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Quality of Minimally Processed *Cucumis melo* var. *saccharinus* as Improved by Controlled Atmosphere

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Summary

'Amarillo' melon (*Cucumis melo* var. *saccharinus*) was freshly-cut into trapezoidal pieces and stored for up to 14 days in air (control) or in controlled atmosphere (CA) of 4 kPa O_2 + 15 kPa CO_2 (low O_2 and high CO_2), and 21 kPa O_2 + 15 kPa CO_2 (high CO_2) at 5 °C. Both types of CA reduced the respiration rate and C_2H_4 emission and led to melon pieces of a better sensory quality than control. Fresh-cut melon softened rapidly, a process slowed by low O_2 plus high CO_2 levels (33 % loss of firmness compared to 41 % in air). That combination reduced the total soluble solids consumption but not that of citric acid. Both CA reduced microbial counts [by 1.8 to 2 $\log_{10}$ cfu g^{-1} (colony forming units per g of sample)], while the control exceeded the Spanish legal limits of fungal counts. Melon pieces under both CA achieved a shelf life of 14 days although 4 kPa O_2 + 15 kPa CO_2 was preferable for keeping the firmness.

Key words. Fresh-cut – respiratory activity – ethylene emission – sugars – organic acids – firmness – sensory quality – microbial counts – shelf life

Introduction

In 2001, melons were the eighth most consumed vegetables in the world with production of about 20.000.000 t per year (USDA 2003). With 1.183.900 t, Spain was the fourth highest producer in the world and the leading country in the European Union in 1999. In the last few years, the world production of melon has increased due to the rapid development of minimal fresh processing or fresh-cut industrial needs (TORRES and MIGUEL 2003).

The most common melon varieties used for minimal fresh processing in the USA are 'Cantaloupe' (*Cucumis melo* L. var. *reticulatus* Naud) and 'Honeydew' (*C. melo* L. var. *inodorus* Naud). However, the most commonly produced melon types in Europe and particularly in Spain are 'Galia' and 'Cantaloupe' (both var. *cantalupensis*), and 'Amarillo' and 'Piel de Sapo' (both var. *saccharinus*). AGUAYO et al. (2004) reported that types of melon from the same botanical variety showed a similar behaviour and 'Galia' and 'Cantaloupe' showed a higher metabolic activity than 'Amarillo' and 'Piel de Sapo'. Moreover, 'Amarillo' melon was considered as the best type of melon for the minimal fresh processing industry because it showed a low metabolic activity and low sensitivity to translucency.

Microbial growth and loss of firmness are the main difficulties for keeping quality of fresh-cut melon. O'CONNOR-SHAW et al. (1994) reported a shelf-life of 14 days in 'Honeydew', but only 4 days in 'Cantaloupe' melon, both held at 4 °C in closed polypropylene containers. Modified or controlled atmosphere (CA) has been shown to extend the shelf life of several fresh-cut vegetables including melon (MADRID and CANTWELL 1993; O'CONNOR-SHAW et al. 1994; PORTELA et al. 1997; ARTÉS et al. 1998; PORTELA and CANTWELL 1998; QI et al. 1999). The gas mixtures recommended in fresh-cut 'Cantaloupe' have been 3 kPa O_2 + 15 kPa CO_2 and air + 15 kPa CO_2 at 7.5 and 15 °C (MADRID and CANTWELL 1993), 6 kPa O_2 + 6 or 15 kPa CO_2 and 3.5 kPa O_2 + 9.5 kPa CO_2 at 4.5 °C (O'CONNOR-SHAW et al. 1994), and 3 kPa O_2 + 7.5 or 15 kPa CO_2, air + 15 kPa CO_2, and 3 kPa O_2 at 5 °C (PORTELA et al. 1997). However, in fresh-cut 'Honeydew' melon air + 15 kPa CO_2 at 5 °C (PORTELA and CANTWELL 1998) and 2 kPa O_2 + 10 kPa CO_2 at 5 and 10 °C (QI et al. 1999) were tested. According to GORNY (2001) 3–5 kPa O_2 + 6–15 kPa CO_2 maintained the quality of 'Cantaloupe' cubes, while 2 kPa O_2 + 10 CO_2 was effective for 'Honeydew' cubes, both at 0–5 °C.

