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Quality changes in packaged salad products during storage

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Abstract The quality of four types of packaged salad products (retail and foodservice Garden salad, Caesar salad, and European salad) manufactured by five major processors and stored at 5 °C for 20 days was assessed. The O_2 and CO_2 concentrations in the bags were 0.2–1.5% and 5–30%, respectively. Overall visual quality scores were generally at or above the minimum acceptable value for salability at the "Best if Used by Date" (12–16 days after processing). Product sensory attributes (visual, flavor and textural properties) determined by a trained judge and a sensory panel significantly correlated for most of the parameters. Off-odors developed in the packages and their scores significantly correlated with ethanol and acetaldehyde concentrations in the lettuce tissue. Sugar content decreased 12% (iceberg) to 20% (romaine) from days 0 to 15. Total aerobic microbial load increased by an average of 2.5–3 log units over 20 days.

Key words Minimally processed lettuce · Modified-atmosphere packaging · Fermentative volatiles · Off-odors

Introduction

There has been a surge in the production of "ready-to-eat" or minimally processed vegetable products, and packaged salads currently comprise about half the total volume. US sales of packaged salads (iceberg, romaine, specialty lettuce, coleslaw and spinach) increased from $168 million in 1991 to $664 million in 1995 [1]. This trend is readily apparent at retail outlets where the volume of packaged salads has dramatically increased in recent years.

Brown discoloration of the cut surfaces has been reported as an important defect of fresh-cut lettuce [2, 3]. Browning has been successfully controlled by using low temperatures and modified atmospheres [4–6]. In commercial lettuce products, the packaging used to achieve 14–16 days shelf-life permits the development of a modified atmosphere that maintains the quality and shelf-life of the product, mainly by delaying the appearance of browning [7, 8]. For example, the visual quality of iceberg lettuce pieces stored for 12 days at 5 °C in either 3% O_2 + 10% CO_2 or in air was "very good" or "poor", respectively [9].

The high CO_2 and low O_2 levels used to control browning of fresh-cut lettuce, however, may induce some visual defects. Mateos et al. [10] reported the development of brown stain (BS) in intact or minimally processed lettuce treated with 5–20% CO_2 at 2.5 °C followed by transfer to air at 20 °C. BS developed in intact heads at CO_2 concentrations similar to those required for its development in the cut product, but the processed tissue was more severely affected than the intact head [10]. BS in intact iceberg [11] and romaine [12] lettuces has been extensively studied.

In addition to visual defects, some flavor defects may be induced by modified atmospheres. For example, high CO_2 (20%) resulted in a significant increase in ethanol and acetaldehyde levels as compared to levels in air-stored products [13]. Increases in these fermentative volatiles may affect the sensory properties of the product [3, 14]. High CO_2 (20%) plus high O_2 (80%) levels affected the sensory quality of fresh-cut lettuce after 10 days because of the development of off-flavors and tissue softening [3]. Ballantyne et al. [7] attributed off-flavor development in minimally processed lettuce after 14–19 days to very low O_2 (0–1%) levels.

To date, most research conducted on quality determinations of minimally processed lettuce has been performed on a laboratory scale. Attention has focused

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mainly on evaluating parameters related to visual appearance. A more critical assessment, however, of other quality factors such as flavor and texture components also needs to be considered. The objective of this paper was to evaluate and compare the changes in several parameters of commercial salad products during storage, with especial emphasis on the quality near the "Best if Used by Date". This study should provide direction for further research aimed at improving the quality of this product category.

Materials and methods

Samples of packaged salad products. Four commercial products obtained from five major salad processors (named by capital letters A–E) in California were evaluated: retail Garden salad (R-GS) (a mix of iceberg lettuce, carrot and red cabbage), foodservice Garden salad (FS-GS) (usually a mix of iceberg lettuce, carrot and red cabbage), Caesar salad (CS) (romaine lettuce with croutons and dressing in separate bags) and European salad (ES) (usually a mix of iceberg, romaine and other specialty greens). Product net weight was 454 g for R-GS, 2270 g for FS-GS, 213–284 g for CS (salad + croutons) and 284–340 g for ES. Products were delivered refrigerated to the laboratory on four dates of consecutive weeks during October and November 1995, after purchasing through a wholesale broker. Products were stored in their cartons on shelves at $5 \pm 0.5\,^{\circ}C$ for up to 20 days. Most of the products reached the "Best if Used by Date" (date printed on the bag and carton box) within 10–15 days from the day of arrival at the laboratory, which was called day 0. We estimate that the products were processed 1–3 days before their arrival.

