Package Atmosphere Affects Postharvest Biology and Quality of Fresh-cut Cilantro Leaves

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Abstract. Experiments were conducted to develop a modified atmosphere packaging system for fresh-cut cilantro (*Coriandrum sativum* L.) leaves, and to determine the effect of package film oxygen transmission rate (OTR) on package atmosphere and the consequence on quality and microbiology of the product. Package film OTR significantly ($P < 0.001$) influenced the package atmospheres and the resultant postharvest physiology and quality of fresh-cut cilantro leaves under the tested package configuration (bag size 19 × 22 cm, product fill weight 85 g/bag) and storage condition (0 °C). Oxygen and carbon dioxide levels of the packages prepared with 3500 mL·d⁻¹·m⁻² OTR films equilibrated at 1.5 to 2.3 kPa and 3.6 to 4.1 kPa, respectively, on day 3 and maintained this level throughout the storage. The gas compositions of the packages with 6200 mL·d⁻¹·m⁻² OTR films showed a similar trend, except they equilibrated at a higher O₂ (3.6 to 5.6 kPa) and lower CO₂ (2.7 to 3.3 kPa) level. Fresh-cut cilantro leaves in both packages exhibited the highest tissue integrity as evidenced by the lowest tissue electrolyte leakage, with high overall visual quality scores (like moderately to like very much) at the end of 14 days storage. However, atmospheres in 1700 mL·d⁻¹·m⁻² OTR film packages displayed a rapid depletion of O₂ and accumulation of CO₂, with essentially no O₂ (≈0.02 kPa) and high CO₂ (7.7 to 9.0 kPa) levels inside the packages from day 6 until the end of storage. A rapid increase in tissue electrolyte leakage was observed in cilantro leaves in these packages starting on day 6, increasing 6-fold at the end of the storage period. Products in these packages developed a strong off-odor, accompanied by a rapid loss of typical aroma and overall visual quality, with an unacceptable quality rating at the end of storage (dislike slightly). Samples packaged in perforated bags (without modified atmosphere) lost moisture over time, and small numbers of wilted leaves were seen. There was a slow but significant ($P < 0.001$) increase in aerobic organisms over time with no significant ($P > 0.05$) difference among treatments. There was an increase in anaerobic microorganisms on cilantro leaves packaged in 1700 mL·d⁻¹·m⁻² OTR film, although only ≈0.5 log cfu/g difference was observed among the treatments and over time.

The fresh-cut fruit and vegetable industry has been rapidly expanding during the past decade, due to the freshness and high nutrition that fresh-cut produce offers, as well as convenience to consumers (Bauer 1997; Hodge 1995; Watada et al., 1996). With the successful use of modified atmosphere packaging (MAP) systems, a wide variety of vegetables have been used successfully in the fresh-cut products, such as packaged fresh-cut iceberg and romaine lettuce (*Lactuca sativa* L.), carrot (*Daucus carota* L.), cabbage (*Brassica oleracea* L.), and spinach (*Spinacia oleracea* L.) (Bauer 1997). However, the processing and sale of packaged fresh-cut culinary herbs have had limited success. Although there is increased demand for

packaged fresh-cut culinary herbs at both the retail and food service sectors, the preparation of fresh-cut herbs with acceptable quality and shelf life remains a challenge due to their high perishability.

Cilantro (*Coriandrum sativum* L.), also called Chinese parsley or coriander, is an important fresh culinary herb in the United States, widely used in Mexican and Asian cuisines (Loaiza and Cantwell, 1997). Fresh cilantro leaves offer unique aroma, taste, and flavor (Potter and Fagerson, 1990). Studies on whole/bunched cilantro indicate that it has a moderately high respiration rate (15 to 20 μL CO₂ /g/h at 5 °C), and requires 0 °C storage to maintain quality and shelf life (Loaiza and Cantwell, 1997). Major defects of cilantro during storage include leaf yellowing, decay, dehydration, and the loss of typical aroma (Cantwell and Reid, 1993). With controlled atmosphere storage, leaf yellowing of cilantro was retarded and shelf life extended under moderately low O₂ and high CO₂ conditions (Aharoni et al., 1989); excessively high CO₂ (> 9 kPa) caused physiological injury resulting in dark lesions (Loaiza and Cantwell, 1997).

