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Controlled atmosphere storage of carrot slices, sticks and shreds

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Abstract

The physiology and quality of carrot (*Daucus carota* L.) slices, sticks, and shreds stored in air or controlled atmosphere (CA) of 0.5% O₂ and 10% CO₂ at 0, 5, and 10°C were monitored. The respiration of all 3 types of cut tissue was reduced when stored in CA and the reduction was greater with slices or sticks than with shreds. The RQ of sticks and shreds was higher in CA than in air at all temperatures. Ethylene production was less than 0.1 μl kg⁻¹ h⁻¹ and off-odor was not detected with any of the samples. CA was beneficial in reducing decay, weight loss, pH of sticks and shreds, white discoloration on shreds, and microbial growth on sticks. The latter two occurred only at 0 and 5°C.

Keywords: Fresh-cut; Respiration; Quality; Carrot; Controlled-atmosphere storage

1. Introduction

Controlled atmosphere (CA) or modified atmosphere (MA) has been shown to be beneficial in maintaining quality of several intact horticultural crops, as reviewed by Saltveit (1993) and Kader (1993), and a few fresh-cut products. The latter includes spinach (Ko et al., 1996), shredded cabbage (Kaji et al., 1993), broccoli (Barth et al., 1993) and cauliflower florets (Voisine et al., 1993), and carrot sticks (Izumi et al., 1996) and shreds (Carlin et al., 1990a,b).

Atmospheres of 2–10% O₂ and 10–40% CO₂ retained sugar content in carrot shreds (Carlin et al., 1990a) and intact roots (Hansen and Rumpf, 1974), but 25–40% CO₂ favored growth of lactic acid bacteria (Carlin et al., 1990a). A 5% O₂ and 20% CO₂ atmosphere in high permeability film packs retained quality of carrot shreds stored at

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10°C, but films with low permeability increased anaerobic respiration (Carlin et al., 1990b). In 0.5% O₂ atmosphere, respiratory quotient (RQ) was about 1.7 due to less O₂ uptake than CO₂ production (Kato-Noguchi and Watada, 1996b). This slight increase in RQ indicated increased glycolysis, which probably was not sufficient to be injurious to the tissue. In film packs, O₂ can be depleted down to 0.5%, particularly when held above 0°C. Therefore quality changes of fresh-cut carrots under these atmospheres need to be better understood to ensure a consistent quality product.

We report here the physiology and quality changes of carrot slices, sticks, and shreds held in CA consisting of 0.5% O₂ and 10% CO₂ at 0, 5, and 10°C.

2. Materials and methods

2.1. Processing and storage conditions

Carrots (*Daucus carota* L.) were obtained from the Wholesale Distribution Center in Jessup, MD. Roots were washed thoroughly with water, peeled, and the upper and lower ends of the root sliced and discarded. Carrot slices (20–40 mm diameter and 5 mm thick) were cut crosswise and sticks (ca. 5 mm wide, 50 mm long and 4 mm thick) and shreds (ca 4 mm wide, 50 mm long and 2 mm thick) cut lengthwise with a food processor (Model DLC-10, Cuisinarts, East Windsor, NJ). The 'cuts' (i.e. slices, sticks and shreds) were rinsed with distilled water at room temperature (≈23°C) and then centrifuged at 580 rpm for 30 s.

A 100-g sample of each type of cut was placed on a screen that was elevated above 100 ml of distilled water in a 2-l glass jar. The jars were placed at 0, 5, or 10°C with air or gas mixture metered through the jars at a rate of 7, 9, and 15 ml/min, respectively. Three storage temperatures were used because fresh-cut carrots are commonly held at 5°C or higher even though 0°C is recommended for intact roots (Hardenburg et al., 1986). The CA condition used was 0.5% O₂ and 10% CO₂, with the balance being N₂. This gas mixture reduced respiration, but did not cause undesirable odors or physiological disorders in preliminary study.

2.2. Gas measurement for respiratory and ethylene studies

Oxygen and CO₂ contents of inlet and outlet streams of each jar of 3 replicated samples were monitored every 8 h with an O₂ and CO₂ analyzer (Model S-3A/I and Model CD-3A, Ametek, Pittsburgh, PA, respectively) and the average of 3 measurements/day was used for data analysis. A 5-ml aliquot of gas was taken daily for measurement of ethylene content using a gas chromatograph (Model AGC-211, Carle, Tulsa, OK) equipped with a flame ionization detector.

2.3. Quality attributes

Three replicated samples of each type of cut were taken periodically to measure decay, odor, weight, color, total microbial count, and pH.