For GS and ES, the different vegetable ingredients were separated and the weight percentage, based on the fresh weight of the total product, was calculated. In GS and CS, lettuce pieces were classified according to size (medium: 8–12 cm^2; large: >12 cm^2; small: <8 cm^2; chunks: from the core) and color (white: white–yellow with some light green tonality; light green; dark green). These determinations were done on day 0.

Package atmosphere measurement. The O_2, CO_2 and ethylene concentrations in the packages were monitored. Gas samples were taken through a septum (a patch of silicone sealant applied to the film) using a 1-ml plastic tuberculin syringe with a 25-gauge needle. The CO_2 and O_2 concentrations were determined sequentially on an infrared analyzer (model PIR-2000, Horiba, Japan) and an electrochemical oxygen analyzer (model S-3A, Applied Electrochemistry, Sunnyvale, Calif., USA). Ethylene was determined by injection of 1 ml gas sample into a gas chromatograph (model 8000, Carle Instruments, Fullerton, Calif., USA) equipped with a modified alumina F1 (mesh size 60/80) column and a flame ionization detector. Gases in four packages of product from each processor for each of the four processing lots were measured.

Total sugars, ethanol and acetaldehyde measurements. These analyses were conducted using samples from the third production lot. Duplicate samples were collected from a composite lettuce sample of three packages of product, and frozen at $-80\,^{\circ}C$. Total sugars were determined by the phenol-sulfuric acid colorimetric method using glucose as a standard [15]. Ethanol and acetaldehyde were measured following the procedure of Mateos et al. [13]; these volatile concentrations were expressed on a liquid volume/mass basis (μl/kg).

Microbiological analysis. Aerobic plate count (APC) was done on plate count agar (PCA) as described in the Bacteriological analytical manual [16]. Total coliforms were determined by the growth response in a brilliant green lactose bile medium; coliforms were calculated according to the most probable number technique [17]. Results were expressed as log cfu (colony forming units)/g.

Product quality evaluation by a trained judge. Product quality was evaluated by a trained judge (first author) in an analytical test. Evaluations were conducted as a blind test so the judge did not know the processor name. Evaluations were carried out in a monadic presentation for a given product from the five processors. For each of the production lots, the order of processor presentation was changed, so that a completely randomized design was achieved.

The entire package contents were poured into white trays which were kept on ice. In a typical sequence of product evaluation, the visual characteristics, then the textural properties, and finally the odors were scored. Off-odors were also evaluated initially when the bags were opened.

Several visual quality parameters were evaluated. The general overall visual quality (all ingredients), the quality of the lettuce, and the quality of other vegetable ingredients were evaluated using a scale of 9 to 1, where 9 = excellent and 1 = unusable [18]; a score of 6 was considered the limit of salability. Leaf surface browning (LSB), leaf edge browning (LEB), translucency (glassy or transparent surface appearance), decay (macroscopic breakdown of the product) and cutting damage (level of injury caused by the cutter) were evaluated on a scale of 1 to 5, where 1 = none, 3 = moderate and 5 = severe; for LSB, LEB, translucency and decay an index value was calculated by multiplying the score by the percentage of pieces affected.

Texture was evaluated by manually breaking approximately 20% of the pieces and determining an average score based on a 5 to 1 scale where 5 = crispy, 3 = moderately crispy and 1 = limp.

The evaluation of odors included aroma and off-odor assessments. For aroma, a scale of 5 to 1 was used, where 5 = full, characteristic, 3 = moderate and 1 = complete loss of characteristic aroma. For off-odors, two evaluations were done. Initial off-odors in the headspace were determined immediately after opening the bag, and final or persistent off-odors were determined by breaking some pieces approximately 8 min after the bag was opened and when the product was in the tray. Off-odors were scored on a 1 to 5 scale, where 1 = none, 3 = moderate and 5 = severe.

Product quality evaluation by a sensory panel. A sensory panel evaluated the products in a scoring difference acceptance test [19]. The panelists used a descriptive graduated scale to record their perceptions of overall visual quality (excellent/fresh appearance, very good, good, fair, poor/appearance not fresh), aroma (excellent/fresh, very good, good, fair/slight, poor/none/not typical), flavor (same scale as for aroma), texture (excellent/crisp/fresh/succulent, very good, good, fair, poor/limp) and purchase intent (definitely would buy, probably would buy, perhaps would buy, unlikely to buy, definitely would not buy). The scales were transformed to a 5-point scoring system, where 5 and 1 were the best and worst scores, respectively.

The panel was composed of 18 people given one training session. Panelists worked in booths equipped with red lights for aroma, flavor and texture determinations, and with white lights for visual quality and consumer acceptability evaluations. Samples were taken from a composite mix of three to six packages for each product and processor and kept on ice until serving. A sample (about 100 g) of the product from each processor was presented in a separate paper bowl and served at $20\,^{\circ}C$. All samples of a given salad type for the five processors were served to the panelists as a multiple presentation.

