EFFECT OF LOW O_2 ATMOSPHERES ON POSTHARVEST QUALITY OF CHINESE CABBAGE, CUCUMBERS, AND EGGPLANTS

Chien Yi Wang
Horticultural Crops Quality Laboratory, Agricultural Research Service, USDA, BARC-West, Beltsville, Maryland 20705

Low O_2 atmospheres have been shown to be beneficial to the keeping quality of some fruits and vegetables (6, 8, 9). However, the feasibility of using low O_2 storage for certain vegetables needs to be further evaluated. This study was initiated to determine the effect of 1% O_2 on the postharvest quality of Chinese cabbage (Brassica campestris L. Pekinensis group), cucumbers (Cucumis sativus L.), and eggplants (Solanum melongena L.).

Materials and Methods

Chinese cabbage, cucumbers, and eggplants were freshly harvested from farms near Beltsville, MD. Samples were selected for their uniformity of size and shape and for freedom from defects. They were placed in 1% O_2 and 0°C within 8 hours after harvest.

Samples were stored in 220-liter stainless steel chambers fitted with inlet and outlet ports and glass doors. The chambers were sealed and flushed initially with 600 liters of N_2 and then connected to gas cylinders containing 1% O_2 + 0% CO_2. A flow-through system was used and the flow rate was maintained at 100 ml/min. Control treatments were similarly established but were flushed with air from air cylinders. Each commodity was stored at the temperatures recommended in USDA Handbook 66 (4): Chinese cabbage, 0°C; cucumbers, 10°C; and eggplants, 10°C. At the end of the 1% O_2 storage period, samples were cooked in boiling water and tasted for detection of off-odor and off-flavor.

The effect of ethylene and low O_2 on leaf abscission of Chinese cabbage was evaluated. In this study, storage temperature was maintained at 10°C. Samples were kept in air with or without 100 ppm ethylene and in 1% O_2 with or without 100 ppm ethylene. The percent of leaf abscission by weight after 2 weeks at 10°C was recorded for each treatment.

The 1% O_2 atmosphere was calibrated and monitored with a Shimadzu gas chromatograph equipped with a molecular sieve and a Porapak Q columns and thermal conductivity detector. Ethylene was measured with a Carle gas chromatograph fitted with an alumina column and flame ionization detector.

Analysis was made of ascorbic acid content in Chinese cabbage after 3 months' storage, in cucumbers after 3 weeks' storage, and in eggplants after 2 weeks' storage. Carbohydrates were also determined in Chinese cabbage and eggplants. Pared mesocarp tissues without seeds were used in cucumbers and eggplants. In Chinese cabbage, separate samples were taken from outer leaves, outer midribs, inner leaves, and inner midribs. Ascorbic acid was extracted with metaphosphoric acid/acetic acid solution and titrated with 2,6-dichlorophenol-indophenol according to the AOAC method (2). Carbohydrates were extracted from tissues with 80% ethanol by vigorous mixing for 2 hours following disintegration by a Polytron homogenizer. The extracts were centrifuged and supernatants were dried in vacuo at 40°C in derivatizing vials. Derivatization of the carbohydrates was carried out according to the procedures described by Li and Schuhmann (7). One µl of the derivatized samples was injected for gas chromatographic separation and quantification. A known amount of ß-phenyl-D-glucopyranoside was included in all samples as an internal standard. The gas chromatographic conditions were the same as previously described (10). Changes of chlorophyll content were determined in the outer leaves of Chinese cabbage by using a spectrophotometric method (3).

Results and Discussion

Chinese cabbage stored in 1% O_2 retained a higher amount of ascorbic acid than those stored in air (Table 1). The difference was

Table 1. Ascorbic acid contents (mg/100 g fr. wt.) in outer leaves, outer midribs, inner leaves, and inner midribs of Chinese cabbage after 3 months of storage in air or in 1% O_2 at 0°C.[z]

Parts of Chinese cabbage	Air	1% O_2
Outer leaves	21.0 e	64.3 a
Outer midribs	20.6 e	28.7 c
Inner leaves	22.8 de	37.9 b
Inner midribs	19.3 e	25.8 cd

[z]Means followed by a common letter are not significantly different at 5% level.

especially profound in outer leaves. The ascorbic acid level in outer leaves from samples stored in 1% O_2 was 3 times as high as the level in leaves from samples stored in air after 3 months at 0°C. Besides slowing down the general metabolism, the 1% O_2 atmosphere may have also reduced the oxidation of the ascorbic acid and prevented its degradation.

Samples from air storage had comparable levels of ascorbic acid in outer leaves, outer midribs, inner leaves, and inner midribs. However, outer leaves of samples from 1% O_2 storage retained much higher levels of ascorbic acid than other parts of the Chinese cabbage.

