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Characteristics of fresh-cut honeydew (*Cucumis x melo* L.) available to processors in winter and summer and its quality maintenance by modified atmosphere packaging

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Abstract

Quality characteristics and physiology of fresh-cut honeydew cubes harvested in summer and winter were evaluated. Sanitized melon cubes were packaged and held at three different atmospheres; passively formed atmosphere (passive modified atmosphere packaging (MAP)), active flushing of package with 5 kPa O₂+5 kPa CO₂ at packaging (active MAP), and perforated film package (PFP) and at three different temperature treatments; continuously at 5 or 10 °C or 2 days at 5 °C and transferred to 10 °C for a total of 11 days. Cubes of summer fruit had higher soluble solids content (SSC), respiration rate, and translucency than that of winter fruit. Translucency and off-odor were the main factors in deterioration of cubes. Cubes in active MAP had better color retention, reduced respiration rate and microbial population, and longer shelf-life than those in passive MAP, which was of better quality and had a longer shelf-life than cubes in PFP. The active MAP and 5 °C continuous was the best combination and the PFP and 10 °C continuous was the worst combination among the treatments for retaining quality and shelf-life of honeydew cubes. Quality attributes differed between cubes of fruit available in winter and summer, but the shelf-life was similar for both winter and summer cubes.

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1. Introduction

The source of honeydew melons for fresh-cut processing differs with the season. Fruit are obtained from local growers or other areas within

the USA during the summer months, and are imported from Central America during the winter months. Fruit from USA and Central America may be of different varieties and harvested at different maturities to accommodate different transit times. These differences can be sufficient to affect the quality, physiology and shelf-life of processed fresh-cut cubes. To our knowledge, there are no data available in comparing quality

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characteristics of summer and winter melon cubes. Data on summer and winter melon cubes would be helpful in developing optimal methods for seasonal handling of fresh-cut honeydew.

Low temperature and high RH are essential for storing and maintaining quality of fresh produce (Kader, 1989), especially fresh-cut products (Watada et al., 1996). Storage temperature of 7–10 °C is recommended for intact honeydew melons due to chilling injury at lower temperature (Hardenburg et al., 1986). However, a temperature near 0 °C is recommended for most fresh-cut products (Gorny, 1997), including honeydew melon tissue (Madrid and Cantwell, 1993; O'Connor-Shaw et al., 1994). An exception is fresh-cut zucchini, where 5 °C is recommended over 0 °C (Izumi and Watada, 1995) due to the sensitivity of zucchini to chilling injury. Commercially, fresh-cut melon cubes are handled and transported at about 5 °C, and often held in supermarkets at 10 °C or higher. The importance of lower temperatures is indicated by significant reduction in the metabolic rate of honeydew cubes. The respiration rate of honeydew cubes was 62, 8.3, 3.0 and 2.3 mg kg⁻¹ h⁻¹ of CO₂ at 20, 10, 5, and 0 °C, respectively (Watada et al., 1996). Qi et al. (1999) reported lower microbial population and longer shelf-life of honeydew cubes stored at 5 °C rather than at 10 °C in both air and controlled atmosphere (CA). Thus, melon cubes should be held at low temperature for maximum shelf-life.

Packaging fresh-cuts can aid in the maintenance of high relative humidity (RH), and protect the product from water loss (Watada et al., 1996). However, moisture condensation with high RH is not desirable. The condensate along with juice leakage can cause blemishes on the product, increase soaked appearance, and provide condition for microbial growth. To prevent accumulation of free fluid at the base, a water absorbent on the bottom of the packaging is useful (Bai and Watada, 1998).

CA and modified atmosphere packaging (MAP) have been shown to extend the shelf-life of many fresh-cut fruit and vegetables such as apple (O'Bieme, 1990), cantaloupe (Bai et al., 2001; O'Connor-Shaw et al., 1996), honeydew (Portela and Cantwell, 1998; Qi et al., 1999), kiwifruit

(Agar et al., 1999), peach and nectarine (Gorny et al., 1999), pear (Gorny et al., 2000), persimmon (Wright and Kader, 1997a), pomegranate (Gil et al., 1996), potato (Gurbuz and Lee, 1997), strawberries (Wright and Kader, 1997b), and zucchini (Izumi et al., 1996). CA/MAP is considered to be the second most effective method, next to proper temperature management, for extending the shelf-life of intact and fresh-cut fruit and vegetables (Schlimme and Rooney, 1994). MAP is used commercially, generally in combination with a very low O₂ partial pressure. We reported that the desired atmosphere was obtained by the active MAP system for retaining shelf-life of fresh-cut cantaloupe (Bai et al., 2001). Cantaloupe cubes maintained better quality in active MAP than that in passive MAP, which was better than air storage.

