effective than low O_2 in reducing the incidence of soft rot at 10C, and of undesirable odor at all temperatures. However, this comparison may not be valid because the incidence of soft rot of samples held in air (control) was lower in the CO_2 experiment (Table 2) than in the O_2 experiment (Table 1), possibly due to the differences in maturity of broccoli and the degree of field and packing house contamination.

A 0.5% O_2 level at 0 and 5C and 1% O_2 level at 10C is recommended for broccoli florets to prevent the development of off-odor induced by low O_2. Others have reported that off-odor occurred with raw broccoli heads held in O_2 below 1% at 2.5C (Kasmire et al., 1974) and by cooked broccoli heads that were held in O_2 below 0.25% at 5 and 7.5C (Lipton and Hams, 1974).

Our results indicate that 0.5% O_2 and 10% CO_2 at 0 and 5C, and 1% O_2 and 10% CO_2 at 10C seemed to be the best atmosphere for preservation of broccoli florets without risking the development of undesirable odors and disorders. These O_2 levels were lower than

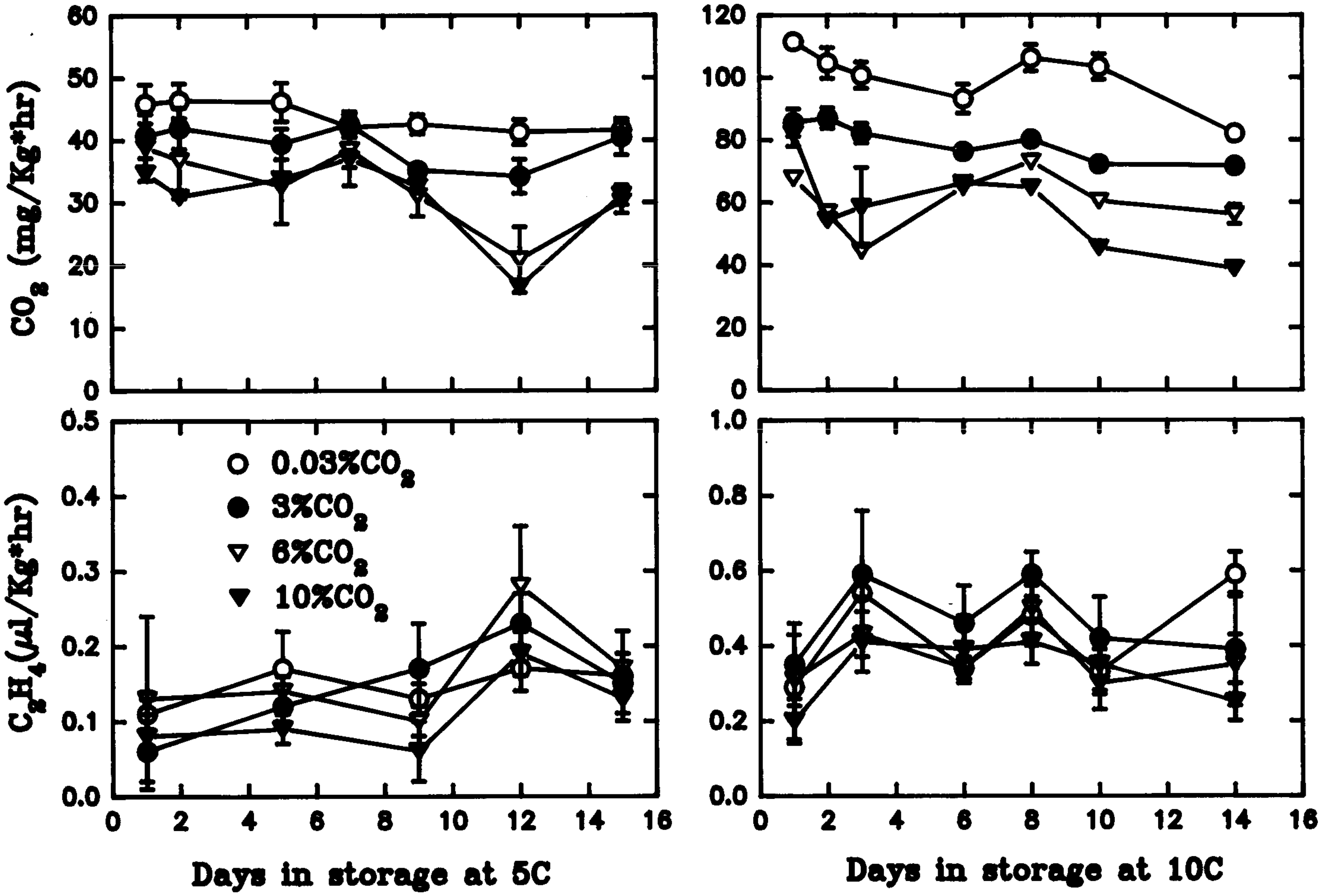

Fig. 4. Rates of CO, production and ethylene production of broccoli florets during storage at 5 and 10C under air or high CO, atmospheres. Vertical lines represent SE. SE bars not shown when within symbols.

Table 2. Incidence of soft rot and browning and development of objectionable odor during storage of broccoli florets at 0, 5, and 10C under air or high CO_2 atmospheres

Storage				Odor[y]	
(°C)	Treatment	Soft rot[z]	Browning	Raw	Cooked
0	0.03% CO_2	0 a	0 a	2.0 a	0.7 a
	3% CO_2	0 a	0 a	1.0b	0a
	6% CO_2	0 a	0 a	1.0b	0a
	10% CO_2	0 a	0 a	1.0b	0.7 a
5	0.03% CO_2	0 a	0 a	1.7a	0.3 a
	3% CO_2	0 a	0 a	1.0a	0.7 a
	6% CO_2	0 a	0 a	1.0a	0.7 a
	10% CO_2	2 a	2 a	1.0a	0.3 a
10	0.03% CO_2	17 a	6 a	1.0a	0a
	3% CO_2	4 b	0 a	1.3a	0a
	6% CO_2	2 b	0 a	1.3a	0a
	10% CO_2	2 b	0 a	1.7a	0a

[z]Number of injured florets × 100 number of observed florets.
[y]Rated on a scale of 0 to 4, with 0 = normal and 4 = severely objectionable.
[x]Mean separation within each temperature by Duncan's multiple range test, $P = 0.05$.

those recommended for broccoli heads at 0 to 5C (Saltveit, 1993), suggesting that a smaller gradient of O_2 concentration from the external to internal tissue had occurred in florets than in heads due to the less distance of gas diffusion in florets. When florets were held at 10C, it is important to keep O_2 levels above 1 %. The results could be beneficial for storage of packaged broccoli florets, because ambient O_2 of packaged florets can become very low due to the high respiration rate of florets as compared with heads (Bastrash et al., 1993; Rushing, 1990).

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