The major carbohydrates found in Chinese cabbage were fructose, glucose, and sucrose (Table 2). Carbohydrates in the outer leaves were

Table 2. Carbohydrates (mg/g fr. wt.) in outer leaves, outer midribs, inner leaves, and inner midribs of Chinese cabbage after 3 months of storage in air or in 1% O_2 at 0°C.[z]

Parts of Chinese cabbage	Fructose	Glucose	Sucrose	Total
Outer leaves				
Air	0.8	0.5	0.3	1.6 f
1% O_2	3.1	2.4	0.7	6.2 e
Outer midribs				
Air	2.9	19.6	1.2	23.7 c
1% O_2	3.6	23.3	1.5	28.3 ab
Inner leaves				
Air	5.5	7.6	2.4	15.5 d
1% O_2	10.1	15.7	2.9	28.7 ab
Inner midribs				
Air	9.6	14.8	2.6	27.0 bc
1% O_2	11.3	17.5	3.1	31.9 a

[z]Means followed by a common letter are not significantly different at 5% level.

different from the other parts of the Chinese cabbage not only in quantity but also in the ratio of the individual sugars. The outer leaves had significantly less total carbohydrates than the rest of the Chinese cabbage. A higher fructose to glucose ratio existed in outer leaves, whereas the reverse was true in outer midribs, inner leaves, and inner midribs. The composition of carbohydrates was similar between inner leaves and inner midribs, but outer midribs had a much higher glucose content than outer leaves.

Higher total carbohydrates were found in the 1% O_2 stored samples than in the air stored samples, primarily because of the higher fructose and glucose contents. Leafy parts of the Chinese cabbage appeared to be affected more than midrib parts by the low O_2 atmosphere. The ratios of total carbohydates for "1% O_2 stored samples/air stored samples" were 3.9, 1.1, 1.9, and 1.1 in outer leaves, outer midribs, inner leaves,

and inner midribs, respectively. Low O_2 appeared to be more effective in retarding the losses of carbohydrates and ascorbic acid in the leafy parts than in the midrib parts of Chinese cabbage. This greater reduction of losses may be partially explained by the fact that the changes of constituents during storage were greater in the leafy parts than in the midrib parts. Therefore, the beneficial effect of low O_2 is likely more evident in the leaves than in the midribs.

A steady loss of chlorophyll occurred in the outer leaves of both air stored samples and 1% O_2 stored samples during storage at 0°C (Table 3). The rate of chlorophyll degradation was much faster in the air

Table 3. Chlorophyll contents (mg/100 g fr. wt.) in the outer leaves of Chinese cabbage during storage in air or in 1% O_2 at 0°C.[z]

Months at 0°C	Air	1% O_2
1	88.6 b	98.2 a
2	71.4 d	92.3 b
3	27.2 f	89.2 b
4	D[y]	79.6 c
5	D	61.5 e

[z]Means followed by a common letter are not significantly different at 5% level.

[y]D = Discarded.

control leaves, however, particularly after 2 months of storage. Samples in air storage were discarded after 3 months at 0°C because of severe yellowing, leaf abscission and decay. However, leaves of the 1% O_2 stored samples still remained mostly green with 61.5 mg/100 g fr. wt. of chlorophyll content after 5 months storage at 0°C in 1% O_2. These Chinese cabbages were still in salable condition after slight trimming. In a study on CA storage of Chinese cabbage, Weichmann (11) found that high CO_2 in storage atmospheres resulted in higher losses, whereas, low O_2 concentration (2%) in combination with low CO_2 concentration (2% or 5%) resulted in lower losses and good shelf-life. Our study further demonstrates that the life of Chinese cabbage can be extended from 3 months to 5 months by using 1% O_2 storage at 0°C.

Treatment of Chinese cabbage with 100 ppm ethylene induced substantial abscission of leaves in 2 weeks at 10°C (Table 4). However,

Table 4. Effect of ethylene and 1% O_2 on leaf abscission of Chinese cabbage at 10°C.[z]

Treatment	% Leaf abscission (fr. wt.) 1 wk	2 wk
Air	0 c	5.3 b
Air + C_2H_4 (100 ppm)	4.7 b	16.4 a
1% O_2	0 c	0 c
1% O_2 + C_2H_4 (100 ppm)	0 c	0 c

[z]Means followed by a common letter are not significantly different at 5% level.

no leaf abscission was observed in samples treated with either 1% O_2 or 1% O_2 + 100 ppm ethylene. These results indicate that low O_2 atmosphere reduces leaf abscission in Chinese cabbage and the effect of ethylene is diminished under low O_2 atmosphere. Reduction of ethylene-induced leaf abscission in cabbage by CA storage also has been observed by Isenberg (6). In addition, Hulme et al. (5) have reported that physiological effects of ethylene can be influenced by O_2 concentrations. Abscission of leaves is one of the serious problems in the bulk storage of Chinese cabbage in China, and is thought to be caused by a combination of high temperatures and ethylene exposure (Zong, R. J., personal communication). Storage of Chinese cabbage in low temperatures under low O_2 atmospheres may minimize this problem.

