Low O_2 Atmospheres Affect Storage Quality of Zucchini Squash Slices Treated with Calcium

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ABSTRACT

Calcium chloride treated or nontreated zucchini squash slices were stored in air or low O_2 (0.25, 0.5 and 1%) at 10°C. Respiration rate, ethylene production, and development of browning/decay were reduced under low O_2. Slices stored under 0.25% O_2 had less weight loss and browning/decay, and greater shear force and L-ascorbic acid content than those stored in air. Microbial count, pH, and color at the end of storage were improved by low O_2. Calcium treatment had no additive effect on maintaining quality of zucchini squash slices stored in 0.25% O_2 atmosphere.

Key Words: zucchini-squash, fresh-cut, controlled atmosphere, respiration, storage quality

INTRODUCTION

STUDIES have shown that controlled atmosphere (CA) extends the shelf life of some fruits and vegetables (Kader, 1986). Similarly, CA or modified atmosphere (MA) has been beneficial for some fresh-cut products such as chopped lettuce (McDonald et al., 1990), shredded cabbage (Kaji et al., 1993), broccoli spears (Barth et al., 1993), and strawberries (Larsen et al., 1995). In film packaged fresh-cut products, atmosphere can become modified extensively, with O_2 depleted below the extinction point. This may occur when the holding temperature is too high and/or permeability of gases through the film is inadequate. Lack of O_2 would result in anaerobiosis followed by injury to tissue. Information is lacking on the minimum O_2 level that fresh-cut products tolerate without undesirable effects and the quality changes that occur in very low O_2 atmospheres.

With whole zucchini squash fruit, a 1% O_2 atmosphere at 2.5°C (Wang and Ji, 1989) or 5% CO_2 at 5°C (Mencarelli, 1987) reduced chilling injury and subsequent decay. A 2% O_2 at 10°C was reported to minimize development of off flavor, which was more pronounced in cooked than in raw fruit (Mencarelli et al., 1983). Slices of zucchini squash may tolerate O_2 atmosphere of 1% because they do not have a continuous barrier to gases. The distance of gas diffusion is less in slices than whole fruit, which would result in a smaller gradient of O_2 (Brecht, 1980; Weichmann, 1986). Equally important is the determination of the minimum O_2 level that zucchini squash slices could tolerate in MA of film wrapped packages held at 5° to 10°C.

We previously reported that calcium dip treatment of zucchini squash slices reduced chilling injury at 0°C and retained quality at 10°C, where deterioration may occur readily (Izumi and Watada, 1995). Our objective was to determine the response of zucchini squash slices to O_2 levels $<1\%$ at 10°C and the effect of low O_2 on quality of calcium treated slices.

MATERIALS & METHODS

ZUCCHINI SQUASH (*Cucurbita pepo* L. cv. Elite) were obtained from a farm in Clinton, MD, washed with water and trimmed at the stem and blossom ends. Trimmed fruit were sliced (5 mm thick, ca 5g each) transversely with a food processor (Model DLC-10, Cuisinarts, East Windsor, NJ).

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Response to low O_2 atmosphere storage

Samples (100g) of slices (3–4 cm diam, 5 mm thick) were placed in a 2L glass jar containing 100 mL distilled water in the bottom to maintain relative humidity >90%. Three replicated samples were stored at 10°C under a continuous humidified stream (15 mL/min) of air or low O_2 (0.25, 0.5 and 1%), with the balance being N_2. Oxygen and CO_2 contents of inlet and outlet streams of each jar were monitored every 8 hrs with an O_2 and CO_2 analyzer (Model S-3A/I and Model CD-3A; Ametek, Pittsburgh, PA) and the average of 3 measurements/day was used for data analysis. A 5 mL aliquot of gas was taken daily and ethylene content was measured with a gas chromatograph (model AGC-211; Carle, Tulsa, OK) equipped with a flame ionization detector.

After 8 days storage, evaluations of browning/decay and off-odor were made for each sample. Data on brown discoloration and subsequent decay were combined in determining percentage of deteriorated slices. The severity of undesirable condition was reported as severity index, because tissues began to decay shortly after development of brown discoloration. Percentage of browning/decay was evaluated on a rating scale (R) of 0 = none, 1 = slight, 2 = moderate, 3 = severe, and 4 = extreme. The severity index (SI) is the weighted average:

$$\mathrm{SI} = \frac{\sum N_i R_i \times 100}{N_T 4}$$

where N_i is the number of slices with ranking R_i, and N_T is the total number of slices × the four scale ratings. This gives a score of severity on a scale ranging from 0 to 100 (Makita, 1985). Odor of slices was rated on a scale of 0 = normal to 4 = severely objectionable.

