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Keeping quality of fresh-cut tomato

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Abstract

The effects of calcium chloride washings and passive or active modified atmosphere packaging (MAP) on the keeping quality of fresh-cut tomato (*Lycopersicon esculentum* Mill., cv. Durinta) were investigated. Fresh-cut tomatoes were washed in chlorinated water (0.7 mM) with and without $CaCl_2$ (0.09 M). Slices were placed in plastic trays, sealed with perforated or non-polymeric films and stored at 2 and 10°C. Firmness, colour, visual quality, aroma, texture, defects and overall quality were determined at harvest and after 7 and 10 days of storage. Soluble solids content (SSC), pH and titratable acidity (TA) were analyzed and a maturity index was designed. The initial CO_2 production at 10°C was 120 nmol kg^{-1} s^{-1} while at 2°C it was $\sim$70 nmol kg^{-1} s^{-1} for both whole and tomato slices. During storage, at 10°C, CO_2 production for whole tomato declined to 80 nmol kg^{-1} s^{-1} whereas for tomato slices after 2 days a continuous increase up to 490 nmol kg^{-1} s^{-1} was observed. Ethylene production was maintained at between 6 and 24 pmol kg^{-1} s^{-1} for whole and tomato slices at 2°C. Ethylene production by tomato slices reached 120 pmol kg^{-1} s^{-1} after 2–4 days of storage at 10°C followed by a decrease to 12 pmol kg^{-1} s^{-1} after 7 days. In the passive MAP packages O_2 decreased to 14 and 2.5% and CO_2 increased to 6 and 20% on day 10 at 2 and 10°C, respectively. However, when active MAP was used (7.5% O_2 + 0% CO_2), O_2 decreased to 6 and 1.5% and CO_2 increased to 6 and 14% on day 10 at 2 and 10°C, respectively. After 10 days of storage, the quality attributes of tomato slices were maintained better at 2 than at 10°C. When slices were stored at 10°C, both passive and active MAP reduced the rate of ripening. The best results were found during storage at 2°C under active or passive MAP. Calcium chloride dips were useful only at 2°C in maintaining quality of tomato slices held in the perforated film. Active MAP should be used for maintaining fresh-cut tomato when stored at 10°C.

Keywords: Fresh-cut; *Lycopersicon esculentum* Mill.; Modified atmosphere packaging (MAP); Organoleptic attributes; Quality attributes; Respiration; Ethylene emission; Calcium chloride

1. Introduction

Extending the shelf life of fresh-cut products has been possible with many vegetables such as lettuce, carrot, celery, spinach, etc. However,

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fresh-cut fruits have a more complicated physiology since the stage of ripeness and ethylene production reduces shelf life (Cantwell, 1996; Gorny and Kader, 1996). Successful methods of maintaining quality of fresh-cut tomato could provide many commercial benefits. However, little information has been published on keeping quality of fresh-cut tomatoes.

Tomato slices are very susceptible to water loss leading to softening (Mencarelli and Saltveit, 1988). Aqueous calcium dips (0.5–2%) have been used to retain firmness of fresh-cut products, including pears (Rosen and Kader, 1989; Gorny et al., 1998), zucchini squash (Izumi and Watada, 1995) and melon disks (Lester, 1996). Calcium helps maintaining cell wall integrity and hence reduces the action of cell wall degrading enzymes and consequently fruit softening (Poovaiah, 1986). Moreover, modified atmosphere packaging (MAP) helps to extend the storage life of fresh-cut products by reducing water loss, metabolic activity (via limiting respiration), cut surface browning, microbial growth, and ethylene biosynthesis and action (Gorny, 1997). The objective of this study therefore, was to investigate the effects of calcium and reduced O_2 and high CO_2 levels on the keeping quality of fresh-cut tomato. The physiological response to light processing of the cultivar Durinta was also determined.