Although the above mentioned CAs may help in keeping visual quality and reducing microbial growth in fresh-cut melon, the effects on firmness are more limited (MADRID and CANTWELL 1993; PORTELA et al. 1997; QI et al. 1999) and cultivar dependent (PORTELA and CANTWELL 1998).

The aim of the present work was to study the effectiveness of CA for keeping quality and safety of 'Amarillo' melon minimally fresh processed into trapezoidal sections. From the best of our knowledge no others studies on minimal fresh processing in the botanical variety *saccharinus* melon under CA have been previously conducted.

Material and Methods

Minimal fresh processing

'Amarillo' (cv. 'Doral') melons, grown under protected cultivation in the Mediterranean climate of Murcia

(Spain), were hand-harvested in July at their commercial maturity stage and transported 30 km to the laboratory. Melon fruits were kept in a cold room at 10 °C until next morning, when they were carefully inspected and only those free from damage, of uniform size, and external skin colour were selected (Table 1).

Whole, unprocessed melons were dipped in a 1.4 mM sodium hypochlorite solution (at 5 °C and pH=7.5) for 1 min, drained, and dried with blotting paper. All the utensils used for minimal fresh processing were carefully sanitized with chlorinated (1.4 mM) water for 30 min. After washing, melons were hand cut into eight parts, parallel to the long axis and the blossom and stem-ends were discarded. Subsequently, seeds and peel were discarded and melons were divided into trapezoidal shaped sections (mean ± S.E.: 4.9±0.1 width x 2.2±0.1 height x 2.5±0.1 length cm). Afterwards, about 3 kg of fresh-cut pieces were washed under the above mentioned conditions in a new hypochlorite solution for 1 min. Finally, 340–360 g of melon pieces were placed into 0.75 L glass jars and stored in a sanitized cold room at 5 °C. A continuous humidified gas (0.03 L min^{-1} and 95 % RH) was bubbled through the jars with a gas mixing system (Flowboard, Davis, CA, USA) which obtained the gas mixtures from commercial cylinders (Air Liquide S.A., Madrid, Spain). The selected gas compositions consisted of 4 kPa O_2 + 15 kPa CO_2 (low O_2 and high CO_2), and 21 kPa O_2 + 15 kPa CO_2 (high CO_2). As control, 21 kPa O_2 + 0 kPa CO_2 was used. The first gas mixture (4 kPa O_2 + 15 kPa CO_2) was chosen for decreasing the microbial counts because a reduction of 6 $\log_{10}$ units were obtained in cylinders of 'Cantaloupe' stored up to 12 days at 5 °C (Portela et al. 1997). According to commercial needs the melon pieces were stored under CA up to 14 days in order to simulate a shelf life. For each treatment and sampling day 5 replicates were used. Samples were monitored on days 0, 7, 10 and 14. This experiment was repeated twice under the same conditions and similar results were found and reported in this paper.

Gas analysis

Changes in gas composition within jars were periodically (everyday or two days) monitored by taking samples with a 1 mL plastic syringe through a rubber seal. Samples were then analysed with a GC Thermo Finnigan Trace (injector temp. 150 °C, TCD temp. 150 °C and oven temp. 40 °C during 5 min and 80 °C during 1 min, ramp of 20 °C min^{-1}), equipped with a Porapack column (30 m length, 0.32 mm Ø) and a thermal conductivity detector. Helium was used as carrier gas (20 mL min^{-1}). For calibrating the GC commercial gas standards (Air Liquid, Madrid, Spain) were used (Gómez and Artés 2004).

Respiration rate and ethylene emission

The respiratory activity (mg CO_2 kg^{-1} h^{-1}) and C_2H_4 emission (μL C_2H_4 kg^{-1} h^{-1}) were determined by using a closed system (Kader 2002). Five glass jars containing each 340–360 g of melon pieces placed at 5 °C for 14 days. The increase in CO_2 and C_2H_4 contents was monitored after closing the jars for 2 to 3 hours. Then 1 mL gas samples were taken with a plastic syringe from the headspace. The CO_2 concentrations were determined by the above mentioned GC. The C_2H_4 was analysed with a GC (Hewlett Packard 5730A, Philadelphia, PA., USA) equipped with a flame ionisation detector.