Calcium treatment and low O_2 storage

A 500g sample of slices (3–4 cm diam and 5 mm thick) was dipped in 2L 0.5% $CaCl_2$ solution or distilled water for 2 min at room temperature (≈23°C) and centrifuged for 10 sec at 590 rpm to remove surface solution, as described earlier (Izumi and Watada, 1995). A 100g sample of slices was placed in a 2L glass jar containing 100 mL distilled water in the bottom. Three replicated samples were stored at 10°C under a continuous humidified stream (15 mL/min) of air or 0.25% O_2. Oxygen, CO_2, and ethylene levels of each sample were monitored as described.

An aliquot from each lot was removed periodically for determination of percentage and SI of browning/decay, score of off-odor, weight, L-ascorbic acid content, texture, total microbial count, pH, and color.

L-ascorbic acid content was determined using HPLC equipped with a PLRP-S 100A column (25 cm × 4.66 mm, 5 μm) (Polymer Laboratories, Co.) and electrochemical detector (Model 400; EG&G, Princeton, NJ) as described (Izumi and Watada, 1995). Texture, based on the force required to shear a 40g sample, and total microbial count on the surface of 10g tissues were determined as described (Izumi and Watada, 1994). The surface pH on both sides of a slice was measured with a pH meter (Model B-113; Horiba, Japan). The surface color of five slices for each sample was measured with a chroma meter (Model CR-300; Minolta, Japan) and results were expressed as L* and hue angle ($\tan^{-1}$b*/a*) values (Izumi and Watada, 1995).

Statistical analysis

Data were subjected to analysis of variance and Duncan's multiple range test for tabulated data, and the standard error of individual means was presented.

RESULTS & DISCUSSION

CARBON DIOXIDE production and O_2 consumption were lower with zucchini slices held in low O_2 than in air, and the rates of slices under different low O_2 atmospheres were similar (Fig. 1). With whole zucchini squash fruit, CO_2 production was reduced as O_2 level was reduced from that in air to 1% at 5° or 10°C (Mencarelli et al., 1983). The rates were lower as O_2 was reduced from 6 to 1%. The respiratory quotient (RQ) of slices held in 0.25% O_2 was similar to those at 0.5 or 1% O_2, and at times was slightly higher than those held in air (data not shown). This indicated that sufficient O_2 was available in the low O_2 atmosphere for aerobic respiration to continue without initiating the anaerobic pathway.

Ethylene production was not detectable from slices in 0.25 and 0.5% O_2 and was minimal in 1.0% O_2, thus its production was suspected to be inhibited by low O_2. A similar type inhibition has been reported for whole fruit (Mencarelli et al., 1983). Apparently low O_2 reduces ethylene production by inhibiting the conversion of ACC to ethylene (Kader, 1986).

The zucchini squash slices developed brown discoloration and subsequently decayed during storage. This was probably due to natural deterioration. Percentage and severity of browning/decay were less under low O_2 than in air, and no differences were observed among various low O_2 atmospheres (Table 1). Low O_2 or high CO_2 atmospheres have been shown to reduce browning via inhibition of phenolics production and polyphenol oxidase activity with lettuce (Siriphanich and Kader, 1985) and shiitake mushroom (Minamide et al., 1980). Thus with zucchini slices, low O_2 may have inhibited some steps in the pathway of phenolic metabolism responsible for browning. CA conditions have been shown to suppress postharvest decay of fruits and vegetables by suppression of pathogenic growth of bacteria and fungi (El Goorani and Sommer, 1981). Low O_2 may have suppressed pathogen growth on the zucchini slices, which resulted in less decay. Off-odor was not induced by either low O_2 or air storage.