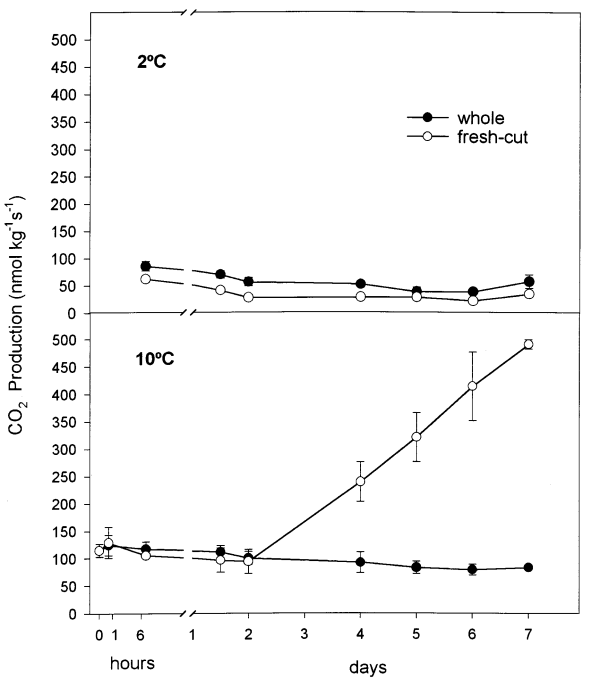

Fig. 1. Respiration rate of whole and fresh-cut 'Durinta' tomato at 2 and 10°C during the first hours after slicing and up to 7 days. Each point represents the mean of six whole fruits or six fresh-cut fruits. Vertical lines represent S.D.s.

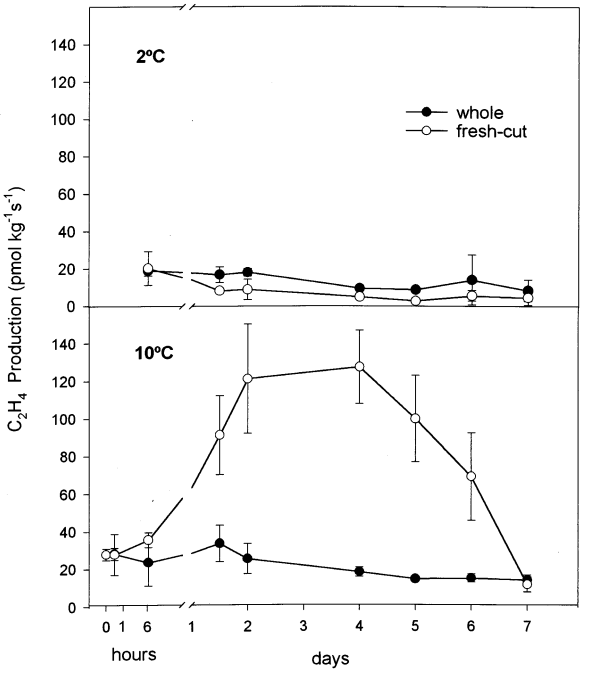

Fig. 2. C_2H_4 production of whole and fresh-cut 'Durinta' tomato at 2 and 10°C during the first hours after slicing and up to 7 days. Each point represents the mean of six whole fruits or six fresh-cut fruits. Vertical lines represent S.D.s.

2. Materials and methods

2.1. Plant material

'Durinta' tomato (*Lycopersicon esculentum* Mill.) is a slow ripening cultivar with a long storage life. Tomatoes grown in a greenhouse under Mediterranean climate conditions were obtained from a commercial grower in Mazarrón (Murcia), Spain. The experiments were conducted with partially ripe fruits, which were harvested

during the winter (from November to February). The maturity stage was 7–8 according to the Kleur-stadia (Holland) tomato colour chart. Medium sized fruit were chosen with a mean fruit mass of 70 ± 8 g, and equatorial and longitudinal dimensions of 33 ± 2 and 27 ± 1 cm, respectively. Immediately after picking, fruits were transported to the laboratory (45 km) where they were stored at 10 ± 0.5°C until the next day. Before processing, tomatoes were carefully selected to ensure that fruits were free of defects and of even appearance. The ripeness stage of whole fruit was based on assessing fruit firmness and surface colour in all fruits. Whole fruit firmness was measured on each fruit using a Lloyd instrument (model LR10K, Fareham, Hants, UK) equipped with two (12×18 cm) flat plates. This test measured firmness based on the resistance of the fruit to deformation. The maximum force required to deform the fruit surface 5 mm (at a speed of 10 mm/min), with the fruit lying transversally and the plate positioned on the fruit equatorial zone, was recorded. Results were expressed in Newtons (N) (Rocha et al., 1998) and fruits requiring ~ 20 N force were selected. The surface colour was determined on three equidistant points of the equatorial region for each individual fruit with a Minolta chromameter (model CR-300; Minolta, Ramsey, NY) and expressed as CIELAB Hue angle (h° = arctangent (b^*/a^*) which is a good indicator of ripeness (Shewfelt et al., 1988). Fruits with h° values between 65 and 75° were selected.