The partial pressure of O₂ in film wrapped packages of honeydew cubes in supermarkets could be as low as 1 kPa and the CO₂ could be as high as 15 kPa (Qi et al., 1999), and 25 out of 30 packages of mixed salad consisting of cut lettuce, sliced carrot and shredded red cabbage had less than 1 kPa O₂ (Cameron et al. 1995). The low O₂ may cause a risk of anaerobic fermentation, and furthermore increase health risk (Barriga et al., 1991; Brackett, 1987; Hintlian and Hotchkiss, 1986).

In this work, we determined and compared the quality, respiration rate, volatile production, and microbial population of fresh-cut cubes processed from honeydew melons available during the summer and winter season. The cubes were held in different packaging atmospheres and at temperatures that are recommended and which simulate commercial practice.

2. Material and methods

2.1. Fruit

Honeydew melons (*Cucumis x melo* L. var. inodorus Naud.) were purchased from the Maryland Wholesale Market from February through September 1998. The study was repeated three times with fruit from the USA (summer season fruit) and three times with fruit from Central

Table 1
Seasonal characteristics of quality of honeydew cubes measured on initial day

Date	Source	SSC (%)	pH	Shear force (N)	Color			O ₂ uptake mmol kg ⁻¹ h ⁻¹	
					L*	C*	<i>h</i> _{ab} (°)	5 °C	10 °C
2/20/98	Honduras	8.7 c ^a	6.0 a	985 a	65 b	23 b	114.4 a	0.07 b	0.15 b
3/16/98	Guatemala	8.3 c	6.2 a	603 c	66 b	27 a	115.9 a	0.08 b	0.14 b
4/22/98	Panama	7.8 c	5.9 ab	400 d	70 a	14 d	112.5 a	0.07 b	0.15 b
7/28/98	Arizona	11.5 a	5.8 b	782 b	63 bc	19 c	114.0 a	0.11 a	0.22 a
8/18/98	California	10.4 b	6.1 a	730 b	64 b	22 b	113.3 a	0.11 a	0.20 a
9/14/98	California	12.6 a	6.1 a	428 d	62 c	21 bc	113.4 a	0.12 a	0.22 a

Cubes were dipped in sanitizer (5 °C, pH 6.5) for 30 s and drained for 1 h prior to measuring.

^a Mean value ($n = 3$) in same column that are not followed by the same level show significant difference ($P < 0.05$) among the sources.

America (winter season fruit) (Table 1). Fruit from Central America were obtained from February through April 1998. Fruit from the USA were obtained from July through September 1998. A fruit size of 1.5–2.0 kg with no external defects was used for the study.

2.2. Fresh-cut processing and packaging

Working area and knives were cleaned with 70% ethanol. For each trial, 24 honeydews were separated into three groups of eight fruit each (three replicates). Whole fruit were dipped in 200 $\mu\text{l l}^{-1}$ sodium hypochlorite solution (5 °C, pH 6.5) for 2 min, then peeled and cut into cubes 2–3 cm on each side. The cubes from eight fruit were mixed and rinsed in 150 $\mu\text{l l}^{-1}$ sodium hypochlorite solution for 30 s and allowed to drain for 1 h at 5 °C. Cubes from each replicate were divided into 33 uniform lots for three package treatments and temperature treatments and up to five storage times with three lots being used immediately after processing. The cubes (150 g for winter and 130 g for summer fruit) were placed in 1-l plastic containers each of which was underlaid with a Fresh 'R' Pax™ Pouch water absorbent packet (Maxwell Chase Technologies, Atlanta, GA) and sealed with LDX-5406 film (Cryovac, Duncan, SC) using a food pack machine (Model FP Basic V/G; Ilpra, Italy). Since the respiration rate was higher for summer than for winter melons, sample weight of summer and winter melon cubes was adjusted to achieve similar modified atmospheres