As noted with water treated slices, CO_2 production and O_2 consumption of calcium treated zucchini slices were lower when held in 0.25% O_2 than in air atmosphere, but no differences occurred between calcium and water treated slices (Fig. 2). The sharp increase in CO_2 production and O_2 consumption noted on day 7 by slices held in air coincided with the sharp increase in deterioration and decay (Table 2). Thus the increase in metabolic activity probably was due to deterioration and decay of tissue. By day 8, the respiration rate was about threefold greater than controls, which had minimal decay, suggesting decay had a notable effect on elevated metabolic rates. Increased metabolic rate or decay was not noted with calcium or water treated slices held in 0.25% O_2. The RQ was higher in slices held in 0.25% O_2 than in air (Fig. 2) which may have resulted from increased glycolysis (Kader, 1986).

A 0.25% O_2 atmosphere seemed to inhibit the rate of ethylene production (Fig. 2). Treatment with calcium had no additive effect on the rates of respiration and ethylene production of slices held in 0.25% O_2.

The percentage and severity of browning/decay in slices were suppressed by 0.25% O_2 regardless of calcium treatment (Table 2). Suppression by the 0.25% O_2 atmosphere may have been at the maximum, since the beneficial effect of calcium noted in a previous study (Izumi and Watada, 1995) was not noted when combined with the low O_2 treatment. Browning/decay in air samples differed widely between the two experiments (Table 1 and 2), which may have related to the difference in maturity of fruit (Mencarelli et al., 1983). Nevertheless, the low O_2 atmosphere was helpful in reducing the amount of browning/decay. Thus in commercial film-packed fresh-cut zucchinis, the reduced O_2 level caused by MA would be desirable in retarding development of browning/decay. Slices held in air developed off-odor on day 10 due to decay, while those slices held in 0.25% O_2 produced only a slight off-odor.

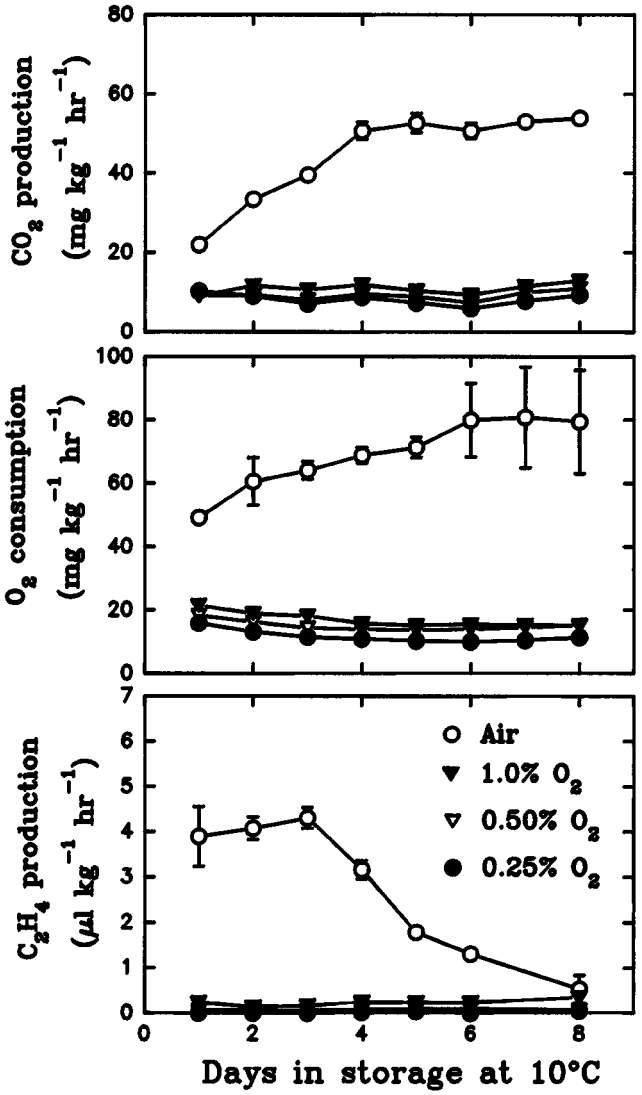

Fig. 1—Rates of gas changes in zucchini squash slices during storage at 10°C under air or low O_2 atmospheres. Vertical lines represent SE. SE bars were not shown when masked by the graph symbol.

