Effect of the perforation level of recycled-LDPE bags on the modification of the atmosphere development, bioactive compounds content, and other qualities of Jalapeño peppers during storage

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Revised: 23 January 2015 / Accepted: 30 January 2015 / Published online: 11 February 2015
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Abstract The impact of modified atmosphere packaging on the content of selected bioactive compounds and other quality attributes of Jalapeño peppers has not been well studied. In this study, Jalapeño peppers were packed in low-cost bags (composed of recycled-LDPE) that had been perforated at several levels (0–4 holes). Packages were stored at 7 °C for 6 weeks. Samples of unpacked peppers were stored at 23 and 7 °C and were used as control groups. The quality of the peppers and the gas composition inside of the packages were evaluated during storage. The best modified atmosphere was obtained with unperforated bags. Significant loss of weight and firmness were prevented by packaging. The loss of weight

and firmness were 20.2–82.6 and 32–100 % in unpacked peppers. Low levels of fermentative metabolites accumulated in packed peppers in unperforated bags and in bags with 1 perforation. The tristimulus color and the bioactive compounds content (phenols, ascorbic acid, β -carotene, and capsaicinoids) remained unchanged in packed peppers. These quality attributes changed gradually in peppers that were stored at 23 °C. The tested bags represent a cost-effective alternative to preserve the quality of intact Jalapeño peppers.

Keywords Modified Atmosphere Packaging · Postharvest storage · Nutritional value · *Capsicum annuum* · Antioxidants

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Introduction

In México, peppers are a traditional element of cultural identity and an important source of income. The cultivar Jalapeño is one of the most cultivated and consumed pepper genotypes (Ornelas-Paz et al. 2010; Alvarez-Parrilla et al. 2012). This pepper type is a rich source of many bioactive compounds that are involved in the maintenance of human health, such as vitamin C, phenolic compounds, capsaicinoids, and carotenoids (Krajewska and Powers 1987; Mejia et al. 1988; Lee et al. 1995; Wall et al. 2001; Ruiz-Cruz et al. 2010). Vitamin C prevents allergies, reduces the levels of circulating proinflammatory cytokines, modulates gene expression and cell cycle progression, and prevents some forms of cancer and

neurological (Alzheimer, Parkinson, Huntington and cerebral ischemia) and cardiovascular diseases (Traber and Stevens 2011). Phenolic compounds act against coronary heart disease, stroke, and some forms of cancer (Yahia et al. 2011). Capsaicinoids exert hypolipidemic, hypocholesterolemic, antilithogenic, anti-inflammatory, anti-tumor, and anti-teratogenic activities (Srinivasan 2005). Carotenoids prevent cardiovascular diseases and some forms of cancer (Yahia and Ornelas-Paz 2010). Extracts from Jalapeño peppers exert high antioxidant activity (Alvarez-Parrilla et al. 2012).

The contents of several bioactive compounds in Jalapeño peppers have been determined as a function of maturity, genotype, agronomical practices, and processing technology or style (Howard et al. 1994; Johnson and Decoteau 1996; Howard et al. 2000; Wall et al. 2001; Ornelas-Paz et al. 2010, 2013; Alvarez-Parrilla et al. 2012). However, little attention has been paid to the effect of the storage conditions on the content of these compounds in intact Jalapeño peppers, most likely because for many years the need to store this pepper cultivar was low. Currently, the demand for intact pungent peppers has increased dramatically world-wide and these peppers are no longer considered a minor crop in the global market (Niu et al. 2010). Therefore, storage technologies and facilities for these vegetables are necessary. However, Jalapeño peppers have a short postharvest life and a reduced commercial value in the unprocessed form that limits transportation to distant markets (Ornelas-Paz et al. 2012). Modified Atmosphere Packaging (MAP) has been helpful in maintaining the quality and extending the postharvest life of some pepper genotypes with high commercial value, such as Bell peppers (Manolopoulou et al. 2010). In peppers, MAP slows changes in color and firmness, reduces the incidence of chilling injury and the loss of nutrients/bioactive compounds and water, and inhibits the microbial growth (Meir et al. 1995; González-Aguilar et al. 2004; Koide and Shi 2007). However, the films that are traditionally used for MAP are patented and generally too costly to be used for horticultural commodities with a low commercial value, such as Jalapeño peppers (González-Aguilar et al. 2004). Macro perforated bags have been helpful to preserve some cultivars of Jalapeño peppers by diminishing water loss during storage (Lownds et al. 1994). Postharvest water loss causes many deteriorative processes in peppers (Kissinger et al. 2005). Macro perforations reduce the possibility of the formation of inadequate atmospheres inside of the package, which can cause the accumulation of fermentative metabolites (ethanol and acetaldehyde), decay, off odors and other negative effects (Imahori et al. 2002). Recently, Jalapeño peppers were preserved by MAP using a cost-effective packaging film, but the developed atmospheres were not optimal, according to the literature, and only a few bioactive compounds were monitored during the storage interval (Ornelas-Paz et al. 2012). The aim of this work was to test the effect of the macro perforation level of such packaging material on the passive development

of the modified atmosphere and the postharvest quality of Jalapeño peppers during storage, emphasizing the content of selected bioactive compounds in this fruit.