The main purposes of this study were to

develop a modified atmosphere packaging system for fresh-cut cilantro leaves with acceptable quality and a 14-d shelf life (required for distribution and retail sales), and to evaluate the postharvest biology and quality changes of fresh-cut cilantro leaves influenced by package atmosphere achieved via package film oxygen transmission rate.

Materials and Methods

Sample preparation. Fresh cilantro (*Coriandrum sativum* L.) were obtained from a commercial salad manufacturer (Natural Selection Foods Inc., San Juan Bautista, Calif.), shipped overnight at 5 °C conditions to our lab at Maryland, and processed within 3 d after harvesting. Outer leaves and unusable stems were removed, and leaves were cut into ≈3-cm segments. The cut leaves were washed and sanitized in 100 ppm chlorine solution (NaOCl) at pH 7.0, 5 °C, for 1 min in a commercial salad washer (model MPW-800 Mini Polywash; Meyer Machine Co., San Antonio, Texas) with gentle agitation. The products were then centrifuged at 300 rpm for 2 min with a commercial salad centrifugal dryer (model T-304; Garrouite Spin Dryer, Meyer Machine Co.) to remove excess water. Samples of 85 g each were packaged in sealed polypropylene bags (19 × 22 cm) of selected film oxygen transmission rate (OTR) of 1700, 3500, or 6200 mL·d⁻¹·m⁻², and perforated bags (film manufacturer: Package Concept Inc., Salinas, Calif.). The packages were flushed with 5 kPa O₂ to accelerate the gas equilibrium rate. Samples were stored at 0 °C for subsequent quality evaluation.

Respiration rate and ethylene production. Fresh (intact) and fresh-cut cilantro samples, 200 g each, were placed in gas-tight containers at 0 °C. Ethylene and CO₂ production rates were monitored for 48 h at a 2-h interval using an automatic sampling, flow-through system (Watada and Massie, 1981). Data reported here were taken 12 h after cutting when respiration and ethylene production reached a steady state after the initial rate peak due to wound response.

Gas composition and product quality. The package atmospheric compositions were measured using an O₂/CO₂ analyzer (model Combi Check 9800-1; PBI Dansensor Inc., Denmark). The color of the leaves was measured using a chromameter (model CR-300; Minolta Corp.; Osaka, Japan). The values of L*, a*, and b* were directly obtained from the color meter and the hue angle was calculated according to Gnanasekharan et al. (1992) and McGuire (1992). To minimize the effect of color variations within the bags, 30 color readings were taken per bag. Sensorial quality attributes of typical aroma, off-odor, and overall quality were

Table 1. Stead state respiration and ethylene production rates of intact and fresh-cut cilantro measured 12 h after cutting.^z

Cilantro	CO ₂ (mg·kg ⁻¹ ·h ⁻¹)	C ₂ H ₄ (μL·kg ⁻¹ ·h ⁻¹)
Intact	25.0 ± 1.6	1.1 ± 0.1
Fresh-cut	35.8 ± 3.3	1.1 ± 0.1

^zData represent the mean ± SE of triplicate samples.

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Fig. 1. Changes in gas composition of packages as influenced by film OTR, film perforation and storage time at 0 °C. Vertical bars represent ± 1 SE of triplicate samples. (A) O₂ (kPa), (B) CO₂ (kPa).

evaluated immediately after opening the bags by a three-member trained panel following a modified procedure from Loaiza and Cantwell (1997). Aroma was scored on a 5 to 1 scale where 5 = maximum, 4 = near typical, 3 = moderate, 2 = slight and 1 = none. Off-odor was scored on a 1 to 5 scale, where 1 = no off-odor and 5 = extremely strong off-odor. Overall quality was evaluated with a 9-point hedonic scale, where 9 = like extremely, 5 = neither like nor dislike and 1 = dislike extremely (Meilgaard et al., 1991). Product moisture loss was assessed based on the weight change at the time of sampling divided by the initial weight. Product decay and damage, tissue yellowing, and wilting were determined by separating cilantro leaves showing those symptoms from the rest of the product, weighed and reported as percentage of decay and damage, wilting, and yellowing.