Table 1—Some changes in zucchini squash slices after 8 days storage under air or low O_2 atmospheres at 10°C

Treatment	% of slices with browning/decay[c]	Severity index of browning/decay[d]	Odor[e]
Air	21.3[a]	5.4[a]	0[a]
1%O_2	3.6[b]	0.9[b]	0[a]
0.5%O_2	1.7[b]	0.4[b]	0.3[a]
0.25%O_2	1.8[b]	0.4[b]	0[a]

[ab] Means with different superscripts in the same column are significantly different ($p<0.01$).

[c] $\frac{\text{Number of browned and decayed slices}}{\text{Number of observed slices}} \times 100.$

[d] $\frac{(\text{Number of slight slices}\times 1)+(\text{Moderate slices}\times 2)+(\text{Severe slices}\times 3)+(\text{Extreme slices}\times 4)}{\text{Number of observed slices} \times 4} \times 100.$

[e] Rated on a scale of 0 to 4, with 0 = normal and 4 = severely objectionable.

Total weight loss of both calcium treated and nontreated slices in 0.25% O_2 was reduced by 40% when compared to those in air (data not shown). Large differences in weight loss between samples in air and 0.25% O_2 atmospheres probably were due to differences in carbon loss in respiration (Fig. 2) and moisture loss. Slices held in air probably lost more water than those in low O_2 because of a difference in histology of tissues. Those in air were in a more advanced stage of senescence as noted by the deteriorated condition, which probably made them more susceptible to water loss.