Sensory evaluation

At harvest and at the end of storage, the sensory quality (appearance, aroma, taste, texture and overall quality) was assessed by five members (three men and two women, aged 25 to 55) of a trained sensory panel. A nine point scale was used to record their perceptions, where 1 = inedible, 3 = poor, 5 = fair (limit of marketability), 7 = good and 9 = excellent. Panellist tasted 5 pieces of melon per treatment. The overall quality (OQ) refers to the overall appreciation of a particular sample (Aguayo et al. 2004).

Physicochemical parameters

Firmness. A puncture test was used to evaluate whole and fresh-cut melon firmness, based on the resistance of each piece to a pressure applied by a Lloyd instrument (LR10K, Fareham, Hants, UK). During the puncture test, a 4.5 mm diameter flat-head stainless steel cylindrical probe penetrated the middle of the longitudinal axis of the piece (5 mm depth) at a speed of 50 mm s^{-1} (Portela and Cantwell 2001, modified). The firmness of 30 pieces from each treatment was measured.

Colour. The changes in pulp (30 pieces/treatment) and juice colour (5 pieces/treatment) of fresh-cut melons were determined with a chromameter (CR-300 Minolta; Ramsey, NY, USA), and expressed as

hue angle ($h° = \tan^{-1}[(b^*)(a^*)^{-1}]$),

chroma ($C^* = [(a^*)^2 + (b^*)^2]^{0.5}$), and

whiteness index ($WI = 100-[(100-L^*)^2 + a^{*2} + b^{*2}]^{0.5}$)

according to Aguayo et al. (2003).

TSS, pH, TA, sugars and organic acid. Half of the melon pieces from each glass jar were homogenized in a commercial blender (Moulinex, Barcelona, Spain) and stored at −70 °C until analysis. The thawed juice was analysed for total soluble solids (TSS), pH, and titratable acidity (TA). TSS were determined with a hand refractometer (Atago N1, Tokyo, Japan) and expressed as °Brix at 20 °C. The

Table 1. External characteristics of whole melon fruits at harvest.

Weight (kg)	Diameters (cm)		Colour		
	Equatorial	Polar	L*	°H	Chroma
2.16[z]±0.1	14.4±0.6[z]	20.8±0.3	78.5±0.5	92.6±0.7	59.1±0.2

[z] Mean values (n=20) ± S.E.

pH was determined by using a digital pH-meter (Crison 501, Barcelona, Spain). For TA, 10 mL juice was titrated with 0.1 N NaOH to an endpoint at pH 8.1 (AOAC 1984) and expressed as g of citric acid L^{-1}.

For organic acids and individual sugar analysis the thawed juice sample was filtered through cheesecloth. The clarified juice was centrifuged for 15 min at 10468g_n at 5 °C (Sigma, 1-13, Osterode, Germany), and filtered twice through a 0.45 µm filter (Whatman, Clifton NJ, USA) and subsequently through a Sep-Pack (C-18 Cartridges Waters, Taunton, Ireland). The extracts were analysed on a HPLC (Merck Hitachi, Darmstadt, Germany) as described by MELGAREJO et al. (2000).

Individual sugars were determined in aliquots of 20 µL with a medium polarity NH_2 column (Lichrospher, 100 NH_2, 5 µm, Merck, Darmstadt, Germany), acetonitrile/H_2O (85:15 v/v, 0.03 mL s^{-1}) as the mobile phase and a refractive index detector (Hitachi, Model Lachrom L-7490, Tokyo, Japan). The main organic acids were analysed in 10 µL aliquots with a non-polar derivatives Lichrospher column (RP-Select B, 5 µm, Merck, Darmstadt, Germany). The mobile phase (0.01 mL s^{-1}) was a combination of water and methanol (99:1 v/v) with a buffer of 50 mM potassium dihydrogenphosphate with sulphuric acid (pH=3). Samples were measured at a 210 nm with a UV-Vis dectector (Hitachi, L-7400, Tokyo, Japan). Samples were quantified by comparison to authentic standards (Sigma-Aldrich Chemie, Steinheim, Germany). Values were given on a fresh juice.