Electrolyte leakage. Samples of 50 g cilantro leaves were submerged in 500 ml of de-ionized water for 30 min. The electrolyte content of the solution was measured using a conductivity meter (model 135A; Orion Research Inc., Beverly, Mass.). Total electrolytes of the samples were determined after freezing the samples at -20 °C for 24 h and thawing at room temperature (Hong et al., 2000). Electrolyte leakage was expressed as a percentage of total electrolytes.

Microbial testing. Cilantro samples (30 g) were macerated for 2 min at 260 rpm in 270 mL of 0.1% sterile peptone water, pH 7.4, with a lab stomacher (model 400; Seward Medical, London, U.K.). The supernatants were then

filtered through sterile glass wool and serially diluted with peptone water. Appropriate dilutions were spread onto selected culture media plates with a spiral plater (Autoplate model 3000; Spiral Biotech, Bethesda, Md.). The total aerobic plate count (APC) was determined by plating the samples on tryptic soy agar (TSA, Difco Lab, Detroit, Mich.) and incubating the

plates at 28 °C for 2 d. The anaerobic plate count (AnPC) was assessed by plating on TSA medium, and incubating the plates at 28 °C for 3 d anaerobically in BBL GasPak pouches (Becton Dickinson and Co., Cockeysville, Md.). Yeast and molds were cultured with potato dextrose agar (PDA, Difco Lab) with the addition of chloramphenicol (200 $\mu\text{L}\cdot\text{L}^{-1}$) and incubated at 28 °C for 3 d. Microbial colonies were counted using a Protos Colony Counter (model 50000; Synoptics Ltd, Cambridge, U.K.) and reported as log cfu/g of tissue.

Experimental design and statistical analysis. All quality evaluations were performed in a temperature-controlled room at 5 °C to minimize the effect of temperature variation during testing. Treatments were arranged in a factorial design with storage time and package film type as main factors. Three replications (three bags) per treatment per evaluation period were examined. Data were analyzed for statistical significance using the Proc Mixed procedure of SAS (SAS Inst., Cary, N.C.).

Results and Discussion

Respiration rate and ethylene production. Fresh-cut preparation markedly increased the respiration rate of cilantro leaves (Table 1). At 0 °C, the respiration rate (CO₂ production) of fresh-cut cilantro leaves was 35.8 $\text{mg}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$, compared to that of the intact at 25.0 $\text{mg}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$. There are no reports of the respiration rate of fresh-cut cilantro leaves; but the trend between fresh-cut and intact of cilantro is similar to other types of vegetable items (Watada et al., 1996). However, both fresh-cut and intact cilantro produced only small amounts of ethylene (1.1 $\mu\text{L}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$, Table 1) and there was no significant difference between them.

Gas composition. Package film OTR significantly ($P < 0.001$) affected the gas composition of the packages (Fig. 1). Oxygen and CO₂ levels inside the 3500 OTR film bags reached equilibria of 1.5 to 2.3 kPa and 3.6 to 4.1 kPa, respectively,

Fig. 2. The effect of package film OTR and perforation on electrolyte leakage of fresh-cut cilantro leaves during storage at 0 °C. Vertical bars represent ± 1 SE of triplicated sample.

Fig. 3. The effect of package film OTR and perforation on sensorial quality of cilantro leaves during storage at 0 °C. (A) Off-odor, (B) aroma, (C) overall quality. Vertical bars represent ± 1 SE of triplicate samples.

on day 3 and maintained this level throughout 14 d of storage. The gas composition of the 6200 OTR film bags showed a similar trend, except they equilibrated at higher O_2 (3.6 to 5.6 kPa) and lower CO_2 (2.7 to 3.3 kPa) levels. However, packages prepared with the lowest OTR film (1700 OTR) performed differently: there was a rapid depletion of O_2 and accumulation of CO_2 with essentially no O_2 (≈ 0.02 kPa) and high CO_2 (7.7 to 9.0 kPa) inside the packages from day 6 until the end of the storage.