within the packages during storage. The oxygen transmission rates (OTR) of the film at 5 and 10 °C were determined. The film was sealed to 1 l containers containing 150 ml deionized water instead of melon cubes. The containers were held at 5 and 10 °C, and were actively flushed with a gas mixture of 2–10 kPa O₂ and 2–10 kPa CO₂ (balance as N₂). Following the gas flushing, the changes of O₂ partial pressures in the packages were monitored using an O₂ analyzer (model S-3A/I, Ametek, Pittsburgh, PA). The OTR were calculated and the average values were 26.09 and 33.68 nmol m⁻² h⁻¹ Pa⁻¹ at 5 and 10 °C, respectively.

2.3. Treatment

Melon cubes were placed in three types of packaging atmosphere and held at three temperatures. The packaging atmosphere were: (1) passively formed modified atmosphere (passive MAP), (2) packages actively flushed with a gas mixture of 5 kPa O₂+5 kPa CO₂ (active MAP), and (3) packaging film perforated with ten 1.5 mm holes (PFP; Bai et al., 2001). The temperature treatments were 5 or 10 °C continuous or 2 days at 5 °C and then transferred to 10 °C (5–10 °C). The latter was to simulate the commercial processing and marketing temperature conditions. Samples were removed on days 0, 2, 4, 7, 9 and 11 for analyses of gas composition, quality, and microbial population.

2.4. Gas monitoring

Gas samples were taken from the packages and analyzed for O₂ and CO₂ using O₂ and CO₂ analyzers (Model S-3A/I and Model CD-3A, respectively; Ametek, Pittsburgh, PA), and ethylene with a gas chromatograph (Model AGC-211; Carle, Tulsa, OK) equipped with a flame ionization detector (FID).

2.5. Quality analyses

Quality analyses included visual quality (VQ), sensory aroma, translucency, texture, pH, soluble solids content (SSC), color and headspace volatiles. The sensory evaluations were conducted by five laboratory personnel using hedonic scales. VQ was scored using a scale of 9, excellent; 7, good; 5, fair; 3, poor and 1, completely deteriorated. Aroma was scored using a scale of 9, full, characteristic honeydew; 7, pleasant, mild honeydew; 5, bland, faint honeydew; 3, faint off-odor and 1, distinct off-odor. For both scales, a score of 5 was considered the threshold level for marketability. Translucency is shown as the percentage of damaged cubes. Shear force was determined with a Kramer-Shear Cell attached to a Texture Test System (Food Technology Corp.; Rockville, MD). Cubes in 100-g samples were placed in the cell randomly and the shear force was expressed in Newton (N). Color was based on the means of L*, a*, and b* values obtained with a chromameter (Model CR-300; Minolta, Japan) using five cubes per replication. Results were expressed as L*, chroma $C^* = [(a^*)^2 + (b^*)^2]^{0.5}$ and hue angle $h_{ab} = \tan^{-1}[(b^*) \times (a^*)^{-1}]$ (Minolta Corp., 1994).

For volatile analyses, 1-ml samples of juice were transferred to 4-ml vials and capped with Teflon-lined septa. The samples were quick frozen (−20 °C) and stored up to 1 week before volatile collection. Preliminary studies indicated that total volatile abundance did not change over a 1 month storage period at this low temperature, and that abundances were essentially the same in crude juice extract and extracts clarified by centrifugation or filtration. Frozen samples were thawed and equilibrated for 5 min at 20 °C before volatile sampling. A solid-phase microextraction (SPME,

Supelco Co., Bellefonte, PA) fiber coated with polydimethylsiloxane (PDME, 1 cm long, 0.34 μm thickness) was used to collect and concentrate volatiles in the headspace of sample vials as previously described (Saftner et al., 1999). The sorbed volatiles were desorbed from the fiber for 2 min at 250 °C into a glass-lined, splitless injection port of a GC (model 6890, Agilent Technologies, Palo Alto, CA) equipped with a FID, which was used to measure relative volatile abundance. The efficacy of the SPME fiber to extract volatile analytes from a sample depends on sample composition and the individual concentration of each volatile analyte in the sample (Pawliszyn, 1997; Sigma-Aldrich, 1999). However, constructing calibration curves for each volatile analyte in each melon sample is not feasible and, thus, total volatile abundance is reported in FID area response units of picoamperes (pA) rather than in absolute amounts of individual volatiles. Melon volatiles were separated and identified using GC and GC/MS procedures as previously described (Saftner et al., 1999).