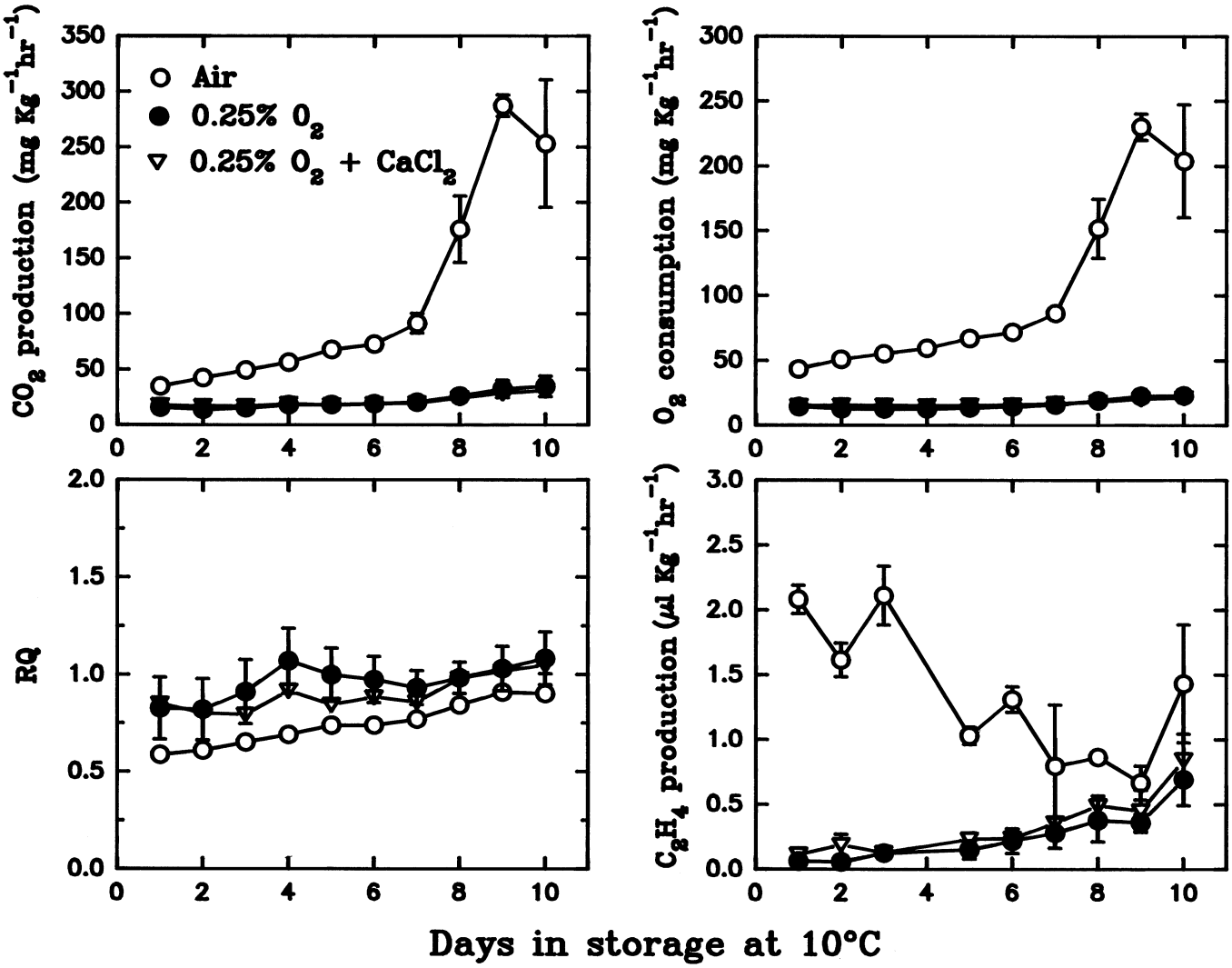

Fig. 2—Rates of gas changes and respiratory quotients (RQ) of zucchini squash slices treated with $CaCl_2$ or water and stored in air or 0.25% O_2 at 10°C. Vertical lines represent SE. SE bars were not shown when masked by the graph symbol.

Table 2—Some changes in zucchini squash slices treated with $CaCl_2$ or water and stored in air or 0.25% O_2 at 10°C

	% of slices with browning/decay[c]			Severity index of browning/decay[d]			Odor[e]		
Treatment	3[f]	7	10	3	7	10	3	7	10
Air	0[a]	89.0[a]	100.0[a]	0[a]	29.9[a]	100.0[a]	0[a]	0[a]	4[a]
0.25%O_2	0[a]	10.7[b]	55.6[b]	0[a]	2.7[b]	23.7[b]	0[a]	0.3[a]	1.3[b]
0.25%O_2+$CaCl_2$	0[a]	4.2[b]	53.2[b]	0[a]	1.1[b]	21.7[b]	0[a]	0.3[a]	1.3[b]

[ab] Means with different superscripts in the same column are significantly different ($p<0.01$).

[c] $\frac{\text{Number of browned and decayed slices}}{\text{Number of observed slices}} \times 100$.

[d] $\frac{(\text{Number of slight slices}\times 1)+(\text{Moderate slices}\times 2)+(\text{Severe slices}\times 3)+(\text{Extreme slices}\times 4)}{\text{Number of observed slices}\times 4} \times 100$.

[e] Rated on a scale of 0 to 4, with 0 = normal and 4 = severely objectionable.

[f] Days in storage.

Shear force of slices in 0.25% O_2 remained unchanged during storage, whereas those in air decreased after day 3 with development of browning/decay (data not shown). The calcium effect of maintaining the shear force index (Izumi and Watada, 1995) seemed to be masked by the beneficial effect of low O_2. The influence of CA storage on texture of vegetables varies with the commodity (Weichmann, 1986) and the mechanism of CA effects is not fully understood (Kader, 1986). In our study, low O_2 atmosphere may have maintained the textural quality of zucchini slices by suppressing browning/decay and weight loss that would occur with senescence.

L-ascorbic acid content of slices in air decreased to about 15% of the initial value by day 10, while those in 0.25% O_2 changed minimally (Fig. 3A). Low O_2 atmosphere has been shown to result in L-ascorbic acid retention in other vegetables (Weichmann, 1986; Klein, 1987) and a decrease in oxidation of L-ascorbic acid to dehydroascorbic acid (Weichmann, 1986). In our zucchini slices, better retention of L-ascorbic acid in 0.25% O_2 samples may have had an effect on reduction of browning (Table 2), because of the antioxidant property of L-ascorbic acid (Liao and Seib, 1987).

The total microbial count increased during storage and the count was higher for samples in air than in 0.25% O_2 on the last day (Fig. 3B). The lower count in the 0.25% O_2 samples may be a direct effect of O_2 below 1% having an inhibitory effect on growth and activities of pathogens and/or an indirect