Electrolyte leakage. Before cutting, fresh cilantro leaves showed low electrolyte leakage, which increased dramatically after fresh-cut preparation (data not shown), probably due to rupture of cell membranes resulting in the release of tissue fluid. Interestingly, from day 0 to day 3, there was a significant ($P < 0.001$) decrease in electrolyte leakage during cold

storage among all treatments (Fig. 2). This decrease in electrolyte leakage is probably due at least in part to influx of electrolytes from cut (ruptured) cells into metabolically active (healthy) cells. Since electrolyte leakage is related to cell membrane integrity (Marangoni et al., 1996; Murata 1989), this decrease in tissue electrolyte leakage may also suggest that a membrane damage recovery process might exist during the early stage of cold storage following

cutting. Studies on membrane structural lipids and the membrane ultrastructures of fresh-cut carrots also suggested the occurrence of a membrane repair process (Picchioni et al., 1994; Picchioni and Watada 1996). In this experiment, there was a significant ($P < 0.001$) increase in electrolyte leakage for samples inside the 1700 OTR film bags beginning on day 6. Since there was a rapid depletion of O_2 and accumulation of CO_2 in this treatment, the rapid increase in electrolyte leakage was probably the result of cell membrane damage caused by low O_2 and high CO_2 injury. However, all other treatments had a very slow increase in electrolyte leakage beginning on day 6 until the end of the storage, suggesting that good cell membrane integrity of cilantro leaves was maintained under those package conditions.

Sensorial quality. A slight to moderate level of off-odor was detected from cilantro leaves packaged in 1700 OTR film bags starting on day 6 (Fig. 3A). The off-odor became very strong on day 14, corresponding to the rapid depletion of O_2 and accumulation of CO_2 in those packages. Since off-odor is often associated with the onset of anaerobic respiration under low O_2 and high CO_2 conditions, this suggests that the low O_2 and high CO_2 levels inside the 1700 OTR film bags had caused anaerobic respiration of cilantro leaves. This also agrees with the electrolyte leakage results. Unlike samples in the low OTR film bags, cilantro leaves in all other treatments had no off-odor throughout day 10, and only trace amounts of off-odor were detected at the end of storage. This indicates that there was no or only trivial anaerobic respiration due to the presence of O_2 and low CO_2 in those treatments. This also agrees with the low electrolyte leakage and good cell membrane integrity results found in those treatments.

There was a gradual loss of typical aroma of cilantro leaves over time (Fig. 3B). Although there was a greater loss of aroma in the perforated bag treatment, the difference among all treatments was minimal. This suggests that the loss of the typical aroma of cilantro is not influenced by the package atmospheres.

With regard to overall visual quality, there was no noticeable quality decline among all treatments from day 0 to day 3 (Fig. 3C). Symptoms of some minor damage (bruises) on fresh-cut cilantro leaves observed on day 0 disappeared by day 3. Considering the early decrease in electrolyte leakage observed on day 0, this may suggest a damage recovery process at the early stage of cold storage of fresh-cut cilantro leaves. However, beginning on day 6, there was a rapid decline in overall quality of cilantro leaves packaged in 1700 OTR film bags, mainly due to the development of off-odor and loss of the fresh appearance. At the end of storage, the overall quality scores of cilantro leaves in this

Table 2. Quality attributes of fresh-cut cilantro leaves held at 0 °C for 14 d.^a

Film type	Moisture loss (%)	Wilting (%)	Decay and damage (%)	Yellowing (%)
1700 OTR	0	0	5.1 $\pm$ 1.6	0
500 OTR	0	0	1.7 $\pm$ 0.3	0
6200 OTR	0	0	1.3 $\pm$ 0.3	0.1 $\pm$ 0.1
Perforated	4.8 $\pm$ 0.5	1.6 $\pm$ 1.9	1.3 $\pm$ 0.2	0.2 $\pm$ 0.2

^aData represent the mean $\pm$ SE of triplicate samples.