2.6. Microbial analysis

The total plate counts (mostly bacteria) were determined by incubating melon extracts on tryptic soy agar (TSA, Difco Laboratories, Detroit, MI) and yeast and mold counts were determined by incubating extracts on potato dextrose agar (PDA) supplemented with 0.5 g l^{−1} chloramphenicol, both at 30 °C for 48 h as described elsewhere (Babic and Watada, 1996).

2.7. Respiration analyses

Respiration in CA and air were determined using a flow-through system for simulating the atmosphere in active MAP and PFP, respectively. A 300-g sample of honeydew cubes was placed on a plastic screen in a 2-l glass jar. The jars were connected to a flow-through system (flow rate of 15 ml min^{−1}) of 5 kPa O₂ plus 5 kPa CO₂ or air. The O₂ and CO₂ levels were measured automatically every 8 h for 12 days.

2.8. Statistical analysis

Results presented were means for the experiment including two seasons, three trials, temperature treatments and package treatments with three replicates. PROC GLM OF SAS VERSION 6.12 (SAS Institute Inc., 1989) was used for analysis of variance. The treatment means were separated at the 1 or 5% significance level by the Scheffe's multiple comparison test.

3. Result and discussion

Some quality attributes differed between fruit available in summer and winter (Table 1). Summer fruit contained 10.4–12.6% SSC, which was approximately 40% higher than those of winter fruit. Variety, harvest maturity and/or pre-harvest condition could have contributed to the differences in SSC. A quality honeydew should have 10% or above SSC (Kader, 1992). Using this as a guideline, winter melons were not up to standard quality. The initial pH ranged from 5.8 to 6.2 among fruit of different harvest dates and, except for the pH of fruit from the first summer harvest (28 July 1998), pH did not differ among fruit of different harvest dates. Low acid fruits and vegetables deteriorate more rapidly than those with high acid content (Brackett, 1994). Shear force firmness ranged from 400 to 985 N among cubes from different harvests and did not differ between seasons of harvest as a category. While preliminary sensory analyses by the authors indicated that summer melons were crisper than winter melons, shear force did not support this observation. Perhaps the apparent crispness of summer melons was greater than winter melons because the transit time from farm to market was shorter in summer than winter resulting in less water loss by transpiration, better turgor maintenance and less loss of fresh crisp texture. Shear force decreased faster with cubes with high initial shear force than those with low shear force (data not shown). The L^* readings of flesh ranged from 62 to 70, C^* from 14 to 27, and h_{ab} from 112.5 to 115.9° (Table 1). Winter melons had a lighter green

flesh with higher lightness (L^*) compared with that of summer fruit, which had a darker green flesh.

Summer melons had higher respiration rate than winter melons (Table 1). The average O_2 uptake of summer melon cubes held in air was 0.11 mmol $kg^{-1} h^{-1}$ at 5 °C and 0.21 mmol $kg^{-1} h^{-1}$ at 10 °C, compared with 0.07 and 0.15 mmol $kg^{-1} h^{-1}$, respectively, for winter melon cubes. With the metabolism of summer melon being greater than that of the winter melon, maintenance of quality would be more difficult with summer melon than with winter melons. In designing a MAP, the difference in respiration rates of melons between seasons would need to be considered.