Microbial analysis

To determine the microbial quality of the melon pieces, random samples of 30 g were homogenized for 1.5 min in 270 mL of sterile peptone buffered water (Merck-1.07228.0500 MERCK KGaA, 64271 Darmstadt, Germany), with a 400 Lab Stomacher (Seward Medical, London, UK). Dilutions were made in peptone water, as needed, for plating. Particular microbial groups were differentiate by using the following media and culture conditions: plate count agar medium (Merck-1.05463.0500 MERCK, 64271 Darmstadt, Germany) for mesophilic and psychrotrophic aerobic bacteria, incubated at 32 °C for 48 hours and at 7 °C for 7 days respectively, and rose bengal agar (MERCK KGaA, 64271 Darmstadt, Germany) for yeast and mould, incubated at 25 °C for 3 and 5 days, respectively. All microbial counts were reported as $\log_{10}$ cfu g^{-1} (colony forming units per g of sample). Microbial quality was evaluated following the criteria of the Spanish legislation (Rd 3484/2000) for minimally fresh processed fruit where maximum microbial limits for safe consumption are 7, 5, and 3 units $\log_{10}$ cfu g^{-1} for aerobic bacteria, yeasts and moulds, respectively.

Statistical analysis

A bifactorial model (time x type of atmosphere) ANOVA was applied and, when interactions were significant, the mean values were compared by an LSD multiple range test. The SigmaStat 2.0 statistical software was used.

Results and Discussion

Respiration rate and ethylene emission

In melon pieces stored in air, an initially high respiratory (11.6 mg CO_2 kg^{-1} h^{-1}) and C_2H_4 emission (70 nL C_2H_4 kg^{-1} h^{-1}) activity was detected due to the wound response by the effect of cutting, in agreement with previous findings in others melon cultivars (AGUAYO et al. 2003, 2004). That initially high respiratory largely declined within three days reaching significant lower respiration rate in CA. From the day 9, an increase in CO_2 (9.2 mg CO_2 kg^{-1} h^{-1}) and C_2H_4 (200 nL C_2H_4 kg^{-1} h^{-1}) levels were detected, in the melon stored in air, very probably due to microbial growth (Fig. 1 and 2, Table 4) and to a general deterioration of the melon tissues. This response was similar to that reported in 'Cantaloupe' cubes stored at 5 °C (DURIGAN and SARGENT 1999).

The melon pieces under CA also showed a wound response as indicated by an initial increase in CO_2 produc-

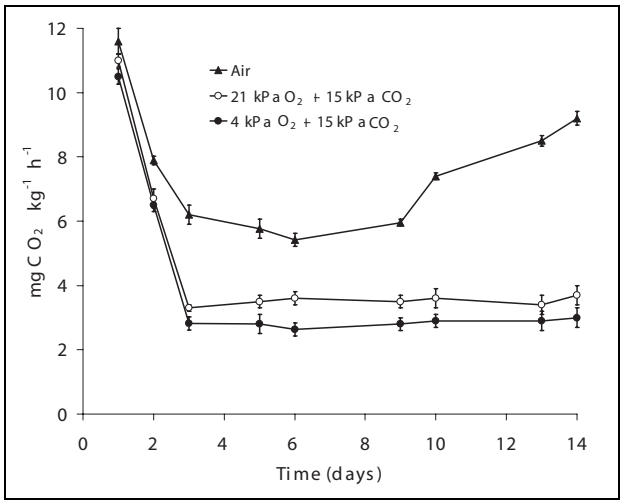


Fig. 1. Respiration rate of fresh-cut 'Amarillo' melon stored in air and in CA at 5 °C up to 14 days. Mean (n=5) ± S.E..