The incidence of decay, observed as black root rot, was expressed as the percentage of the total number of pieces in each jar. The odor of fresh and cooked samples

(microwaved for 1.5 min) were rated on a scale of 0 = normal to 4 = severely objectionable.

Surface color of cut carrots become white due to dehydration of damaged surface cells (Tatsumi et al., 1991). The white tissue was quantified by measuring the surface color of 10 carrot samples, in which each sample consisted of a slice, 4 sticks, or 5-g shreds, with a chromameter (Model CR-300, Minolta, Japan). The L^* , a^* , and b^* readings were converted to a whitish index (Wi) using the equation, $100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{1/2}$ (Bolin and Huxsoll, 1991).

Total microbial count on the surface of 10-g tissues was determined and was expressed as \log_{10} CFU/g sample as previously described (Izumi and Watada, 1994). The surface pH on the same samples as color measurements was measured with a compact pH meter (Model B-113, Horiba, Japan).

Data were subjected to analysis of variance and means separated by least significant difference (LSD) and standard error.

3. Results

CA reduced CO_2 production and O_2 consumption of all fresh-cut carrots with the average reduction being about 55% at 0°C, about 65% at 5°C and about 75% at 10°C (Table 1). Exception to this was with shreds, where CO_2 production was reduced by 38% at 0 and 10°C and 22% at 5°C. Respiration rates of all cuts increased with temperature with the Q_{10} ranging from 1.6 to 4.0 between 0 and 10°C, except for slices in air which had Q_{10} of 5.2 for CO_2 production and 7.9 for O_2 consumption. The Q_{10} of slices and sticks was less when held in CA than in air. The average respiratory quotient (RQ) ranged from 0.5 to 1.3 among the samples. The quotients were larger with shreds held in CA than in air at 0, 5, and 10°C and with sticks at 0 and 5°C.

Respiration patterns differed among carrot cuts (Fig. 1). The respiration rates of slices decreased with time to a steady state at about the 8th day. Respiration of sticks had a slight increase initially and then decreased after 6 and 8 days in CA and in air, respectively. Respiration of shreds increased sharply and then decreased to a steady state on about the 12th day. The shreds and sticks had similar respiration patterns at 0°C, but not at 10°C, where the rates decreased with time (data not shown).

Ethylene production of all samples was less than $0.1 \mu\text{l kg}^{-1} \text{h}^{-1}$ during storage and was not affected by CA (data not shown).

No decay was found on any of the carrots held in CA, but spoilage was found on air-stored slices at 5 and 10°C, sticks in air at all temperatures, and shreds in air at 10°C (Table 2). Fresh or cooked sticks and shreds produced no off-odor after storage in air or CA at all temperatures. Fresh slices held in air for 28 days 0°C emitted a slight off-odor, which dissipated after cooking (data not shown).

Weight loss occurred continually during storage with all samples (data not shown) and CA reduced the weight loss by about 10–50% among the samples (Table 2). Slices lost the least weight and shreds lost the most among the 3 cuts and weight loss was greater at 5 and 10°C compared to 0°C. White tissue developed on all carrot cuts and increased during storage (data not shown). CA had a slight inhibitory effect on development of white tissue, as indicated by the whitish index, of shreds held at 0 and 5°C (Table 2).

Table 1

Average rates of CO₂ production, O₂ consumption, and respiratory quotient (RQ) of carrot slices, sticks, and shreds during storage in air or CA for 27, 20, and 11 days at 0, 5, and 10°C, respectively

Type of cut	Treatment	CO ₂ production (ml kg ⁻¹ h ⁻¹)	O ₂ consumption (ml kg ⁻¹ h ⁻¹)	RQ
0°C storage				
Slices	Air	2.5	3.9	0.6
	CA ^a	1.1 ^c	1.7 ^c	0.7
Sticks	Air	7.6	8.0	1.0
	CA	3.8 ^c	3.4 ^c	1.1 ^b
Shreds	Air	5.7	10.0	0.6
	CA	3.5 ^c	3.6 ^c	1.0 ^c
5°C storage				
Slices	Air	6.5	8.5	0.8
	CA	2.4 ^c	3.3 ^c	0.7
Sticks	Air	9.7	9.9	1.0
	CA	3.3 ^c	2.5 ^c	1.3 ^c
Shreds	Air	12.1	15.2	0.8
	CA	9.4 ^c	7.4 ^c	1.3 ^c
10°C storage				
Slices	Air	13.0	31.0	0.4
	CA	3.3 ^c	6.0 ^c	0.6
Sticks	Air	24.3	24.5	1.0
	CA	6.2 ^c	6.5 ^c	1.0
Shreds	Air	22.1	41.0	0.5
	CA	13.8 ^c	12.7 ^c	1.1 ^b

^a 0.5% O₂ + 10% CO₂.