Packaging and temperature treatments affected the shelf-life of winter and summer melon cubes as shown in Table 2. Shelf-life based on VQ was generally due to the development of greater than 20% translucency and the end of aroma quality was associated with the development of a rancid off-odor. Shelf-life of winter and summer melon cubes was similar when held in PFP and passive MAP. When cubes were held in active MAP, the shelf-life of summer cubes was shorter by at least 1 day than winter cubes when given the temperature treatment of 5–10 or 10 °C continuous. However, when cubes were held in active MAP at 5 °C continuous, the shelf-life of winter and summer cubes were both 11 days. Holding in passive MAP extended the shelf-life by 1.3–3.7 days when compared with those held in PFP at different temperatures. Storing in active MAP provided the longest shelf-life with 5, 7 and 11 days for summer melon (limited by VQ), and 6, 8.3 and 11 days for winter melon (limited by aroma) at 10, 5–10 and 5 °C, respectively. For both winter and summer melons held in passive or active MAP, the shelf-life of cubes was extended by 2–4 days when the cubes were held for 2 days at 5 °C prior to 10 °C, and extended by an additional 1–3 days when held at 5 °C continuously compared with continuous storage at 10 °C. The shelf-life of melon cubes stored in PFP at 5 °C continuously was longer than those given the temperature treatment of 5–10 or 10 °C continuous.

Deterioration was primarily due to the development of translucency. The percent translucency of cubes in PFP was greater than 20% after 4–5, 5–6,

Table 2
Shelf-life (days) of fresh-cut honeydew cubes stored in three packagings at three temperatures over two seasons

Season	Temperature	VQ			Aroma		
		PFP ^c	Passive MAP	Active MAP	PFP	Passive MAP	Active MAP
Winter	5 °C	9.7 bcd ^b	11.0 a	11.0 a	11.0 a	11.0 a	11.0 a
	5–10 °C ^a	4.0 h	7.7 defg	9.0 c	7.0 d	7.7 cd	8.3 bc
	10 °C	2.0 i	4.0 h	8.3 bcde	4.0 e	4.0 e	6.0 bcd
Summer	5 °C	8.3 bcde	10.3 ab	11.0 a	11.0 a	11.0 a	11.0 a
	5–10 °C	4.0 h	6.0 defg	7.0 f	7.0 d	7.0 d	7.0 d
	10 °C	2.0 i	4.0 h	5.0 gh	4.0 e	4.0 e	6.0 bcd

^a Two days at 5 °C and then transferred to 10 °C.

^b Mean value ($n = 9$) in VQ or aroma category that are not followed by the same letter show significant difference ($P < 0.05$) among treatments.

^c PFP, packages had film overlap perforated to have 10 1.5-mm holes; passive MAP, packages in which modified atmosphere was formed naturally; active MAP, packages in which the internal atmosphere was flushed with a gas mixture of 5 kPa O₂ plus 5 kPa CO₂ prior to storage.

and 9–10 days at 10, 5–10 and 5 °C, respectively (Fig. 1), which may be considered the limit of salable quality. Summer melon cubes tended to develop translucency slightly faster and to a greater degree than winter melon cubes probably because summer melons were harvested at a later maturity than winter melons to ensure greater than minimal acceptability of their SSC and flavor quality to consumers. The authors' research with cantaloupe also showed a similar translucency problem (Bai et al., 2001). Translucency development limiting shelf stability in fresh-cut honeydew has been previously reported by O'Connor-Shaw et al. (1996). They indicated that tissue translucency occurred in all of the treatments with 0 kPa CO₂ (irrespective of O₂ concentration), and some treatments with greater than 15 kPa O₂. The cause for the off-odor development was not identified, but was often associated with samples having a yeast and mold count $> \log 7.0$ CFU kg⁻¹ (see below). Most of the volatiles in the headspace of melon cube extracts were esters (Table 3); the rest were alcohols, aldehydes, a ketone and a sesquiterpene. Combined packaging analyses are reported in Fig. 2 for total volatile abundance (panel A and C) and melon-associated volatile abundance (panel B and D) for the different temperature treatments across packaging treatments since treatment comparisons between