2.2. Respiration rate and ethylene production

Rates of CO_2 and C_2H_4 production were measured using a closed system (Kader, 1992). Two whole fruits and two cut in slices were placed in 690-ml gas-tight glass jars at 2 and 10°C; three replicates were used at both temperatures. The increase in CO_2 and C_2H_4 content in the headspace was measured after closing the jars for

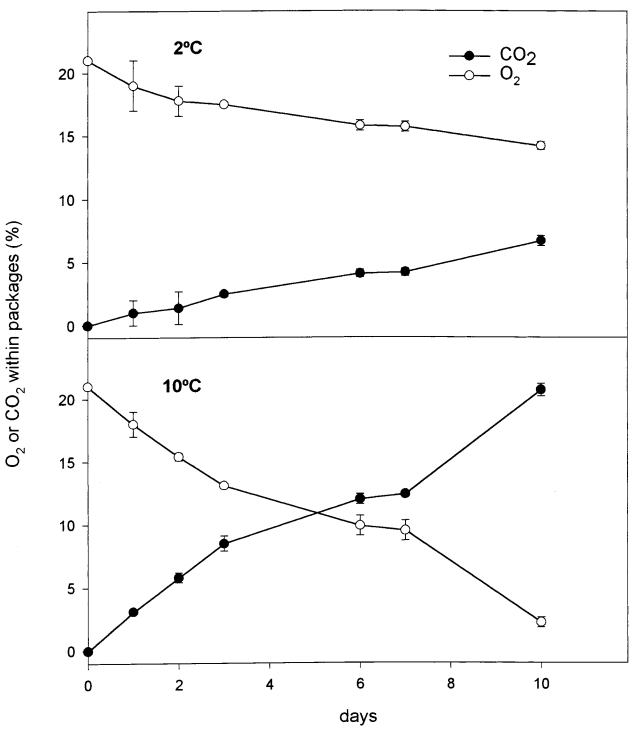

Fig. 3. Changes in O_2 and CO_2 in passive MAP-stored fresh-cut 'Durinta' tomato at 2 and 10°C for 10 days. Three replicates of six slices per package were used. Vertical lines represent S.D.s.

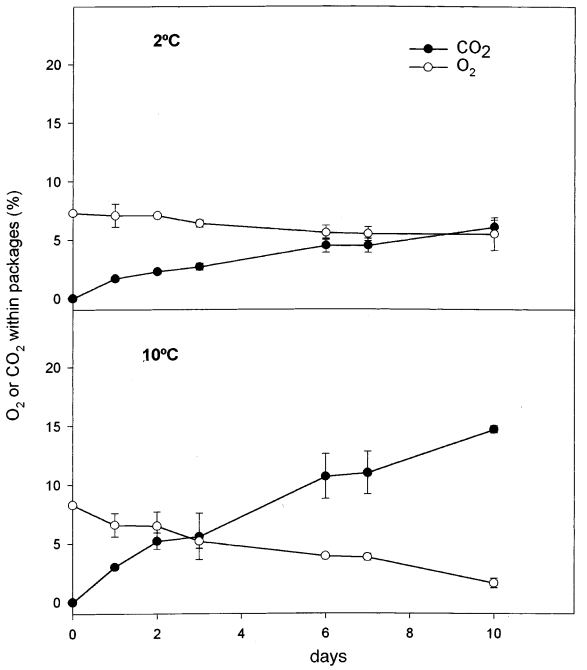

Fig. 4. Changes in O_2 and CO_2 in active MAP (7.5% O_2 + 0% CO_2)-stored fresh-cut 'Durinta' tomato at 2 and 10°C for 10 days. Three replicates of six slices per package were used. Vertical lines represent S.D.s.

60 min and then taking gas samples from the headspace. After each measurement, the jars were opened. Carbon dioxide concentrations were determined using a Perkin Elmer (CT, USA) autosystem gas chromatograph equipped with a thermal conductivity detector (TCD), and C_2H_4 was analyzed using a gas chromatograph (Hewlett Packard 5370 A, Hewlett Packard, Avondale, PA, USA) equipped with a flame ionization detector (FID). Samples were analyzed in triplicate and the fruit and slices monitored daily for 7 days.