Table 3. Color changes of fresh-cut cilantro leaves during storage at 0 °C.^z

Color parameter	Film type	Storage time (d)				
		0	3	6	10	14
L*	1700 OTR	48.2 ± 0.6	48.8 ± 0.8	49.4 ± 0.5	48.7 ± 0.8	48.6 ± 0.6
	3500 OTR	50.1 ± 0.6	50.0 ± 0.7	49.4 ± 0.5	50.4 ± 0.5	50.6 ± 0.5
	6200 OTR	48.7 ± 0.8	49.8 ± 0.6	50.7 ± 0.6	50.6 ± 0.8	50.1 ± 0.6
	Perforated	48.9 ± 0.7	52.0 ± 0.5	50.6 ± 0.7	51.0 ± 0.6	51.3 ± 0.6
a*	1700 OTR	-8.2 ± 0.3	-8.7 ± 0.3	-8.7 ± 0.2	-8.6 ± 0.2	-8.4 ± 0.2
	500 OTR	-8.4 ± 0.2	-8.7 ± 0.3	-8.3 ± 0.2	-8.6 ± 0.2	-8.6 ± 0.2
	6200 OTR	-8.8 ± 0.2	-9.0 ± 0.2	-9.1 ± 0.2	-9.2 ± 0.2	-8.9 ± 0.2
	Perforated	-8.0 ± 0.2	-8.7 ± 0.2	-8.3 ± 0.2	-8.6 ± 0.2	-8.8 ± 0.2
b*	1700 OTR	11.1 ± 0.3	11.9 ± 0.5	11.9 ± 0.3	11.4 ± 0.4	11.4 ± 0.4
	3500 OTR	10.9 ± 0.4	11.4 ± 0.6	10.8 ± 0.3	11.1 ± 0.4	10.9 ± 0.5
	6200 OTR	11.8 ± 0.4	12.5 ± 0.4	12.3 ± 0.3	12.4 ± 0.5	11.9 ± 0.4
	Perforated	10.5 ± 0.4	11.6 ± 0.4	11.2 ± 0.6	11.3 ± 0.4	11.1 ± 0.4
Hue	1700 OTR	-4.7 ± 0.8	-4.9 ± 0.5	-4.7 ± 0.5	-4.0 ± 0.4	-4.6 ± 0.5
	3500 OTR	-3.5 ± 0.6	-3.9 ± 0.7	-3.5 ± 0.6	-3.4 ± 0.5	-3.2 ± 0.9
	6200 OTR	-4.3 ± 0.5	-5.3 ± 0.5	-4.7 ± 0.6	-4.7 ± 0.6	-4.2 ± 0.5
	Perforated	-3.7 ± 0.6	-4.2 ± 0.5	-4.3 ± 0.5	-3.9 ± 0.5	-3.2 ± 0.6

^zMeans ±SE of triplicate samples with 30 readings per sample.

Table 4. Effect of packaging film and storage time on the changes of microflora (log cfu) of fresh-cut cilantro leaves held at 0 °C.^z

	Film type	Storage time (d)				
		0	3	6	10	14
APC	1700 OTR	7.3 ± 0.4	7.5 ± 0.1	7.8 ± 0.1	8.1 ± 0.1	8.4 ± 0.2
	3500 OTR		7.5 ± 0.1	7.9 ± 0.1	8.0 ± 0.1	8.2 ± 0.2
	6200 OTR		7.7 ± 0.1	7.8 ± 0.1	8.3 ± 0.1	8.5 ± 0.1
	Perforated		7.4 ± 0.2	7.6 ± 0.1	8.1 ± 0.1	8.5 ± 0.1
AnPC	1700 OTR	5.4 ± 0.2	5.6 ± 0.1	6.0 ± 0.1	6.2 ± 0.1	6.6 ± 0.1
	3500 OTR		5.3 ± 0.1	5.4 ± 0.1	5.7 ± 0.2	6.0 ± 0.1
	6200 OTR		5.6 ± 0.1	5.3 ± 0.4	6.1 ± 0.1	6.0 ± 0.1
	Perforated		5.7 ± 0.2	5.5 ± 0.1	6.0 ± 0.2	6.1 ± 0.1