A test for panelist consistency was carried out in which the panelists evaluated five products (from which pairs 1/4 and 3/5 were the same product) for three attributes with a total of 12 observations per judge. Those panelists having 25% or more of the observations with 20% or more error were eliminated for subsequent statistical analyses of the results; based on this consistency test, five panelists were eliminated.

Statistical analysis. Data of a given salad type were subjected to a two-way analysis of variance (SigmaStat, Statistical Software, Jandel) for Day × Processor, using product lots as replicates. LSD values were calculated at the $P \leq 0.05$ level. Correlation analyses were performed to establish the association between subjective and objective parameters evaluated, and between parameters assessed by the trained evaluator and the sensory panel.

Results and discussion

Description of salad components

In R-GS and FS-GS, the average weight percentages of iceberg lettuce, carrot strips and red cabbage pieces were 86, 9 and 5%, respectively. In the ES mixes, the components and weight percentages were variable among the processors; in general each processor included iceberg and romaine lettuce, comprising about 85% of the total weight, and two of the following minor components: raddichio, endive, frisée, butter lettuce, Nagoya kale, tat-soi or mizuna.

In R-GS and FS-GS, small pieces ranged from 2 to 37% of total lettuce weight for four processors, while processor D had high percentages of small pieces (46–66%). The percentage of medium- and large-sized pieces was similar for four processors, while for processor D the percentage of medium-sized lettuce pieces was double that of larger pieces. For all processors, white and light-green pieces predominated (about four fold) over the dark-green pieces of iceberg lettuce.

In CS, the percentage of small pieces was low. The percentage of medium- and large-sized pieces was similar (≈35% each) for product from processors A, B and D; product from processor C had more medium-sized pieces and product from E had more large pieces. The percentage of the white and dark-green romaine pieces was similar for products from processors A–C and E (≈40% each); processor D product had more white pieces.

Package atmosphere

The O_2 concentrations in the R-GS packages were low, ranging from 0.15 to 0.8% (Fig. 1). The range of O_2 concentrations in the FS-GS packages (data not shown) was similar to that in the R-GS bags. The O_2 concentrations in the CS were similar to those in the GS bags, except for bags from processor E which had higher levels (Fig. 1). There was more apparent variation in the O_2 than in the CO_2 concentrations in the bags (Fig. 1). Subsequent to this study we observed that measurements with plastic tuberculin syringes can lead to overestimates of O_2, especially at very low concentrations.

The CO_2 concentrations at day 15 in the R-GS packages were different for each processor and ranged from 6% (processor A) to 30% (processor D) (Fig. 1).

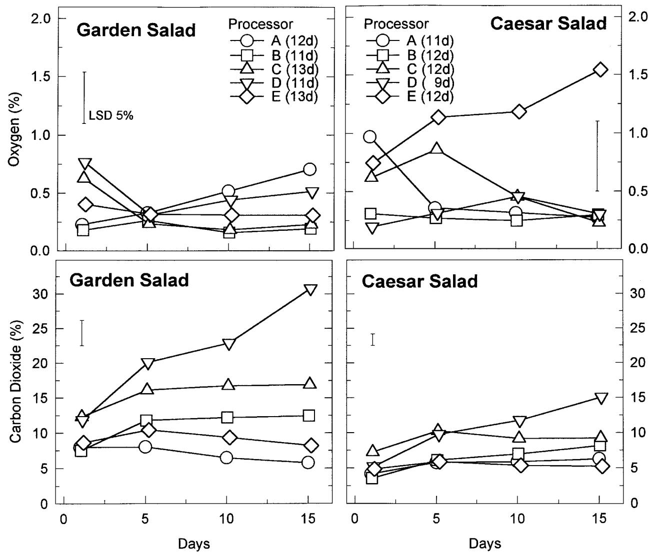

Fig. 1 Oxygen (*upper*) and carbon dioxide (*lower*) concentrations in retail Garden salad (*left*) and Caesar salad (*right*) bags during storage at 5 °C for 15 days. The *numbers* in *parentheses* in the *inset* indicate the average "Best of Used by Date". Day 0 is 1–3 days after product preparation and packaging. Each data point is the average of 12 determinations. The *vertical bars* represent the 5% LSD values

From days 5–15 the CO_2 concentrations plateaued in bags from all processors except D; in the latter case the CO_2 levels increased to about 20% at the "Best if Used by Date". The CO_2 concentrations in the FS-GS bags were less variable, ranging from 7 to 16% (data not shown). In the CS bags, CO_2 concentrations ranged from 4 to 15% (Fig. 1), and those in the ES mix bags were similar (data not shown).