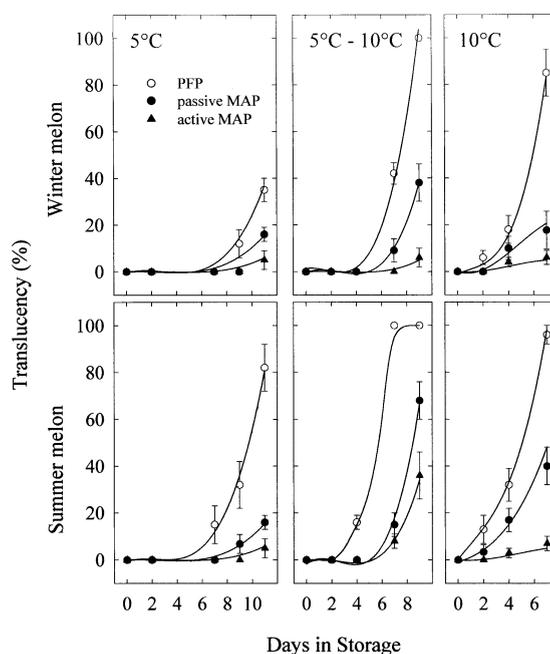


Fig. 1. Percent translucency on honeydew cubes harvested in winter or summer and stored in PFP, passive MAP or active MAP at 5, 5–10, and 10 °C over three trials. PFP, packages had film overlap perforated to have 10 1.5-mm holes; passive MAP, packages in which modified atmosphere was formed passively; active MAP, packages in which the internal atmosphere was actively flushed with a gas mixture of 5 kPa O₂+5 kPa CO₂ prior to storage. Vertical lines represent S.D. ($n = 9$). S.D. bars were not shown when masked by the symbol.

Table 3
Volatile compounds in the headspace above extracts collected from freshly prepared melon cubes

Peak	Volatile compound	Relative retention time	GC/FID response $\times 10^3$
1	Ethanol	0.13	0–1
2	Methyl acetate	0.18	0–1
3	Ethyl acetate	0.26	2–3
4	1-Butanol	0.34	0–1
5	Ethyl propionate	0.43	0–1
6	Propyl acetate	0.48	2–3
7	2-Methylpropyl acetate	0.71	2–4
8	Ethyl butanoate	0.80	1–2
9	Butyl acetate	0.84	1–2
10	Ethyl 2-methylbutanoate	0.94	4–6
11	2-Methylbutyl acetate	1.00	16–19
12	Propyl butanoate	1.04	0–1
13	Butyl propanoate	1.06	0–1
14	Pentyl acetate	1.07	0–1
15	2-Methylpropyl 2-methylbutanoate	1.13	5–7
16	6-Methyl-5-hepten-2-one	1.21	2–4
17	Ethyl hexanoate	1.23	5–6
18	2-Methylbutyl butanoate	1.25	0–1
19	<i>cis</i> -3-Hexenyl acetate	1.26	0–1
20	Unknown	1.30	0–1
21	Unknown	1.35	0–1
22	Unknown	1.39	0–1
23	2-Methylbutyl 2-methylbutanoate ^a	1.40	0–1
24	<i>cis</i> -3-Nonenal and Nonanal	1.41	0–1
25	Heptyl acetate	1.43	0–1
26	<i>cis</i> -2-Nonen-1-ol	1.48	0–1
27	<i>trans</i> -2- <i>cis</i> -6-Nonadien-1-ol, <i>cis</i> -6-Nonen-1-ol and <i>trans</i> -2- <i>cis</i> -6-Nonadienal	1.49	1–2
28	Benzyl acetate	1.51	3–5
29	Unknown	1.53	0–1
30	Unknown	1.68	0–1
31	Hexyl hexanoate	1.80	0–1
32	α -Farnesene	1.96	0–1

Retention time relative to 2-methylbutyl acetate.

^a Tentative identification.

packaging treatments were either inconsequential or nonsignificant. For both winter and summer available melons, total volatile abundance increased during storage at 5, 5–10 and 10 °C with the greatest increase occurring at the higher temperature (Fig. 2A and C). Most of the increase was due to increased ester levels, many of which are known to have a fruity or sweet aroma (Sigma-Aldrich, 2001), and to saturated alcohols (data not shown). While total volatile abundance increased during storage, specific melon-associated volatiles having a fresh fruity and/or melon aroma, peaks

number 24 through 28 in Table 3 (Sigma-Aldrich 2001), decreased during storage at all temperatures and the decrease was the most at 10 °C (Fig. 2B and D). Each of the melon-associated volatiles followed a similar pattern of change with storage time and temperatures (data not shown). In addition, total volatile abundance was 1.4–3.4 times higher in extracts from freshly cut summer melons than that in freshly cut winter melons. Melon-associated volatile abundance also was similarly higher in extracts from freshly cut summer melons versus winter melons. Differences