2.3. Slice preparation

Whole fruits were dipped into chlorinated water (1.3 mM) for 1 min at 4°C and then blotted dry. A total of six slices (each 7 mm thick) were cut perpendicular to the long axis from the stem-end portion of the fruit with a commercial slicing machine (Jata, model Slim, Vizcaya, Spain). The two ends were discarded. One slice of each fruit was included in every treatment. Each replicate contained six slices and all data are the means of three replicates. Previous experiments determined the beneficial effect of sodium hypochlorite on the quality maintenance of tomato slices (Gil et al., 1999). Immediately after cutting, the slices were immersed into 2 l of chlorinated water (0.7 mM) for 1 min at 4°C. The chemical treatment consisted of adding calcium chloride (0.09 M) to the chlorinated water. Slices were drained and placed in a polypropylene tray (19.2 length × 13.7 width × 5.5 depth cm). Trays containing control and calcium-treated slices were heat-sealed (Barket, model Befor, Chassieu, France) with perforated polypropylene film (33 holes of 2 mm/dm^2 and 35-μm thickness; Borden, Alicante, Spain) to ensure an air atmosphere was within the packages. The physical treatments consisted of passive and active modified atmospheres. The trays for passive and active MAP were held in heat-sealed (Packer model IS/300H, Plásticos del Segura, Murcia, Spain) polymeric film bags (Vascolan, Vaessen Schoemaker Industrial, Barcelona, Spain). The film permeance at 23°C and 75% RH was $< 2.35 \times 10^{-14}$ mol s^{-1} m^{-2} Pa^{-1} for O_2 and $< 6.11 \times 10^{-14}$ mol s^{-1} m^{-2} Pa^{-1} for CO_2. Active modifications were carried out by flushing a gas mixture of 7.5%O_2 + 0% CO_2 balanced with N_2, in a gas exchange device with a vacuum packaging machine (Zermat, Carburos Metálicos, Madrid, Spain) and a mixing station (Witt-Gasetechnik, model KM 100-3 M, Carburos Metálicos, Madrid, Spain). Changes in concentrations of O_2 and CO_2 were monitored using a Perkin Elmer (CT, USA) autosystem gas chromatograph equipped with a thermal conductivity detector (TCD), after taking atmosphere samples through a septum. Sample processing and conditioning was conducted in an isolated and cleaned minimal processing room at 8°C.

2.4. Storage conditions and organoleptic evaluations

Temperatures of 2 and 10°C with 95% RH were selected, taking into consideration probable changes from shipping to retail sale and home

storage conditions. Samples were analyzed at the beginning of the experiments and after 7 and 10 days of storage. After equilibrium at room temperature, a panel of three trained judges evaluated visual quality. This was based on a nine-point scale (9 = excellent; 7 = very good; 5 = good, limit of marketability; 3 = fair, limit of usability; and 1 = poor, inedible; Gil et al., 1998). Aromas and off-odours were evaluated immediately and 5 min after the packages were opened. For aroma evaluation, a scale of 5 to 1 was used, where 5 = full characteristic, 3 = moderate and 1 = complete lack of characteristic aroma. Texture was evaluated by manual pressing based on a 5 to 1 scale where 5 = fresh, 3 = moderately fresh and 1 = soft. Defects such as water loss, discoloration, seed germination, translucency and cutting damage were scored as 1 = none, 3 = moderate, and 5 = severe. Finally, overall visual quality (all parameters and flavour) was evaluated using the above nine-point scale. Tomato slice firmness was determined on each slice using a Lloyd instrument (model LR10K, Fareham, Hants, UK) equipped with two (12 × 18 cm) flat plates. The maximum force required to deform the slice 0.4 mm at a speed of 4 mm/min, with the slice lying on the bottom plate, was recorded. A half slice of each replicate was liquefied in a commercial turmix

Table 1
Firmness and h° values of fresh-cut 'Durinta' tomato in air, with or without $CaCl_2$ (0.09 M), or in passive or active MAP, initially and after 7 and 10 days of storage at 2 and 10°C[a]