^{b,c} Significant at $P < 0.05$ or 0.01, respectively, between paired air and CA treatments.

Microbial growth increased sharply during storage until a plateau was attained on about the 5th day (data not shown). CA had an inhibitory effect on the growth only with sticks at 0 and 5°C and the final microbial count (log₁₀ CFU/g) was lower on slices compared to sticks or shreds (Table 2). The pH of cut surface changed minimally during storage. CA lowered the pH of sticks held at 0 and 5°C and shreds held at all temperatures (Table 2).

4. Discussion

Controlled atmosphere had a significant inhibitory effect on respiration rates of carrots processed as slices, sticks or shreds. The effect was greater at 5 and 10°C for slices and sticks, but not for shreds. With a 50% or greater reduction in the respiration rate, the shelf life of a CA sample theoretically should increase by a comparable amount. Although the shelf life of cut carrots was not determined in this study, samples in CA did not have any decay as compared to those in air after 28, 21, and 11 days at 0, 5, and 10°C, respectively. The lack of decay may have been due to reduced metabolism.

The increase in respiration rate of fresh-cut carrots with increasing temperature is typical to that of intact commodities, as the average Q_{10} of all samples, excluding slices

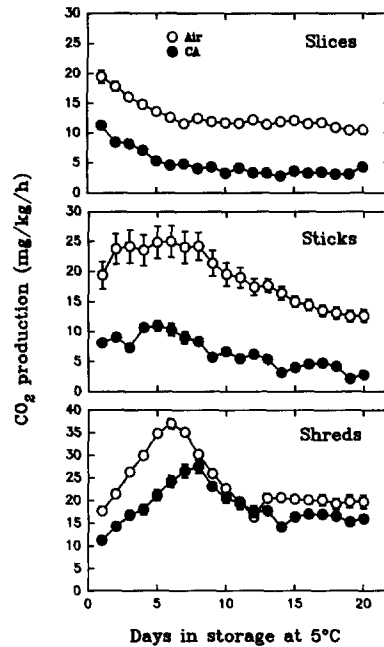


Fig. 1. Rates of CO₂ production carrot slices, sticks, and shreds during storage at 5°C under air or CA of 0.5% O₂ and 10% CO₂. Vertical lines represent SE. SE bars were not shown when masked by the graph symbol.

in air, was 3.2 in the 0–10°C range. The reason for the greater inhibitory effect of CA on respiration at 10°C than at 0 or 5°C is unknown. The slightly higher RQ of some samples held in CA compared to those in air indicates that glycolysis or anaerobic respiration had increased in samples held in CA. This effect is suspected to be due to the low O₂ level rather than the elevated CO₂. The increase in glycolysis was not sufficient to cause injury. Kato-Noguchi and Watada (1996a) indicated that the increased glycolysis of shreds caused by the 0.5% O₂ atmosphere maintains a supply of energy needed for metabolism.

The cause for the increased respiration of shreds and sticks for a few days is unknown, but may be due to suberization of the cut cells. Carrot cuts which had larger surface area for suberization, that is shreds > sticks > slices, had a larger increase in respiration. The lack of increase at 10°C may be due to the high metabolic rate, which allowed the suberization to proceed rapidly and the effect on respiration was not apparent.

Ethylene production of less than 0.1 $\mu\text{l kg}^{-1} \text{h}^{-1}$ was similar among the different carrot cuts and was not affected by CA. This level of ethylene is not sufficient to induce production of isocoumarin in carrots and render them bitter (Chalutz et al., 1969; Sarkar and Phan, 1979).

Off-odor or decay was not detected with any of the cuts held in CA at all temperatures. The decay observed in samples held in air was suspected to be the black

Table 2
Incidence of decay, weight loss, whitish index, total microbial count, and pH of carrot slices, sticks, and shreds stored in air or CA for 28, 21, and 11 days at 0, 5, and 10°C, respectively