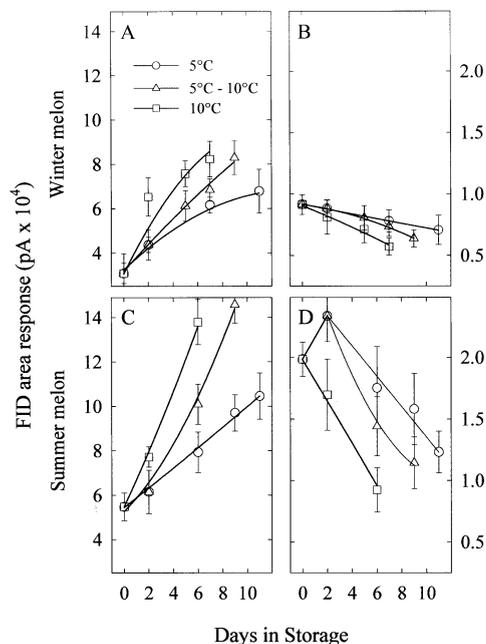


Fig. 2. Total and melon-associated volatile abundances (FID area response) in the headspace of extracts collected from winter and summer melon cubes. (2 A and C) total abundance of volatiles listed in Table 3 for winter and summer melon cubes, respectively; (2 B and D) total abundance of volatiles having a fresh fruity and/or melon aroma as represented by peaks #24 through #28 of Table 3 for winter and summer melon cubes, respectively. Data was merged for the different packaging treatments. Vertical lines represent S.D. ($n=3$ for day 0; $n=9$ for other time points).

in volatile abundances between summer and winter melons may be associated with differences in their respiratory patterns and/or harvest maturity.

Changes in the O_2 and CO_2 content in packages differed with temperature treatment (Fig. 3). At 5 °C, the O_2 level in passive MAP gradually decreased to 13.5 kPa by day 11, while CO_2 level increased to 4.4 kPa. In active MAP, the O_2 and CO_2 levels were ~ 5 kPa, and remained relatively stable throughout storage. Gas composition in PFP was similar to the ambient air composition. At 10 °C, O_2 level in passive MAP decreased to 15.9 kPa within the first 4 days, then decreased more rapidly to 6.1 kPa by day 7, while the CO_2 level increased to 8.0 kPa. In active MAP, the O_2 level did not change until day 4 and then decreased slightly, whereas, the CO_2 level increased gradually

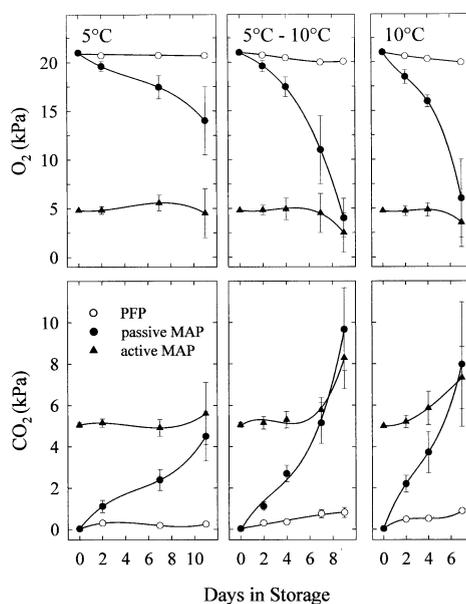


Fig. 3. Average partial pressure of O_2 and CO_2 in packages of fresh-cut honeydew cubes stored in PFP, passive MAP or active MAP at 5, 5–10 and 10 °C over six trials. PFP, packages had film overlap perforated to have 10 1.5-mm holes; passive MAP, packages in which modified atmosphere was formed passively; active MAP, packages in which the internal atmosphere was actively flushed with a gas mixture of 5 kPa O_2 +5 kPa CO_2 prior to storage. Vertical lines represent S.D. ($n=18$). S.D. bars were not shown when masked by the symbol.

to 7.3 kPa by day 7. The gas composition in packages stored for 2 days at 5 °C and transferred to 10 °C were between that of samples held continuously at 5 and 10 °C. Among all the samples, the highest CO_2 content was 9.6 kPa and the lowest O_2 content was 2.5 kPa, which were within the safe levels from toxicity or anoxia. Ethylene accumulated continually in passive MAP, its partial pressure reached 1–10 Pa during 10 and 5–10 °C storage, and 0.1–1 Pa at 5 °C, depending on trials (data not shown). Ethylene accumulation in active MAP was <10% of that in passive MAP (data not shown).