Cucumbers were evaluated for yellowing and ascorbic acid content after 3 weeks of storage in air or in 1% O_2 at 10°C. The ascorbic acid content was not significantly affected by 1% O_2 but cucumbers stored in 1% O_2 were less yellow than cucumbers stored in air (Table 5).

Table 5. Ascorbic acid contents and percent of fruit showing yellowing in cucumbers after 3 weeks of storage in air or in 1% O_2 at 10°C.[z]

Treatment	% Fruit yellowing	Ascorbic acid (mg/100 g fr. wt.)
Air	21.7 a	3.1 a
1% O_2	6.2 b	2.9 a

[z]Means followed by a common letter are not significantly different at 5% level.

Yellowing is a problem when cucumbers are stored at a nonchilling temperature of 10°C or above. Most of the yellowing occurs at the blossom end. The average number of fruit showing yellowing from the 3 replicates was approximately 3 times as great in air storage as it was in 1% O_2 storage. Apeland (1) studied the effect of 5 and 16% O_2 in combination with 0 and 5% CO_2 on storage quality of cucumbers and concluded that the low concentration of oxygen was likely to be the most important factor for maintaining the quality of cucumbers. Our results with 1% O_2 agree with Apeland's conclusion.

At the end of 2 weeks storage at 10°C, eggplants exposed to 1% O_2 retained higher amount of carbohydrates than those exposed to air (Table 6). The higher total carbohydrate level in the 1% O_2 stored

Table 6. Carbohydrates, ascorbic acid, and decay of eggplants after 2 weeks of storage in air or in 1% O_2 at 10°C.[z]

Treatment	Carbohydrates (mg/g fr.wt.)				Ascorbic acid (mg/100 g fr.wt.)	% Decay
	Fructose	Glucose	Sucrose	Total		
Air	4.7	6.8	2.6	14.1 b	0.9 a	33 a
1% O_2	7.2	11.6	2.9	21.7 a	1.2 a	6 b

[z]Means followed by a common letter are not significantly different at 5% level.

samples were primarily due to higher contents of fructose and glucose.

The levels of sucrose were relatively low in both air stored samples and 1% O_2 stored samples. The ascorbic acid content of eggplants was very low and no difference could be discerned between air control samples and 1% O_2 treated samples. However, the number of samples showing decay was lower in the 1% O_2 storage than in the air storage.

Conclusions

Low O_2 (1%) atmosphere during storage reduced the losses of ascorbic acid, carbohydrates, and chlorophyll of Chinese cabbage, retarded the yellowing of cucumbers, and reduced the carbohydrate losses and decay of eggplants. However, low O_2 had no effect on the ascorbic acid contents of cucumbers and eggplants. No off-odor or off-flavor was detected in Chinese cabbage, cucumbers, or eggplants after storage in 1% O_2. Keeping the Chinese cabbage at 0°C in 1% O_2 atmosphere extended the storage life from 3 months to 5 months. Low O_2 also suppressed the effect of applied ethylene and reduced the abscission of leaves of Chinese cabbage during storage.

Acknowledgement

The technical assistance of Noreen Krause is gratefully acknowledged.

Literature Cited

1. Apeland, J. 1961. Factors affecting the keeping quality of cucumbers. Intl. Inst. Refrig. Bull. Suppl. 1: 45-58.
2. Assoc. Official Anal. Chem. 1970. Official Methods of Analysis. Washington, D.C. p. 769.
3. Bruinsma, J. 1961. A comment on the spectrophotometric determination of chlorophyll. Biochem. Biophy. Acta 52: 576-578.
4. Hardenburg, R. E., A. E. Watada, and C. Y. Wang. 1985. The commercial storage of fruits, vegetables, and florist and nursery stocks. U.S. Dept. Agr., Agr. Handb. 66. (In press)
5. Hulme, A. C., M. J. C. Rhodes, and L. S. C. Wooltorton. 1971. The effect of ethylene on the respiration, ethylene production, RNA and protein synthesis of apples stored in low oxygen and in air. Phytochem. 10: 1315-1323.
6. Isenberg, F. M. R. 1979. Controlled atmosphere storage of vegetables. Hort. Rev. 1: 337-394.
7. Li, B. W. and P. J. Schuhmann. 1980. Gas-liquid chromatographic analysis of sugars in ready-to-eat breakfast cereals. J. Food Sci. 45: 138-141.
8. Richardson, D. G. and M. Meheriuk (ed.). 1982. Controlled atmospheres for storage and transport of perishable agricultural commodities. Ore. State Univ. Symp. Ser. No. 1, Timber Press, Beaverton, OR. pp. 390.
9. Smock, R. M. 1979. Controlled atmosphere storage of fruits. Hort. Rev. 1: 301-336.

10. Wang, C. Y. 1983. Postharvest responses of Chinese cabbage to high CO_2 treatment or low O_2 storage. J. Amer. Soc. Hort. Sci. 108: 125-129.
11. Weichmann, J. 1977. CA storage of Chinese cabbage. Acta Hort. 62: 119-129.