Type of cut	Treatment	Decay ^b (%)	Weight loss (%)	Whitish index	Log ₁₀ CFU/g	pH
0°C storage						
Slices	Air	0	1.2	39.6	6.1	5.2
	CA ^a	0	0.6 ^d	38.2	6.0	5.2
Sticks	Air	7	2.9	38.8	8.7	5.7
	CA	0 ^e	2.0 ^d	42.5	7.9 ^e	5.3 ^d
Shreds	Air	0	3.2	41.7	7.5	5.3
	CA	0	2.8 ^d	37.9 ^d	7.9	4.8 ^e
5°C storage						
Slices	Air	33	1.5	38.8	5.8	5.0
	CA	0 ^e	1.4	40.3	5.3	4.9
Sticks	Air	6	2.7	39.7	8.1	6.0
	CA	0 ^e	1.8 ^e	40.5	7.7 ^e	5.7 ^e
Shreds	Air	0	3.3	42.0	8.3	5.4
	CA	0	2.1 ^d	35.9 ^e	8.3	5.2 ^e
10°C storage						
Slices	Air	7	2.2	43.2	5.7	4.9
	CA	0 ^e	1.6 ^d	40.2	5.2	5.0
Sticks	Air	20	4.4	39.4	7.9	5.7
	CA	0 ^e	2.1 ^e	42.2	7.8	5.6
Shreds	Air	10	4.6	40.1	8.0	5.3
	CA	0 ^e	4.4	39.1	8.3	5.1 ^e

^a 0.5% O₂ + 10% CO₂.

^b Number of decayed pieces/number of observed pieces × 100.

^c High values indicate enhanced surface whitening.

^{d,e} Significant at $P < 0.05$ or 0.01, respectively, between paired air and CA treatments.

root rot caused by *Chalara elegans* (Punja and Gaye, 1993), and not the watery rot that preceded black root rot as described by Abe and Chachin (1995). CA conditions have been shown to suppress postharvest decay of fruits and vegetables by affecting the resistance of the host commodity and/or the growth of the pathogen (El-Goorani and Sommer, 1981).

CA was effective in reducing weight loss of slices at 0 and 10°C, sticks at all temperatures, and shreds at 0 and 5°C. Using the average rate of CO₂ production of each cut, about 10–20% of total weight loss was due to loss of carbon by respiration. Thus, the difference in weight loss between CA and air samples was mainly due to moisture loss. Since the formation of white tissue is due to dehydration (Tatsumi et al., 1991; Avena-Bustillos et al., 1994), the reduction in moisture loss in CA may have been partly responsible for the lower whitish index for shreds in CA than air at 0 and 5°C. This was not a strong effect as noted by the lack of relationship with the other cuts. Application of edible coating, such as sodium caseinate–stearic acid (Avena-Bustillos et al., 1994) or heating and raising the pH (Bolin and Huxsoll, 1991) may be helpful in reducing the white tissue of fresh-cut carrots.

CA had suppressive effects on growth of aerobic mesophilic bacteria only with sticks at 0 and 5°C, which may have been associated with the lower pH of sticks in CA. However, CA did not affect the total microbial count on slices and shreds despite the lower pH of shreds held in CA. Labuza et al. (1992) reported that microbial spoilage of CA-packaged foods was caused by several factors, such as atmosphere, pH, temperature, and water activity. Thus, other factors also have to be controlled to reduce microbial population for fresh-cut carrots. The combination of low O₂ and high CO₂ of >25% has been shown to increase the growth of lactic acid bacteria (LAB), as noted with carrot shreds stored in CA at 10°C (Carlin et al., 1990a). In our study, LAB counts were below the detection level on carrot sticks held in CA, when performed on MRS medium (data not shown) and no decay was detected with any types of cuts held in CA. Apparently any increased anaerobic respiration caused by CA was not of sufficient magnitude to have an effect on the population of LAB or subsequent decay.

5. Conclusion

The CA atmospheres of 0.5% O₂ and 10% CO₂ reduced the respiration rate of carrot slices, sticks, and shreds at all temperatures, and had desirable effects on storage quality, as noted by reduced decay, and weight loss. Overall, carrot sticks and shreds benefited from CA when stored at 0 and 5°C, but not at 10°C. None of the cuts were affected deleteriously by the gas mixtures used. Thus, O₂ can be allowed to drop down to 0.5% and CO₂ be allowed to increase up to 10% in film bags without any consequence on shelf life of the commodities, providing the temperature is kept near 0°C. At 0°C, cut carrots can be held in film bags without deleterious effect with O₂ levels as low as 0.5% and CO₂ levels as high as 10%.