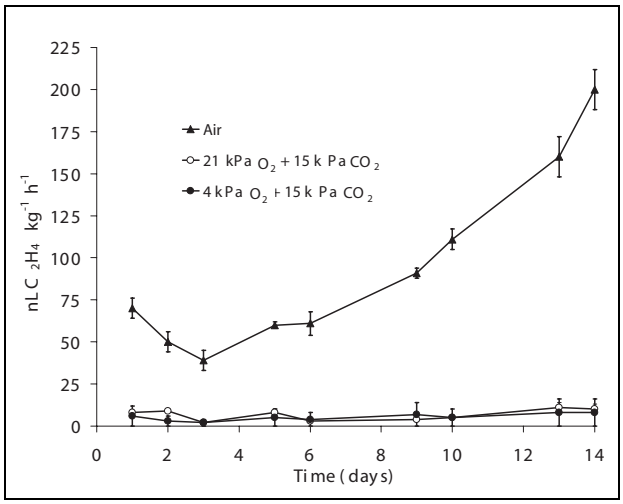


Fig. 2. Ethylene emission of fresh-cut 'Amarillo' melon stored in air and in CA at 5 °C up to 14 days. Mean (n = 5) ± S.E..

Table 2. Effect of storage time and gas mixture on sensory evaluations, firmness and colour pulp of fresh-cut melon pieces at 5 °C up to 14 days.

Storage time	Gas mixture	Appearance (1–9)	Taste (1–9)	Aroma (1–9)	Texture (1–9)	Overall (1–9)	Firmness (N)	L*	Whiteness Index	Chroma
Day 0		8.8[z]	7.8	7.5	8.0	7.8	15.11	73.0	70.3	12.2
Day 7	Air	6.4	6.3	5.8	5.3	6.0	9.83	70.7	68.2	11.0
	Air + 15 kPa CO_2	7.5	7.0	7.3	8.0	7.3	9.21	71.2	68.5	12.1
	4 kPa O_2 + 15 kPa CO_2	7.1	7.6	7.4	7.0	7.4	11.15	71.7	68.6	12.2
Day 10	Air	6.0	5.3	5.3	5.3	5.1	9.00	72.5	70.5	10.4
	Air + 15 kPa CO_2	7.0	7.0	6.8	6.5	6.8	9.97	72.2	70.0	11.1
	4 kPa O_2 + 15 kPa CO_2	7.0	7.0	7.0	6.8	7.3	10.56	72.5	69.8	12.2
Day 14	Air	1.8	1.0	4.5	2.3	3.0	8.93	71.6	69.7	10.2
	Air + 15 kPa CO_2	7.0	7.0	7.3	6.5	6.8	9.21	71.1	70.6	10.6
	4 kPa O_2 + 15 kPa CO_2	6.8	6.5	6.5	6.8	6.6	10.06	71.6	69.3	11.6
Time		(0.7)[c]	(0.7)[c]	(0.9)[c]	(0.9)[c]	(0.8)[c]	(1.24)[a]	(1.2)[c]	(1.2)[a]	(0.9)[b]
Gas mixture		(0.6)[c]	(0.6)[c]	(0.8)[c]	(0.8)[c]	(0.7)[c]	(0.84)[b]	NS	NS	(0.7)[b]
Time x GM		(0.9)[c]	(0.7)	NS	(1.5)[c]	(1.3)[c]	NS	NS	NS	NS

[z]Values are means (n=5); NS, not significant. LSD values are in brackets, [a]P<0.05, [b]P<0.01, [c]P<0.001.
Hedonic scale where 1 = unusable, 3 = poor, 5 = fair (limit of marketability), 7 = good and 9 = excellent.

Table 3. Effect of time storage and gas composition (GC) on TSS, sugars, pH, TA and organic acids of fresh-cut melon at 5 °C up to 14 days.