Temperature	Time	Treatments	Firmness (N)	h°
	Initial		75.0	77.3
2°C	7 days	Control	66.6	75.4
		$CaCl_2$ 1%	69.9	75.5
		Passive MAP	65.7	77.6
		Active MAP	71.0	76.6
	10 days	Control	59.0	78.9
		$CaCl_2$ 1%	53.1	77.9
		Passive MAP	58.5	81.6
		Active MAP	52.4	78.1
10°C	7 days	Control	57.2	66.8
		$CaCl_2$ 1%	59.4	64.2
		Passive MAP	62.5	66.3
		Active MAP	62.2	69.3
	10 days	Control	41.6	66.3
		$CaCl_2$ 1%	39.9	64.6
		Passive MAP	46.1	69.3
		Active MAP	47.0	69.0
	Temperature		(3.4)***	(0.9)***
	Time		(4.2)***	(1.1)***
	Treatment		NS	(1.3)**
	Temperature × Time		(5.9)*	(1.6)***
	Temperature × Treatment		NS	NS
	Time × Treatment		NS	NS
	Temperature × Time × Treatment		NS	NS

[a] Values are means (n = 18 slices). NS, not significant. L.S.D. values are in brackets.
* $P = 0.05$.
** $P = 0.01$.
*** $P = 0.001$.

Table 2
Soluble solids content (SSC), pH, titratable acidity (TA) and the maturity index (SSC/TA) of fresh-cut 'Durinta' tomato in air, with or without $CaCl_2$ (0.09 M), or in passive or active MAP, initially and after 7 and 10 storage days at 2 and 10°C[a]

Temperature	Time	Treatments	SSC (°Brix)	pH	TA (g citric acid/100 ml)	SSC/TA
	Initial		4.6	4.2	0.40	11.5
2°C	7 days	Control	4.6	4.1	0.37	12.4
		$CaCl_2$ 1%	4.4	4.0	0.38	11.6
		Passive MAP	4.4	4.1	0.36	12.2
		active MAP	4.4	4.1	0.36	12.2
	10 days	Control	4.3	4.2	0.33	13.0
		$CaCl_2$ 1%	4.3	4.0	0.36	11.9
		Passive MAP	4.3	4.1	0.33	13.0
		Active MAP	4.2	4.1	0.34	12.3
10°C	7 days	Control	4.1	4.3	0.26	15.8
		$CaCl_2$ 1%	3.9	4.3	0.23	16.9
		Passive MAP	4.0	4.4	0.23	17.4
		Active MAP	4.1	4.3	0.29	14.1
	10 days	Control	3.9	4.6	0.17	22.9
		$CaCl_2$ 1%	3.8	4.5	0.16	23.7
		Passive MAP	3.9	4.4	0.24	16.2
		Active MAP	4.1	4.3	0.26	15.8
	Temperature		(0.1)*	(0.1)*	(0.13)*	(0.02)*
	Time		(0.1)*	NS	(0.16)*	(0.03)*
	Treatment		NS	NS	(0.18)*	(0.04)*
	Temperature × Time		(0.1)*	(0.1)*	(0.22)*	(0.04)*
	Temperature × Treatment		NS	NS	(0.26)*	(0.05)*
	Time × Treatment		NS	NS	(0.31)*	(0.06)*
	Temperature × Time × Treatment		NS	NS	(0.44)*	(0.09)*

[a] Values are means ($n = 18$ slices). NS, not significant. L.S.D. values are in brackets.
* $P = 0.05$.

blender (Moulinex, Barcelona, Spain). Juice colour changes were monitored by measuring h° with a Minolta chromameter using a liquid sample holder (CR-A70) containing 35 ml of juice. The pH was measured and the titratable acidity (TA) determined by titrating juice samples with 0.1 mol/l NaOH (AOAC, 1984) and expressed as g of citric acid/100 ml. The soluble solids content (SSC) was measured with an Atago N1 refractometer (Tokyo, Japan) (refractometric reading at 20°C) and expressed in °Brix. The maturity index was expressed as the ratio of soluble solids content/titratable acidity (Artés et al., 1998).

The results were submitted to a factorial analysis of variance and the mean values compared using the least significant difference test (L.S.D.).