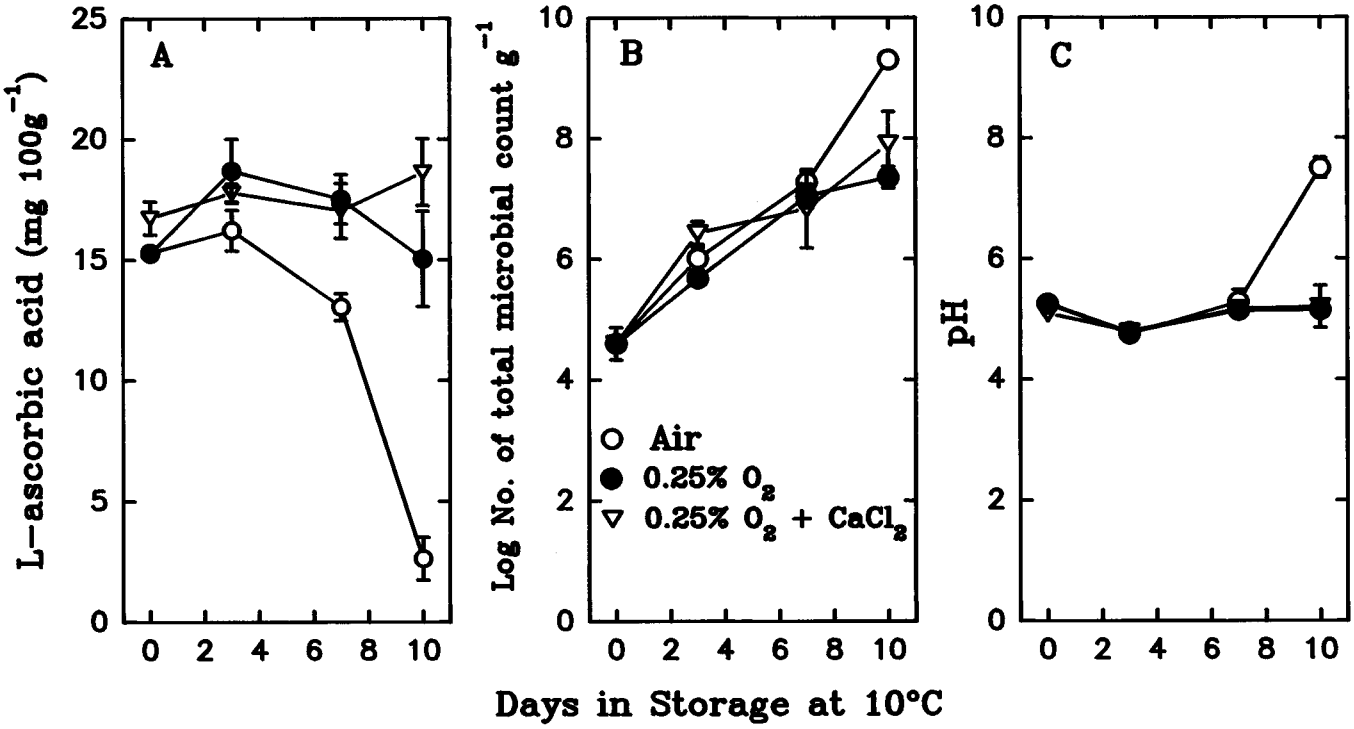

Fig. 3—Changes in L-ascorbic acid, microbial counts, and surface pH of zucchini squash slices treated with $CaCl_2$ or water and stored in air or 0.25% O_2 at 10°C. Vertical lines represent SE. SE bars were not shown when masked by the graph symbol.