^zData represent mean ± SE of triplicate samples.

treatment decreased to 4.1, an unacceptable rating. There were small amounts of decayed leaves in this treatment (Table 2). In contrast, there was only a slight decline in overall quality of cilantro leaves packaged in 3500 or 6200 OTR film bags after 6 d in storage. At the end of 14 d storage, the overall quality of samples from those treatments were scored at 7.1 to 7.2, representing a “like strongly” to “like moderately” rating. These cilantro leaves appeared to be near the fresh, initial condition with green, fresh appearance, no yellowing or dehydration, and trace off-odor. Cilantro leaves packaged in the perforated bags (control) had a faster decline in overall quality than those packaged in 3500 or 6200 OTR films, but less than those in 1700 OTR film bags. At the end of storage, cilantro in perforated bags was rated as 5.7, representing “neither like nor dislike” to “like slightly”. The loss of quality of products in perforated bags was mainly due to the loss of moisture and fresh appearance, and the presence of wilted cilantro leaves, in addition to a small amount of yellow leaves (Table 2).

Color: The changes in color, as measured by L*, a*, b*, and hue angle values, of fresh-cut cilantro leaves were insignificant ($P > 0.05$) over time and among treatments (Table 3), although there was a slightly larger difference in L* and hue angle values of cilantro leaves packaged in perforated bags between day 0 and day 14. The minimal changes in color are probably due to the low temperature storage slowing down the degradation of chlorophyll, the major pigment of cilantro leaves. Similar findings were also reported for bunched cilantro stored at 0 °C (Loaiza and Cantwell 1997).

Microbial changes. Cilantro is a low-growing vegetable crop, and the initial aerobic plate count (APC) was relatively high (Table 4), similar to that of spinach (Babic and Watada 1996), and higher than other fresh-cut vegetables (Garg et al., 1990; Magnuson et al., 1990). During storage at 0 °C, there was a slow, but significant ($P < 0.001$) increase in APC over time, suggesting that the aerobic bacteria on fresh-cut cilantro grew slowly during 0 °C storage. Although there was a significant difference in gas composition among all four treatments, there was no significant difference in APC among treatments ($P > 0.05$), suggesting that gas composition under the testing conditions did not influence the overall growth of aerobic bacteria of fresh-cut cilantro leaves. Beuchat and Brackett (1991) found similar results with sliced tomatoes. Anaerobic plate counts (AnPC), however, showed a slightly different trend from APC. There was a slightly, yet significantly ($P < 0.001$), higher number of AnPC in samples packaged in 1700 OTR film bags starting on day 6 when the packages had depleted O₂ and accumulated CO₂. This difference was maintained from day 6 throughout the storage. Yeasts and molds (Y&M) were present on fresh-cut cilantro leaves in very low numbers (data not shown) and there was no significant difference among all four treatments or storage duration, suggesting that the growth of Y&M on cilantro was not affected by the test gas compositions, and had little or no effect on the quality loss seen in packaged cilantro. Similar findings were reported for fresh-cut spinach (Babic and Watada, 1996).

Conclusions

Package film OTR had a significant impact on the gas composition of the packages of fresh-cut cilantro leaves, and consequently affected the quality and microbiology of fresh-cut cilantro leaves. With the tested package configurations, packages prepared with 3500 and 6200 OTR films maintained a beneficial package atmosphere condition (1.5 to 5.6 kPa O₂, 2.7 to 4.1 kPa CO₂) and maintained acceptable quality of fresh-cut cilantro leaves. Other treatments either had rapidly depleted O₂ and accumulated CO₂, resulting in the development of an off-odor and loss of quality (1700 OTR film bags) or failed to maintain the moisture and color of the fresh-cut cilantro leaves (perforated bags).

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