3. Results and discussion

3.1. Respiration rate and ethylene production

The effect of slicing resulted in an instantaneous but not significant rise in CO_2 production of whole and fresh-cut tomato at 10°C (Fig. 1). This increase was associated with the wound response (Mencarelli et al., 1989). No others peaks associated with the ripening process were observed. Partially ripe fruit was used in this study, whereas Mencarelli et al. (1989) used mature green tomatoes, which could explain the climateric stage reported. At 2°C, whole tomatoes had similar respiratory patterns to those of fresh-cut fruit. However, the respiration rate of fresh-cut tomatoes increased significantly after 2 days at

10°C (Fig. 1). This suggested that the higher temperature promoted deterioration and decay of the tissues (*Rhizopus* spp. colonies were observed after 6 days). The respiration rate of whole tomatoes at 2°C was half that at 10°C and no chilling injury disorders were observed after 7 days at either temperature. This similarity of whole and fresh-cut tomato respiration rates at low temperature has also been observed by Watada et al. (1996). The higher temperature increased respiration rates of fresh-cut tomato compared to whole fruit, probably in response to ethylene production following the start of decay (Fig. 1). Hong and Gross (1998) detected an increase in CO_2 and C_2H_4 production due to microbial growth on tomato slices from control fruit. However, slices from tomatoes treated with NaOCl prior to slicing showed no increase in CO_2 and C_2H_4 production.

There was little detectable C_2H_4 production at 2°C in whole and fresh-cut tomato and few differences were detected over the storage period (Fig. 2). On the other hand, storing tomato slices at 10°C caused the rate of C_2H_4 production to be 5-fold higher than that of whole fruit. This increase started immediately after cutting, rising to ~ 95–120 pmol kg^{-1} s^{-1} on day 1 and remaining quite constant until 4 days after storage, de-

Table 3
Visual quality, aroma, texture, defects and overall visual quality of fresh-cut 'Durinta' tomato in air, with or without $CaCl_2$ (0.09 M), or in passive or active MAP, initially and after 7 and 10 days of storage at 2 and 10°C[a]

Temperature	Time	Treatments	Visual quality	Aroma	Texture	Defects	Overall visual quality
	Initial		9.0	5.0	5.0	1.0	8.5
2°C	7 days	Control	8.2	3.5	5.0	1.0	7.8
		$CaCl_2$ 1%	8.2	3.3	5.0	1.0	7.8
		Passive MAP	8.5	4.7	5.0	1.0	8.2
		Active MAP	8.5	4.7	5.0	1.0	8.2
	10 days	Control	6.2	2.7	3.1	1.0	5.2
		$CaCl_2$ 1%	6.5	2.7	3.5	1.0	6.2
		Passive MAP	6.9	3.7	2.9	1.0	6.1
		Active MAP	7.0	3.7	3.4	1.0	6.2
10°C	7 days	Control	2.1	3.3	4.0	4.3	1.5
		$CaCl_2$ 1%	2.0	3.3	3.9	4.3	1.5
		Passive MAP	5.2	4.5	4.0	1.3	4.7
		Active MAP	6.0	4.5	4.1	1.3	5.3
	10 days	Control	1.0	1.7	1.0	4.8	1.0
		$CaCl_2$ 1%	1.0	1.9	1.0	4.8	1.0
		Passive MAP	4.2	3.0	2.8	3.5	3.5
		Active MAP	5.0	3.0	3.3	3.5	4.9
	Temperature		(0.2)***	(0.2)**	(0.1)***	(0.1)***	(0.2)***
	Time		(0.2)***	(0.3)***	(0.2)***	(0.1)***	(0.3)***
	Treatment		(0.2)***	(0.3)***	(0.2)***	(0.2)***	(0.3)***
	Temperature × Time		(0.3)***	(0.4)**	(0.3)***	(0.2)***	(0.4)***
	Temperature × Treatment		(0.3)***	NS	(0.3)***	(0.2)***	(0.5)***
	Time × Treatment		(0.4)***	(0.6)**	(0.4)***	(0.3)***	(0.6)***
	Temperature × Time × Treatment		(0.5)***	NS	(0.5)***	(0.4)***	(0.8)***

[a] Values are means ($n = 18$ slices). NS, not significant. L.S.D. values are in brackets.
** $P = 0.01$.
*** $P = 0.001$.

clining thereafter. This behaviour confirms the results described by Lee et al. and cited by Watada et al. (1990), where cutting tomato fruit into small disks caused ethylene production to increase substantially.