Storage time	Gas mixture	TSS (°Brix)	Fructose (g L^{-1})	Glucose (g L^{-1})	Sucrose (g L^{-1})	pH	TA (g citric 100 mL^{-1})	Malic (g 100 mL^{-1})	Citric (g 100 mL^{-1})
Day 0		10.3 [z]	19.66	21.40	54.08	5.59	0.10	0.04	0.13
Day 7	Air	9.9	19.27	20.97	52.13	5.49	0.13	0.04	0.13
	Air + 15 kPa CO_2	10.1	19.35	21.99	53.36	5.68	0.09	0.02	0.13
	4 kPa O_2 + 15 kPa CO_2	10.4	21.92	25.41	53.44	5.71	0.09	0.03	0.12
Day 10	Air	9.7	20.81	23.40	45.48	5.25	0.14	0.03	0.13
	Air + 15 kPa CO_2	9.8	20.56	22.94	49.32	5.54	0.10	0.02	0.13
	4 kPa O_2 + 15 kPa CO_2	10.2	21.41	23.95	53.95	5.65	0.09	0.02	0.11
Day 14	Air	9.6	22.13	24.24	42.22	5.54	0.12	0.02	0.12
	Air + 15 kPa CO_2	10.0	23.14	25.80	48.58	5.61	0.11	0.03	0.13
	4 kPa O_2 + 15 kPa CO_2	10.3	23.17	26.08	49.19	5.70	0.08	0.02	0.08
Time		NS	(2.14)[b]	(2.43)[b]	(4.94)[b]	(0.07)[c]	NS	(0.01)[c]	(0.02)[b]
Gas mixture		(0.3)[a]	NS	NS	(3.16)[a]	(0.06)[c]	(0.02)[c]	NS	(0.13)[c]
Time x GM		NS	NS	NS	(11.46)	(0.11)[c]	(0.03)[c]	NS	(0.02)

[z]Values are means (n=5); NS, not significant. LSD values are in brackets, [a]P<0.05, [b]P<0.01, [c]P<0.001.

tion. However, the CA significantly reduced both CO_2 and C_2H_4 emissions, extending the shelf life of fresh-cut melon (Fig. 1 and 2). However, lowering O_2 concentration, 4 kPa O_2 + 15 kPa compared to 21 kPa O_2 + 15 kPa, had only very minor effects on respiration and C_2H_4 emissions. The decrease in the respiration rate started the second day, from this day to onward it become stable with an average of at 3.5 mg CO_2 kg^{-1} h^{-1} in air + 15 kPa CO_2 and

at 2.8 mg CO_2 kg^{-1} h^{-1} in 4 kPa O_2 + 15 kPa CO_2. The highest CA effect on reducing the respiration rates was found from day 10 onwards (60–67 %) probably due to the high CO_2 productions of the control pieces with higher microbial growth (Fig. 1). However, during the first 2 to 3 days the lower CA effects on reducing of CO_2 were found. This can be attributed to the lack of metabolic adaptation of fruit to the imposed CA. QI et al. (1999) noticed as early as the fourth day a difference in respiration rates for 'Honeydew' cubes at 10 °C between those in air and in 2 kPa O_2 + 10 kPa CO_2. WATADA et al. (1996) also found a higher respiration rate in Muskmelon (long type) stored at 5 °C in air than in 1 kPa O_2 + 10 kPa CO_2. In our experiment, compared to air storage both CA induced a 90–95 % decrease in the C_2H_4 emission with no significant difference between them (Fig. 2). This result agree with those of QI et al. (1999) who reported low levels of C_2H_4 emission in 'Honeydew' cubes at 5 °C in air, which fell to near zero in CA.

Sensory evaluation

For all sensory parameters evaluated the influence of temperature and gas composition was significant, as was the interaction between these factors (Table 2), except in the aroma which was not influenced by the interaction temperature x gas composition. Fresh-cut melon pieces gradually lost aroma during storage although to a lesser extent under both CA. No off-flavour was detected in the melon pieces under CA. In fact, the high CO_2 could retard the development of the strange aromas associated with microbial growth (Table 4) in agreement with results of PORTELA and CANTWELL (1998).

The sensory quality of the control pieces had already deteriorated by day 7, although they were still considered marketable. However, by day 10, the quality was scored poor or unacceptable. There was no significant difference among quality attributes recorded at different times during CA storage (Table 2). In agreement with results from QI et al. (1999) and PORTELA and CANTWELL (1998), low O_2 combined with high CO_2, or high CO_2 alone, provided a better sensory quality to melon pieces than air. As regards overall quality changes, there were no significant difference between both CA, and melon pieces remained of marketable quality after 14 days (Table 2).