The concentrations of O_2 and CO_2 in the commercial salad packages were somewhat different from those used in most laboratory studies in which levels of 0.5–5% O_2 and 5–15% CO_2 were evaluated [3, 9, 20]. In particular, the O_2 concentrations in the commercial bags were lower than those frequently examined in laboratory studies.

Ethylene concentrations in the R-GS and FS-GS packages were similar for all processors (0.2–0.9 μl/l) and to those reported by Krahn [4]. Ethylene concentrations were more variable in the CS and ES (0.5–2.0 μl/l). Ethylene concentrations remained constant during the 20-day storage period. Since ethylene was not produced by the films (data not shown), it was presumably produced by the product as a result of cutting [21] and handling. This leads to the conclusion that the commercial bags had low permeability to ethylene, since levels did not change significantly during the storage period.

Ethanol and acetaldehyde content

Ethanol concentrations in lettuce tissue increased notably in the R-GS, whereas increases in the CS were less

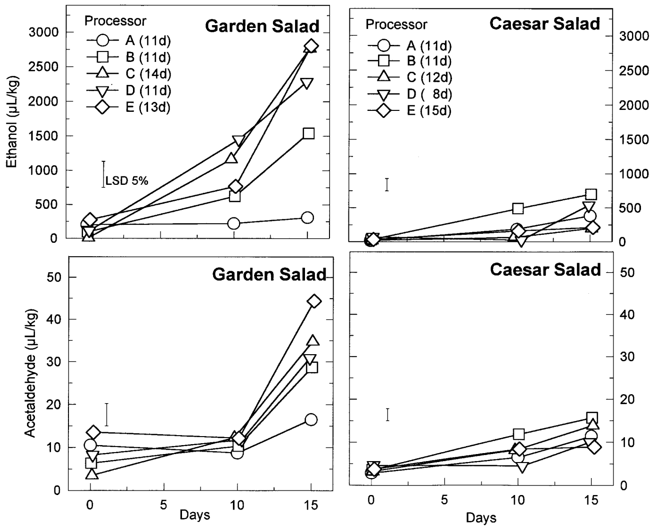

Fig. 2 Ethanol (*upper*) and acetaldehyde (*lower*) concentrations in tissue samples from retail Garden salad (*left*) and Caesar salad (*right*) bags during storage at 5 °C for 15 days. The *numbers* in *parentheses* in the *inset* indicate the "Best if Used by Date". Day 0 is 1–3 days after product preparation and packaging. Each data point is the average of duplicate analyses. The *vertical bars* represent the 5% LSD values

(Fig. 2). In the R-GS the ethanol levels began to increase at day 10 except in product from processor A, in which a constant low level was found. In the FS-GS, ethanol levels increased after day 10 except in products from processors C and E (data not shown). The highest levels observed in FS-GS were similar to those in the retail bags, about 2800 µl/kg. R-GS from processors C–E had ethanol levels near 1500 µl/kg by the "Best if Used by Date" (Fig. 2). For the FS-GS packages ethanol levels varied from 100 (processor E) to 1500 µl/kg (processor A) at the "Best if Used by Date".

Acetaldehyde did not increase significantly in the lettuce of R-GS until after day 10 (Fig. 2). At the "Best if Used by Date" acetaldehyde levels were highest in product from processors C and E (about 30 µl/kg). The acetaldehyde levels in the FS-GS product were somewhat lower than those in the R-GS, and ranged from 5 to 18 µl/kg at the "Best if Used by Date" (data not shown). Acetaldehyde levels in CS were similar among processors, not exceeding 12 µl/kg at the "Best if Used by Date" (Fig. 2). These results are consistent with those of Hamza et al. [20], who found little increase in acetaldehyde and ethanol concentrations in controlled-atmosphere-stored (2% O_2 + 10–15% CO_2), minimally processed romaine lettuce.

Based on the determination of ethanol in the tissue and in the bag headspace, we have estimated that 1500 µl/kg in the tissue (ethanol as liquid volume) leads to 100 µl/l in the headspace (ethanol as gas volume); for acetaldehyde 25 µl/kg in the tissue results in about 15 µl/l in the headspace (unpublished data). According to Leonardos et al. [14], 10 and 0.21 µl/l are the threshold concentrations in air for humans to perceive a "sweet" odor due to ethanol and a "green sweet" odor due to acetaldehyde, respectively.