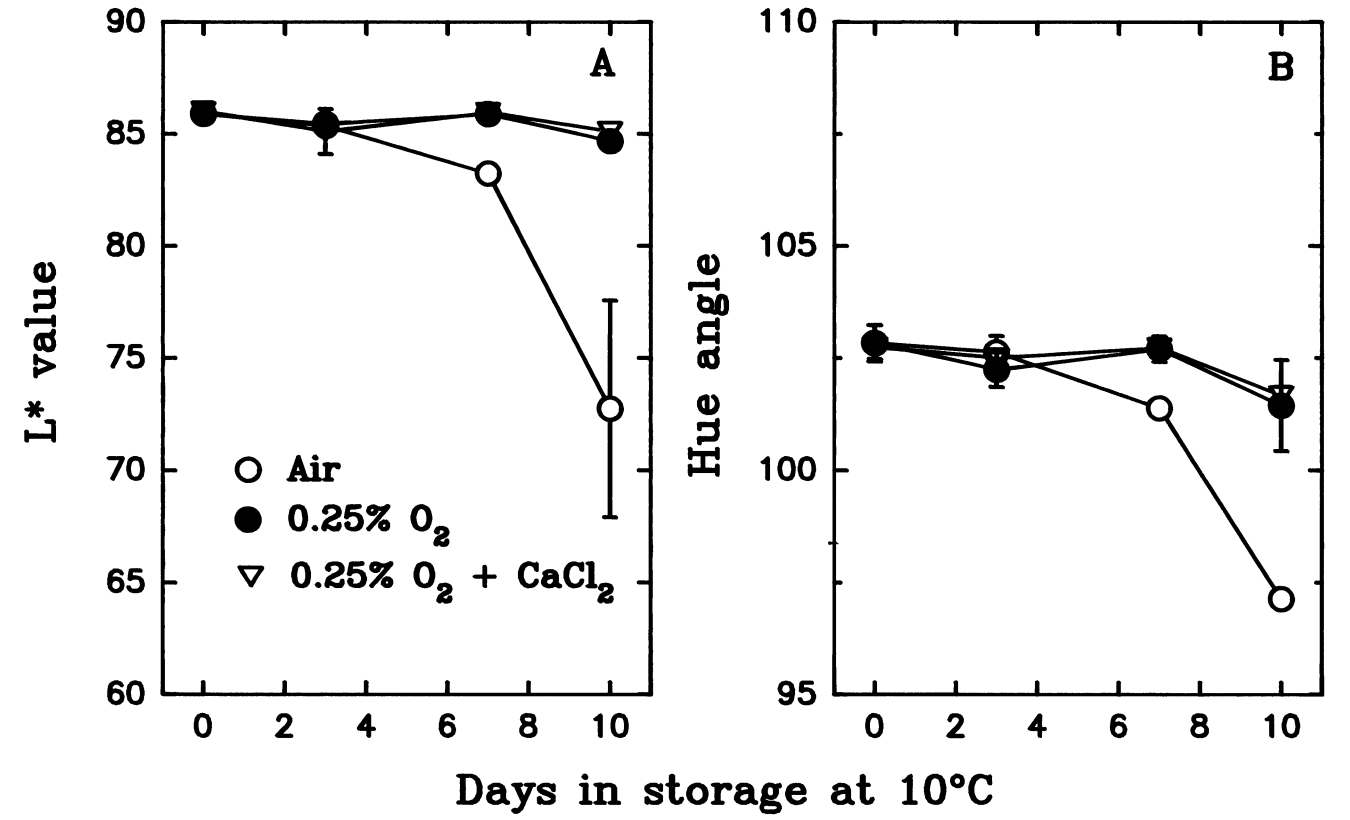

Fig. 4—Some color values of zucchini squash slices treated with $CaCl_2$ or water and stored in air or 0.25% O_2 at 10°C. Vertical lines represent SE. SE bars were not shown when masked by the graph symbol.

effect with the host commodity being less susceptible to pathogen growth. Ripening and senescence of fruit in low O_2 atmosphere are delayed relative to those in air, thus samples in low O_2 would not be as susceptible to infection as those in air (El-Goorani and Sommer, 1981).

The pH of slices held in air increased sharply on the last day which may have been associated with microbial growth (Fig. 3C). Microbial spoilage of CA packaged foods may be caused by several factors, which include pH, atmosphere, temperature, and water activity (Labuza et al., 1992).

Surface lightness, expressed as L* values, was retained by the 0.25% O_2 sample, whereas it decreased in the air sample after day 3 (Fig. 4A). Hue angle values of air samples also decreased due to the decrease in L* values (Fig. 4B), which indicated that the green color was lost and yellow and shades of red were embodied in the mixture (McGuire, 1992). These brightness and color differences indicated that brownish discoloration was minimized by low O_2 (Table 2). Treatment with calcium did not affect the quality attributes of zucchini squash slices held in low O_2 atmosphere.

CONCLUSIONS

Low O_2 of 0.25 to 1% reduced respiration and ethylene production rates and retained visual quality of zucchini squash slices held at 10°C. A 0.25% O_2 atmosphere had a beneficial effect on attributes including weight loss, development of browning/decay, shear force, L-ascorbic acid content, microbial count, pH, and color, and probably masked beneficial effects of calcium dip. Zucchini squash slices were not deleteriously affected by 0.25% O_2 atmosphere, so O_2 levels in the film packaged slices could be allowed to reach this level.

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