Physicochemical parameters

Firmness. Single factors like storage time and type of atmosphere (Table 2) influenced in the firmness changes. The melon pieces rapidly lost firmness during the first 7 days without significant difference among samples at days 7, 10 and 14. However, after 14 days of storage, the softening under CA of 3 kPa O_2 + 15 kPa CO_2, was 33 % compared to 41 % in air atmosphere. Storage in the CA of air + 15 kPa CO_2 had an intermediate effect; softening was 39 %. MADRID and CANTWELL (1993) found a lost firmness faster in air than under CA treatments when 'Cantaloupe' cylinders were stored at 15 °C. An atmosphere of 3 kPa O_2 + 15 kPa CO_2 was most effective in reducing softening than air + 15 kPa CO_2 during storage at 15 °C, although during storage at 7.5 °C no differences were found. Our findings in 'Amarillo' melon are partially disagree with this last result, because at 5 °C, 4 kPa O_2 + 15 kPa CO_2 was significantly better to prevent softness than 15 kPa CO_2 enriched air.

Table 4. Microbial counts (log_{10} cfu g^{-1}) changes on fresh-cut melon pieces at 5 °C up to 14 days.

Gas mixture	Mesophilic bacteria			
	Day 0	Day 7	Day 10	Day 14
Air	1.4[z]±0.1	2.2±0.4	4.3±0.3	4.7±0.4
Air + 15 kPa CO_2		1.6±0.2	1.7±0.1	2.4±0.3
4 kPa O_2 + 15 kPa CO_2		1.5±0.2	2.4±0.1	2.7±0.2
	Psychrotrophic bacteria			
Air	<1	2.2±0.2	4.1±0.5	6.6±0.4
Air + 15 kPa CO_2		<1	1.5±0.1	3.9±0.2
4 kPa O_2 + 15 kPa CO_2		<1	2.1±0.5	3.3±0.1
	Yeast			
Air	<2	<2	2.8±0.2	3.8±0.1
Air + 15 kPa CO_2		<2	<2	<2
4 kPa O_2 + 15 kPa CO_2		<2	<2	<2
	Mould			
Air	<2	<2	1.4±0.2	3.2±0.2
Air + 15 kPa CO_2		<2	<2	<2
4 kPa O_2 + 15 kPa CO_2		<2	<2	<2

[z]Mean values (n=5) ± S.E.

Colour. Juice colour parameters like L*, WI, chroma and °h (the last also measured in pulp), showed no significant difference between storage time and gas treatments (data not shown). However, L*, WI and chroma in pulp depended on storage time. Chroma also was influenced by the type of atmosphere (Table 2). All these values declined throughout storage, especially after day 10. Both CA treatments only inhibited the decrease of chroma in agreement to PORTELA and CANTWELL (1998) where the CA lessened the reduction in chroma in three of the four 'Honeydew' cultivars studied. A decrease of chroma values is commonly related to senescence symptoms. In fact the highest chroma values were well correlated to firmness and texture values (Table 2). The influence of CO_2 enriched atmospheres in keeping chroma values has been reported in flat peaches stored at 2 °C under 4 kPa O_2 + 15 kPa CO_2 (FERNÁNDEZ-TRUJILLO et al. 1998). No translucency was found in any treatment at any time due to the low sensitivity of 'Amarillo' melon to this disorder (AGUAYO et al. 2003).