Significant but low correlations were found between CO_2 concentrations and those of the fermentative volatile compounds i.e., ethanol ($r = 0.681$, $P \leq 0.001$) and acetaldehyde ($r = 0.483$, $P \leq 0.01$) for GS and CS. However, significant correlations were not found between levels of volatile compounds and O_2 concentrations. This might be due to the small range in O_2 concentrations in the bags and the larger variation in CO_2 concentrations. Based on our unpublished controlled-atmosphere work, high CO_2 levels appeared to potentiate production of fermentative volatile compounds under a low O_2 atmosphere.

We found a dramatic increase in the amount of fermentative volatile compounds in the commercially packaged GS lettuce (Fig. 2). By day 15, the levels of acetaldehyde and ethanol were 15–45 and 250–3000 µl/kg, respectively. These values are higher than those reported for intact lettuce heads exposed to high CO_2 levels in air [13]. In the latter study the acetaldehyde and ethanol levels (11 and 109 µl/kg, respectively) measured after 20 days in samples stored in 10% CO_2 at 7.5 °C were similar to those stored in air. With 20% CO_2, levels of acetaldehyde and ethanol concentrations were 17 and 604 µl/kg, respectively.

Sugar content

Average total sugar content decreased from 2.1 to 1.9 g/100g in iceberg from day 0 to day 15 (Table 1). However, the changes with time were less than the differences in sugar content in the product from different processors (1.7–2.6 g/100 g at day 0). The sugar values were higher than those reported by Heimdal et al. [3] for shredded iceberg lettuce and may be related to the much larger piece size used in our study. Our data do not agree with those of Bolin and Huxsoll [6] who reported no changes in sugars (glucose, fructose, and sucrose) in packaged iceberg salad during 21 days of storage at 2 °C. The total sugar content of romaine lettuce decreased from 2.1 to 1.7 g/100 g (Table 2). The rate of sugar loss was somewhat higher in romaine than in iceberg lettuce. The sugar levels reported here are consistent with those of other studies for iceberg [3, 22] and romaine [23] lettuces.

Microbiological quality

Initial microbial counts on iceberg lettuce from R-GS were 5.15 log cfu/g and increased to 7.1 after 10 days (Table 1). The microbial load was somewhat higher than that reported by King et al. [24] for commercially prepared salad. This could be due to the higher storage

Table 1 Quality and defect attributes of retail Garden salads stored at 5 °C. Commercially prepared salads were obtained from 5 processors on 4 processing dates. Day 0 refers to arrival at the laboratory and was 1–3 days after processing. Average "Best if Used by Date" was 11–13 days from day 0 (see Fig. 1). (*OVQ* Overall visual quality)

Ingredient	Parameter	Day	Processor					Average
			A	B	C	D	E	
Lettuce	OVQ[a]	0	8.3[f]	8.0	7.9	7.9	8.3	8.1
		10	6.9	7.3	7.3	6.5	7.4	7.1
		15	6.0	6.9	6.5	5.0	6.9	6.3
			LSD = 1.1[g]					
	Texture[b]	0	4.4	4.0	4.1	4.3	4.6	4.3
		10	3.3	3.2	3.5	3.1	3.5	3.3
		15	3.1	3.2	3.1	2.4	3.5	3.1
			LSD = 0.8					
	Aroma[c]	0	4.4	4.6	4.7	4.1	4.8	4.5
		10	3.8	3.7	3.8	3.5	3.7	3.7
		15	3.5	3.3	3.4	3.3	3.5	3.4
			LSD = 0.8					
	Initial off-doors[d]	0	1.4	1.5	1.5	1.5	1.5	1.5
		10	2.1	2.4	3.0	3.5	3.1	2.8
		15	3.0	3.6	4.0	4.6	4.0	3.8
			LSD = 0.9					
	Decay[e]	0	1.2	1.0	1.1	1.2	1.0	1.1
		10	1.2	1.2	1.2	1.7	1.1	1.3
		15	1.2	1.2	1.3	1.8	1.2	1.3
			LSD = 0.6					
	Sugar content (g/100 g FW)	0	2.6	2.1	2.3	1.7	2.0	2.1
		10	2.3	1.7	2.0	1.7	1.8	1.9
		15	2.2	1.8	1.8	1.7	1.9	1.9
			LSD = 0.4					
Carrot	OVQ[a]	0	8.3	7.8	7.9	8.3	8.7	8.2
		10	7.5	6.8	6.4	6.9	6.9	6.9
		15	6.6	6.3	6.0	5.9	6.4	6.2
			LSD = 1.0					
Cabbage	OVQ[a]	0	8.0	8.6	8.1	8.6	8.6	8.4
		10	7.6	6.8	7.0	7.3	7.0	7.1
		15	6.7	6.9	6.5	6.9	6.7	6.7
			LSD = 1.0					
All ingredients	Gen. OVQ[a]	0	8.7	8.5	8.5	8.0	8.6	8.5
		10	7.6	7.8	7.8	7.2	7.5	7.6
		15	6.5	7.7	7.2	5.8	7.3	6.9
			LSD = 1.2					
	Microb. load (log cfu/g)	0	5.2	4.9	5.5	4.5	4.3	5.1
		10	6.9	7.3	6.5	7.2	7.2	7.1
		20	7.8	7.5	7.3	6.7	8.4	7.9