The average total plate count, mostly bacteria (TSA), was $< \log 5.8$ CFU kg^{-1} , while those for yeasts and molds (PDA) were $< \log 4.9$ CFU kg^{-1} (Fig. 4). Microbial populations on both TSA and PDA increased in all samples as storage time increased, regardless of the temperature and

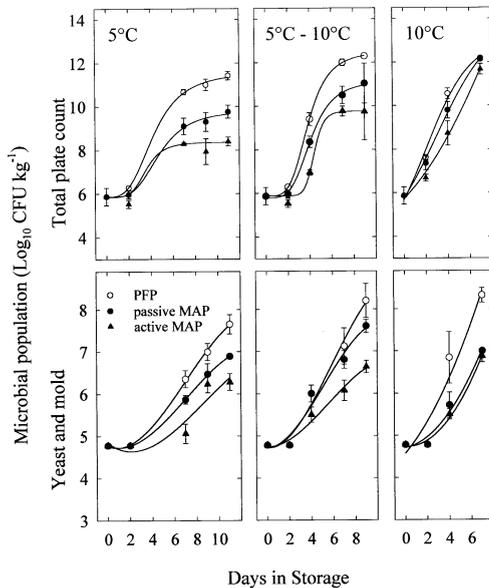


Fig. 4. Total microbial (mostly bacteria), yeast and mold populations of fresh-cut honeydew cubes stored in PFP, passive MAP or active MAP at 5, 5–10 and 10 °C over six trials. PFP, packages had film overlap perforated to have 10 1.5-mm holes; passive MAP, packages in which modified atmosphere was formed passively; active MAP, packages in which the internal atmosphere was actively flushed with a gas mixture of 5 kPa O₂+5 kPa CO₂ prior to storage. Vertical lines represent S.D. ($n=18$). S.D. bars were not shown when masked by the symbol.

packaging treatment. At 5 °C, bacterial counts in PFP increased up to log 11 CFU kg⁻¹ and yeast and mold counts to log 6 CFU kg⁻¹ by day 7, and the cubes were still marketable. However, by day 11 when yeast and mold had increased to log 7.7 CFU kg⁻¹ (Fig. 4), the cubes were no longer marketable due to deterioration of visual and/or aroma quality (Table 2). The microbial populations in passive MAP were significantly lower than that in PFP, and higher than that in active MAP. Microbial populations increased most rapidly at the higher storage temperature. The bacterial counts in all samples ranged from log 5.8–12.3 CFU kg⁻¹, whereas, the yeast and mold counts were lower than that of bacteria. High levels (≥ 40 kPa) of CO₂ in MAP can be desirable because of its fungi-static and bacteria-static effects at refrigerated temperatures (Enfors and Molin, 1978). Carbon dioxide also can increase the lag phase of

growth curves for several spoilage organisms (Farber, 1991). Low levels (≤ 1 kPa) of O₂ in MAP generally inhibit the growth of aerobic microorganisms (Farber, 1991). The degrees to which CO₂ and O₂ were modified in the passive and active MAP in this study were not enough to generally inhibit microbial growth (Farber, 1991). However, microbial populations were lower in the passive and active MAP having limited CO₂ and O₂ modifications than in PFP having essentially no atmospheric CO₂ and O₂ modifications. One possible explanation for our finding is that the limited CO₂ and O₂ modifications of passive and active MAP in this study had an additive retarding effect on microbial growth. Alternatively or in addition, the higher contamination in the PFP vs. the passive and active MAP may be due to the influx of microorganisms through the 1.5 mm holes of the PFP. Similar findings have been reported with other fresh-cut produce (Bai et al., 2001; Nguyen-The and Cartin 1994; Qi et al., 1999).

4. Conclusion

Total and melon-associated volatile abundance and SSC were higher in honeydews harvested in summer than in winter. Translucency of cubes was greater with summer melons than winter melons. However, no differences were noted in other quality characteristics or on the shelf-life of the cubes. MAP retarded deterioration of cubes at all temperatures, with active MAP being better than passive MAP.

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