References

- Abe, K. and Chachin, K., 1995. Physiological properties of carrot sections having difference in ration of vertical- or transverse-cut surface. *J. Jpn. Soc. Cold Preserv. Food*, 21: 87–92.
- Avena-Bustillos, R.J., Cisneros-Zevallos, L.A., Krochta, J.M. and Saltveit, M.E., 1994. Application of casein-lipid edible film emulsions to reduce white blush on minimally processed carrots. *Postharvest Biol. Technol.*, 4: 319–329.
- Barth, M.M., Kerbel, E.L., Broussard, S. and Schmidt, S.J., 1993. Modified atmosphere packaging protects market quality in broccoli spears under ambient temperature storage. *J. Food Sci.*, 58: 1070–1072.
- Bolin, H.R. and Huxsoll, C.C., 1991. Control of minimally processed carrot (*Daucus carota*) surface discoloration caused by abrasion peeling. *J. Food Sci.*, 56: 416–418.
- Carlin, F., Nguyen-the, C., Chambroy, Y. and Reich, M., 1990a. Effects of controlled atmospheres on microbial spoilage, electrolyte leakage and sugar content of fresh 'ready-to-use' grated carrots. *Int. J. Food Sci. Technol.*, 25: 110–119.
- Carlin, F., Nguyen-the, C., Hilbert, G. and Chambroy, Y., 1990b. Modified atmosphere packaging of fresh, 'ready-to-use' grated carrots in polymeric films. *J. Food Sci.*, 55: 1033–1038.
- Chalutz, E., DeVay, J.E. and Maxie, E.C., 1969. Ethylene-induced isocoumarin formation in carrot root tissue. *Plant Physiol.*, 44: 235–241.
- El-Goorani, M.A. and Sommer, N.F., 1981. Effects of modified atmospheres on postharvest pathogens of fruits and vegetables. *Hort. Rev.*, 3: 412–461.
- Hansen, H. and Rumpf, G., 1974. Storage of carrots (variety Nantaise): the influence of the storage atmosphere on flavor, decay and content of sucrose, glucose and fructose. *Acta Hort.*, 38: 321–326.

- Hardenburg, R.E., Watada, A.E. and Wang, C.Y., 1986. Fresh vegetables. In: The commercial storage of fruits, vegetables, and florist and nursery stocks. US Dept. Agr., Agr. Handbook No. 66., Washington, DC, pp. 50–72.
- Izumi, H. and Watada, A.E., 1994. Calcium treatments affect storage quality of shredded carrots. *J. Food Sci.*, 59: 106–109.
- Izumi, H., Watada, A.E. and Douglas, W., 1996. Optimum O₂ or CO₂ atmosphere for storage of broccoli florets at various temperatures. *J. Am. Soc. Hort. Sci.*, 121: 127–131.
- Kader, A.A., 1993. A summary of CA requirements and recommendations for fruits other than pome fruits. Proc. Sixth Int. Controlled Atmosphere Research Conference, Ithaca, NY, pp. 859–887.
- Kaji, H., Ueno, M. and Osajima, Y., 1993. Storage of shredded cabbage under a dynamically controlled atmosphere of high oxygen and high carbon dioxide. *Biosci. Biotechnol. Biochem.*, 57: 1049–1052.
- Kato-Noguchi, H. and Watada, A.E., 1996a. Low oxygen atmosphere-induced increase in fructose 2,6-bisphosphate in fresh-cut carrots. *J. Am. Soc. Hort. Sci.*, 121: 307–309.
- Kato-Noguchi, H. and Watada, A.E., 1996b. Regulation of glycolytic metabolism in fresh-cut carrots under low oxygen atmosphere. *J. Am. Soc. Hort. Sci.*, 121: 123–126.
- Ko, N.P., Watada, A.E., Schlimme, D.V. and Bouwkamp, J.C., 1996. Storage of spinach under low O₂ atmosphere above the extinction point. *J. Food Sci.*, 61: 398–400 and 406.
- Labuza, T.P., Fu, B. and Taoukis, P.S., 1992. Prediction for shelf life and safety of minimally processed CAP/MAP chilled foods: a review. *J. Food Prot.*, 55: 741–750.
- Punja, Z.K. and Gaye, M.M., 1993. Influence of postharvest handling practices and dip treatments on development of black root rot on fresh market carrots. *Plant Dis.*, 77: 989–995.
- Saltveit, M.E., 1993. A summary of CA and MA requirements and recommendations for the storage of harvested vegetables. Proc. 6th Natl. CA Conf., Cornell Univ., Ithaca, NY, pp. 800–818.
- Sarkar, S.K. and Phan, C.T., 1979. Naturally-occurring and ethylene-induced phenolic compounds in the carrot root. *J. Food Prot.*, 42: 526–534.
- Tatsumi, Y., Watada, A.E. and Wergin, W.P., 1991. Scanning electron microscopy of carrot stick surface to determine cause of white translucent appearance. *J. Food Sci.*, 56: 1357–1359.
- Voisine, R., Houbourger, C., Willemot, C., Castaigne, F. and Makhoulouf, J., 1993. Effect of high carbon dioxide storage and gamma irradiation on membrane deterioration in cauliflower florets. *Postharvest Biol. Technol.*, 2: 279–289.