[a] Overall visual quality. Scoring system: 9 = excellent, 7 = good, 5 = fair, 3 = poor, 1 = unusable. 6 is considered the limit of salability
[b] Scoring system: 5 = crisp, 3 = moderately crisp, 1 = very poor
[c] Scoring system: 5 = full, characteristic, 3 = moderate, 1 = none or not characteristic
[d] Scoring system: 1 = none, 3 = moderate, 5 = severe
[e] Calculated by multiplying the scores of severity (1 = none, 3 = moderate, 5 = severe) by the percentage of pieces affected
[f] Each value is the average of 12 observations. For sugar content and microbial load, each value is the average of 4 and 2 determinations, respectively
[g] LSD values calculated for Day × Processor at $P \leq 0.05$

temperature used in our study (5 °C vs 1.1 or 2.8 °C). Barriga et al. [25] found an increase from 4 to 7 log cfu/g in mesophilic microorganisms in laboratory-prepared shredded lettuce stored for 12 days under 3% O_2 at 4 °C. For minimally processed vegetables, French legislation allows a maximum of 4.7 log cfu/g (5×10^4 cfu/g) at production and 7.7 log cfu/g (5×10^7 cfu/g) at consumption {Anonymous (1988), cited in [25]}. Using this criterion, the microbiological quality of the commercial products analyzed in the present

Table 2 Quality and defect attributes of lettuce in Caesar salads stored at 5 °C. Commercially prepared salads were obtained from 5 processors on 4 processing dates. Day 0 refers to arrival at the laboratory and was 1–3 days after processing. Average "Best if Used by Date" was 9–12 days from day 0 (see Fig. 1)

Parameter	Day	Processor					Average
		A	B	C	D	E	
OVQ[a]	0	7.4[f]	7.5	7.8	8.0	7.9	7.7
	10	6.6	7.3	6.6	7.7	6.3	6.9
	15	5.8	6.7	6.5	6.7	5.0	6.1
		LSD = 0.9[g]					
Texture[b]	0	4.2	3.9	4.2	4.2	4.3	4.2
	10	4.1	4.1	4.0	3.7	3.9	4.0
	15	3.9	3.6	3.4	4.0	3.9	3.8
		LSD = 0.7					
Aroma[c]	0	4.3	4.0	3.4	3.7	4.1	3.9
	10	4.0	3.5	3.4	3.1	3.4	4.1
	15	2.3	2.8	2.2	3.0	2.7	2.6
		LSD = 1.0					
Initial off-odors[d]	0	1.0	1.3	1.1	1.3	1.2	1.2
	10	1.8	1.4	1.6	2.2	1.0	1.6
	15	2.2	1.9	1.5	2.2	1.7	1.9
		LSD = 0.8					
Decay[e]	0	1.3	1.2	1.2	1.2	1.1	1.2
	10	1.2	1.2	1.3	1.5	1.3	1.3
	15	1.9	1.3	1.4	1.7	2.1	1.7
		LSD = 0.4					
Sugar content (g/100 g FW)	0	2.7	2.1	1.9	1.8	2.3	2.1
	10	2.1	1.9	1.9	1.5	1.8	1.9
	15	1.8	1.5	1.7	1.6	1.7	1.7
		LSD = 0.3					
Microb. load (log cfu/g)	0	5.3	4.0	4.3	5.2	5.0	5.9
	10	7.5	6.0	6.6	7.3	5.7	7.1
	20	7.8	6.6	7.5	7.8	6.5	8.1

[a] Overall visual quality. Scoring system: 9 = excellent, 7 = good, 5 = fair, 3 = poor, 1 = unusable. 6 is considered the limit of salability

[b] Scoring system: 5 = crisp, 3 = moderately crisp, 1 = very poor

[c] Scoring system: 5 = full, characteristic, 3 = moderate, 1 = none or not characteristic

[d] Scoring system: 1 = none, 3 = moderate, 5 = severe

[e] Calculated by multiplying the scores for severity (1 = none, 3 = moderate, 5 = severe) by the percentage of pieces affected

[f] Each value is the average of 12 observations. For sugar content and microbial load, each value is the average of 4 and 2 determinations, respectively

[g] LSD values calculated for Day × Processor at $P \leq 0.05$

study could be considered satisfactory for both GS (Table 1 and data not shown) and CS (Table 2).