3.2. Atmosphere composition in MAP-stored tomato slices

A decrease in O_2 and an increase in CO_2 levels were detected for passive MAP at 2°C (final concentrations were 14% O_2 and 6.5% CO_2) (Fig. 3). Larger changes were observed on day 10 at 10°C and steady state conditions were not reached in the packages. When active MAP was applied at the starting point at 2°C, there was a slight consumption of O_2 during storage but there was not a clear indication that the steady state was reached after 6 days (Fig. 4). On the other hand, when active MAP was used at 10°C, consumption of O_2 and accumulation of CO_2 were observed over the whole storage period. At 2°C, active MAP did not reduce CO_2 production compared with that in samples under passive MAP, and the same CO_2 levels were reached during storage under both conditions. However, after 2 days at 10°C, active MAP reduced CO_2 production compared with passive MAP.

3.3. Firmness

Firmness was higher when slices were taken nearer the stem end and therefore a large variability was observed. Firmness of tomato slices was influenced by temperature and storage time ($P = 0.001$) (Table 1). A significant reduction in firmness was detected when samples were kept at 10°C compared with those stored at 2°C. In relation to the values detected after cutting (75 N), firmness decreased during storage at both temperatures. On the other hand, there was no effect on firmness retention from calcium dips, passive or active MAP. Slicing caused a slight softening in 'Durinta' tomato when compared with other fruits such as pears (Gorny et al., 1998) or kiwifruit (Varoquaux et al., 1990).

3.4. Colour

Temperature, time and treatment affected juice colour measured as h° (Table 1). The a^* value is good parameter for red colour development and the degree of ripening in tomato, while the b^* parameter shows yellow discoloration due to chilling injury (Escriche et al., 1993). Red colour development was enhanced by high temperature when comparing h° for the same treatments and times. These results are in agreement with those obtained for intermittently warmed tomato (Artés and Escriche, 1994). In general, 2°C maintained the colour close to that at the beginning of the experiment for all treatments. At 10°C, tomato slices under passive or active MAP did not advance in colour compared with the other treatments. The fastest rate of colour development occurred with calcium-treated slices at 10°C.

3.5. Chemical quality attributes

Higher SSC and TA contents have been reported for 'Daniela' tomatoes, another long life cultivar, than found in the 'Durinta' cultivar (Artés et al., 1998). A significant difference in SSC was observed at 2 and 10°C and for 7 and 10 days (Table 2). However, no significant differences were noted when comparing different treatments at both temperatures. An increase in pH was found with increasing temperature and time of storage. In addition, a significant reduction in TA was observed under all storage conditions, temperature, time and treatments, as well as their interactions (Table 2). Since the maturity index is a derived parameter based on SSC and TA, significant differences were found for temperatures, times and treatments. At 2°C, tomato slices did not continue to mature compared with samples kept at 10°C. After 10 days of storage at 10°C, the increase in maturity was very marked for both control and calcium-treated slices. However, passive or active MAP delayed the maturity development, particularly in tomato slices kept under active MAP.

3.6. Organoleptic evaluations

Significant differences in quality attributes were observed between temperatures, time and treatments (Table 3). Compared to 10°C, tomato slices kept at 2°C had better visual quality. When prolonging the storage time from 7 to 10 days, losses in visual quality and texture were enhanced for both temperatures. The aroma was moderate for most of the conditions assayed, except that control and calcium-treated samples stored at 10°C lost their characteristic aroma. The temperature of 2°C did not induce any defects and was considered the best to maintain the overall visual quality, except for control samples that showed the lowest quality. Compared to those at 2°C, slices at 10°C showed significant differences as regards the loss of visual quality, aroma and texture, and increase in defects (Table 3). Control and calcium-treated samples were inedible after 10 days at 10°C and a dehydrated appearance was the most important defect. The reduced O_2 and elevated CO_2 levels reached under MAP-stored tomato slices at 10°C did not confer off-flavours or any taste of fermentation. Active MAP showed the best results with regard to the quality attributes at 10°C.

Fluid accumulation and moisture condensation were of concern in the quality of fresh-cut tomato. Thus, the use of a water-absorbent packet in the tray is recommended as in fresh-cut honeydew melon (Bai and Watada, 1998). No injuries from chilling or high CO_2 levels at either temperature were observed.

4. Conclusion

Shelf life of tomato slices could be maintained for 10 days at 2°C. The best treatments for preserving quality were MAP (without significant differences between active and passive) followed by calcium dips. During 7 or 10 days of shelf life, quality attributes became lower when samples were kept at 10°C than when kept at 2°C. During storage at 10°C, poor quality was found for control and calcium-treated slices, and therefore the active MAP technique must be recommended.

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