TSS and individual sugars. Changes in TSS varied according to the kind of atmosphere (Table 3). Comparing to control, both CA treatments, and in a greater extent the combination of low O_2 and high CO_2, retarded the reduction of TSS due to the lower respiration rate and ethylene emission (Fig. 1 and 2), catabolic activity and degradative process (KADER 1986). The difference in these effects between storage in air and in air + 15 kPa CO_2 was only significant at the end of storage. Additionally at day 14, a significant reduction in sucrose level was found in air-stored fresh-cut melon (Table 3). However, the levels of fructose and glucose were higher than at harvest in agreement to results from LAMIKANRA et al. (2000) and PORTELA and CANTWELL (2001) in other melon cultivars. In our study, the monosaccharide levels increased to some extend, in particular in fresh-cut melon under CA, but with no significant differences among gas composition treatments. This increase of monosaccharide levels during cold storage was mostly explained by the hydrolysis of sucrose and the subsequent utilization of derived reducing sugar in fruit respiration. The decrease in sucrose content at the end of storage in air-stored melon pieces corresponds to the increase in rate of respiration (Fig. 1).

TA, pH and organic acids. At any time air-stored melon pieces showed lower pH and higher TA values than those CA stored. However, neither pH nor TA showed a regular tendency to increase or decrease when the storage time was extended (Table 3). QI et al. (1999) found that pH declined in 'Honeydew' cylinders, especially in air. The reasons for these variations in pH during short cold storage periods of fresh-cut products are still unknown (RATTANAPANONE et al. 2001). According to HOLCROFT and KADER (1999), CO_2 may play a role in decreasing cell pH in strawberry because of the dissociation of carbonic acid to bicarbonate and hydrogen ions. However, BUESCHER and ADAMS (1983) reported that CO_2 probably increases the pH by decreasing the malic acid content. Our results do not support either of these hypotheses since the malic acid concentration depended only on storage time and decreased during storage (Table 3). On the other hand, the decrease in citric acid concentration depended on the type of atmosphere. The decrease in TA under 4 kPa O2 + 15 kPa CO2 was probably due to an inhibition in glycolysis and a reduction in the formation of citrate (Table 3). Numerous studies support the finding that low O_2 and/or high CO_2 atmosphere can retard decomposition of organic acids in plant tissue. However, since the mechanism remains unclear, the results are varied and sometimes contradictory (WEICHMANN 1986; ZAGORY and KADER 1989; KE et al. 1993).The higher TA of the control would result from the citric acid concentration in the Krebs cycle being maintained at the expense of reduced sucrose and monosaccharide levels in glycolysis.

In agreement with results of LAMIKANRA et al. (2000), the main organic acids in melon were malic and citric, although these authors registered much lower concentrations in fresh-cut 'Cantaloupe' stored at 4 °C than those in our experiment (Table 3).

Microbial analysis

Bacterial growth in both CA was 2 $\log_{10}$ units lower than in air, while the difference between yeast and moulds was at least 1.2 and 1.8 $\log_{10}$ units, respectively (Table 4). These results agree with those of QI et al. (1999) in 'Honeydew', but contrast with the 6 $\log_{10}$ units reported by PORTELA et al. (1997) in 'Cantaloupe' cylinders under 3 kPa O_2 + 15 kPa CO_2.

Except in the fungus growth in CA, the microbial counts increased with time in all treatments, especially in control. Our results agree with results from CARLIN and NGUYEN-THE (1990) in fresh-cut carrot which showed that high CO_2, whether combined with low O_2 or not, reduced fungal, mesophilic and psychrotrophic growth. The use of both CA provided a shelf life of 14 days at 5 °C, while in fresh-cut melon kept in air the moulds count exceeded the Spanish legal limit of 3 $\log_{10}$ cfu g^{-1}.

Conclusions

CA of 4 kPa O_2 + 15 kPa CO_2 or air + 15 kPa CO_2 enabled minimal fresh processed trapezoidal pieces of 'Amarillo' melon to reach a shelf life of 14 d at 5 °C. Compared to air, both CA reduced the respiration rate (by 39–48 %), ethylene emission (by 90 %), softening, TSS consumption and microbial counts, leading to fruit pieces with a better sensory quality. The difference between favourable effects of both CA and air became greater as time elapsed, especially after day 10. There were no significant differences between both CA, except that 4 kPa O_2 + 15 kPa CO_2 retarded softening to a greater extent and led to a slightly greater reduction in the respiration rate. Consequently, that gas mixture should be considered when designing modified atmosphere packaging for fresh-cut trapezoidal pieces of 'Amarillo' melon.

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