Total coliforms tended to increase over time but never exceeded the value of 4 log cfu/g (data not shown). These results are somewhat higher than those reported by Barriga et al. [25] for shredded lettuce stored in air or a controlled atmosphere (3% O_2 alone or in combination with up to 10% CO_2) for 12 days at 4 °C. At the end of the storage period total coliform count in FS-GS packages was less than that in R-GS. In CS, more variation among processors was found, with D and E being the most and least contaminated with coliforms, respectively.

Product quality evaluation by a trained judge

General overall visual quality of salads and visual quality of the individual ingredients

Considering all components in the R-GS, there were no significant differences in general overall visual quality (Gen. OVQ) among the five processors from days 0–15 (Table 1). However, in the FS-GS and ES differences among processors were found at day 0 (data not shown). The Gen. OVQ of the lettuce in the R-GS decreased on average from "very good" (8.1) at day 0 to near the "limit of salability" (6.3) at day 15. For the romaine lettuce in CS, quality also decreased from "very good" to the "limit of salability" over the 15-day storage period. The lower score for processor E product was mainly related to decay and browning defects (Table 2).

The color items (carrot and red cabbage) in the GS showed a decrease in quality similar to that of lettuce (Table 1), but no significant differences were found among the processors. For the carrot strips, the main defect was surface whiteness due to dehydration [26]. For red cabbage, the main visual defect was browning of the cut tissue; a fermentative odor was detected, especially in the cabbage packaged separately from other ingredients (i.e., FS-GS packages from processors B and D). The iceberg, frisée, Nagoya kale, raddichio and endive components in ES retained quality longer than did romaine and butter lettuces and the brassica greens (tat-soi and mizuna).

LSB, LEB and translucency

Browning of the surface and edges of the cut lettuce was minimal. The brown discoloration was minimized due to low temperature storage and modified-atmosphere packaging [6]. However, in "leaking bags" LSB was an important defect. The term "leaking bag" was used to describe those packages in which O_2 concentrations were at least 10 times the average value; this condition was probably a consequence of film or seal defects. When O_2 levels increased in the package, browning defects appeared, with BS being the most prominent one. Unlike previous studies [10, 13], BS appeared on lettuce tissue during low temperature storage under a modified atmosphere.

Cutting damage, texture, and decay

Since cutting damage is not modified by storage time, it was calculated as an average index for days 0, 10, and

15. Cutting damage indexes averaged about 3.5 (moderate) for the lettuce in the R-GS and CS packages, and moderately severe (4.0) for the lettuce in the FS-GS packages. The damage caused by irregular or incomplete cutting reduces the shelf-life of minimally processed lettuce [5].

The lettuce pieces lost crispness during the storage period (Tables 1, 2). For GS and CS, the texture of the lettuce pieces from the various processors was significantly different at day 15. We used a subjective technique to evaluate lettuce texture but an objective technique to assess crispness is needed for future work.

Macroscopic decay was not an important defect in the commercial salads. Decay indexes never exceeded a value of 2 (slight) but did vary among processors (Tables 1 and 2). Occasionally serious decay was found on pieces which probably had been retained or trapped for a period of time in the processing line and later dislodged.

Initial off-odor, final off-odor, and final aroma

In R-GS, initial off-odor scores at day 15 varied from moderate (processor A) to severe (processor D) (Table 1). Final off-odor scores were lower than initial off-odor scores, but both parameters increased with storage time. Off-odor scores over the 15-day period were much lower for CS than for GS (Table 2).

Although the Gen. OVQ of the products was good, the development of off-odors was one of the main defects of the commercial salads. We found development of off-odors starting at day 10, and in some cases the off-odors were very offensive. In GS, cutting damage (data not shown) and initial off-odors (Table 1) were the only defects scoring moderate or above at day 15.

The correlation of off-odors and aroma, measured sensorially, with ethanol and acetaldehyde concentrations is shown in Table 3 for data from iceberg lettuce in GS. As expected, off-odor scores were positively correlated with fermentative volatile concentrations and negatively correlated with aroma scores. Correlation coefficients were higher for ethanol than for acetaldehyde levels. Ke et al. [27] examined lettuce for ethyl acetate, lactate, acetaldehyde, and ethanol when stored in a low-O_2/high-CO_2 controlled atmosphere; ethyl acetate was the only volatile compound not detected. Volatile compounds other than these, however, may be important contributors to off-odors in lettuce.

Initial off-odors and gas composition data were subjected to a correlation analysis; in the presence of low O_2 levels in the bags, CO_2 concentrations correlated significantly but lowly with off-odor scores ($r = 0.39$, $P \leq 0.001$, based on 138 observations). Since the development of off-odors appeared to be a common problem in commercial salad products, further work is warranted.

Table 4 Quality attributes of retail Garden salads evaluated by a sensory panel

Parameter	Day	Processor					Average
		A	B	C	D	E	
OVQ[a]	0	4.0[c]	3.8	3.6	3.6	4.2	3.8
	10	3.4	3.0	3.1	1.5	3.1	2.8
		LSD = 0.5[d]					
Texture[a]	0	3.7	3.4	3.5	3.3	3.6	3.5
	10	3.4	3.0	2.9	2.4	2.9	2.9
		LSD = 0.5					
Aroma[a]	0	2.8	2.9	2.7	3.0	3.4	3.0
	10	2.9	2.5	2.7	1.7	2.5	2.5
		LSD = 0.4					
Flavor[a]	0	3.2	3.2	3.1	3.1	3.3	3.2
	10	3.0	2.6	2.6	1.8	2.8	2.6
		LSD = 0.4					
Purchase[b]	0	3.8	3.6	3.5	3.3	3.8	3.6
	10	3.2	2.8	3.0	1.3	3.0	2.7
		LSD = 0.5					

[a] Transformed scores from evaluation sheets: 5 = excellent, 3 = good, 1 = poor
[b] Transformed scores from evaluation sheets: 5 = definitely would buy, 3 = perhaps would buy, 1 = definitely would not buy
[c] For day 0, each value is the average of 38 observations. For day 10, each value is the average of 25 observations
[d] LSD values calculated for Day × Processor at $P \leq 0.05$

Table 3 Correlation coefficients between scores for off-odors and aroma with the amounts of fermentative volatile (ethanol and acetaldehyde) compounds in iceberg lettuce from retail and foodservice Garden salads. Off-odors and aroma scores were determined sensorially by a trained evaluator. Initial off-odors were determined right after opening the bag; final off-odors were evaluated approx. 8 min after opening the bag. Fermentative volatile compounds were determined by gas chromatography

	Initial off-odors	Final off-odors	Final aroma	Ethanol	Acetaldehyde
Initial off-odors	1.000[a]				
Final off-odors	0.852***	1.000			
Final aroma	– 0.521**	– 0.601***	1.000		
Ethanol	0.661***	0.644***	– 0.398*	1.000	
Acetaldehyde	0.427*	0.489**	– 0.297	0.915***	1.000

[a] Each coefficient is based on 30 observations.
*, **, *** Indicate significance at the 0.05, 0.01 or 0.001 level, respectively

Table 5 Correlation coefficients between quality scores reported by a sensory panel with those determined by a trained evaluator.

	Product (salad type)			
	Garden retail	Garden foodservice	Caesar	European
Aroma	0.623*** [a]	0.529**	0.543**	0.442*
Texture	0.614***	0.636***	0.430*	0.467*
Visual quality	0.690***	0.733***	0.212	0.356

[a] Each coefficient is based on 25 observations
*, **, *** Indicate significance at the 0.05, 0.01 or 0.001 level, respectively

Product quality evaluation by a sensory panel

The consumer panel evaluated products on days 0 and 10 for overall quality, texture, aroma, flavor, and also indicated their willingness to buy the product. At day 0, no significant differences were found in Gen. OVQ, texture and flavor of R-GS; at day 10, scores were similar for products from all processors except for processor D, whose product had lower scores (Table 4). The FS-GS received scores similar to those of the R-GS product (data not shown). In the CS, the only difference among the processors was a slight variation in flavor at day 10 (data not shown).

Positive and significant correlations were found for aroma, texture, and visual quality evaluations by the trained evaluator and sensory panel for the R-GS and FS-GS (Table 5). For the CS and ES, aroma and texture scores by the trained evaluator and the consumer panel were significantly correlated. However, the consumer panel scored the visual quality of these products lower than did the trained evaluator, resulting in low and nonsignificant correlation coefficients. A group and/or a contrast effect could have affected the scores of the sensory panel and/or those of the trained evaluator, since samples were provided as a multiple presentation to the former and monadic to the latter [28]. The sensory panel also evaluated a smaller quantity of product than did the trained evaluator.

Summary

In packaged salads from five processors, O_2 concentrations in the bags were very low and similar; CO_2 concentrations varied significantly among processors. The quality of the commercial salads decreased with time but was above the limit of salability at the "Best if Used by Date". In general for GS, four processors had products of similar quality and one processor and lower quality; in CS and ES more variability was found among processors. Browning of the cut lettuce pieces was minimal. Cutting damage and off-odors were the most noticeable defects. Concentrations of fermentative volatile compounds in the lettuce tissue were significantly correlated with off-odors and aroma scores.

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