Materials and methods

Materials

The films that were used as packaging material were generated from recycled low-density polyethylene (RLDPE) (thickness=35.2 μm , $P_{\text{O}_2/23^\circ\text{C}}=1.34\times 10^{-15}\text{ mol / m s Pa}$, $P_{\text{CO}_2/23^\circ\text{C}}=3.15\times 10^{-15}\text{ mol / m s Pa}$ and $P_{\text{H}_2\text{O}/23^\circ\text{C}}=87.4\times 10^{-15}\text{ mol / m s Pa}$) and were provided by a local factory in Chihuahua, México. The bags were transparent. Freshly harvested Jalapeño peppers were obtained from a local market in Chihuahua, México. Chemicals were purchased from Sigma-Aldrich (St. Louis, MO, USA) and J.T. Baker (Mallinckrodt-Baker Inc., México), unless stated otherwise.

MAP of the peppers

Bags (14.5×33 cm) were constructed from the generated films and were then perforated at several levels (0, 1, 2, 3, and 4 holes of 2 mm in diameter). Green Jalapeño peppers were washed with tap water and dried using paper towels. Only fruits that were free of blemishes and defects were included in the study. Peppers were divided into 129 samples, each weighing 500 g. Three samples were immediately evaluated for quality. Ninety samples were packed in the constructed bags (18 samples for each perforation level) and then stored at 7 °C for 6 weeks. Samples of unpacked peppers were also stored at 7 °C (18 samples) and 23 °C (18 samples) to be used as control groups. Three samples from each experimental group were removed weekly from storage and evaluated for quality (tristimulus color, firmness, weight loss, fermentative metabolites, total phenols, vitamin C and capsaicinoids). The β -carotene content of the peppers was determined every two weeks. The levels of O_2 and CO_2 inside the packages were also monitored weekly through a single-use septum (PBI-Dansensor A/S, Ringsted, Denmark) by an O_2/CO_2 analyzer (Model 2825; Bacharach, Inc., New Kensington, PA, USA).

Tristimulus color

Two measurements were obtained from two opposite sides of the surface of 15 fruits using a Minolta colorimeter (Minolta, Co. Ltd., Osaka, Japan). The L^* , a^* and b^* values were recorded.

Firmness

The firmness of the pericarps of 15 fruits was determined using a TA-XT2i texture analyzer (Stable Micro Systems Ltd; Godalming, UK). This apparatus was equipped with a 6 mm diameter, stainless steel striker pin, which punctured half of the pericarp thickness at a rate of 10 mm / s. Two measurements were obtained from opposite sides of each fruit, recording the maximum force (in Newtons) that was needed to puncture the fruit.

Weight loss

The weight of 5 peppers from each sample was determined at the beginning of the experiment and at each sampling time. Weight loss was determined gravimetrically. Fifteen independent measurements were obtained for each experimental group at each sampling time.

Fermentative metabolites

Triplicate pepper samples (10 fruits each) were individually homogenized to a puree in a kitchen blender, and the fermentative metabolites, total phenols, vitamin C, capsaicinoids, and β -carotene were analyzed in the purees. The ethanol and acetaldehyde contents in the peppers were determined by gas chromatography. Puree aliquots (10 g) were immediately homogenized with 0.1 M HCl (25 mL), and then 5 mL of the mixture were transferred into 20 mL gas-tight tubes, which were kept on a metal-block thermostat at 65 °C for 15 min. A 20 μ L sample of the head space gas was removed with a syringe and injected into a gas chromatograph (Model Varian 3800; Varian Inc., Walnut Creek, CA, USA) that was equipped with a flame ionization detector (FID) and a Chrompack Haysep Q column (1.8 m $\times$ 2 mm). Helium was used as the gas carrier (30 mL / min), and the oven, injector, and detector temperatures were 120, 110, and, 160 °C, respectively. Quantitative data were obtained by calibration curves that were constructed using three independent sets of dilutions of standard compounds.

Determination of the total phenolic content

Samples of pureed peppers (1 g) were homogenized in 80 % methanol containing 0.5 % sodium bisulfite (10 mL) and were then sonicated and centrifuged at 13000 $\times$ g for 7 min at 5 °C. Aliquots (0.1 mL) of the extract were mixed with 0.5 mL of 50 % Folin-Ciocalteu reagent and 7.9 mL of deionized water. After the reaction solution had been incubated at room temperature for 10 min, 1.5 mL of 20 % sodium carbonate solution were added. The mixture was incubated at room temperature for 60 min. The absorbance of the solution was determined at λ =750 nm using a 6405 Jenway UV/Vis

spectrophotometer (Jenway Ltd., Essex, UK). Gallic acid was used as the standard reference. Total phenolic content was expressed as μ g gallic acid equivalents per g fresh pepper (μ g GAE / g).

Vitamin C analysis

Aliquots of the pureed peppers (4 g) were homogenized in 4 % metaphosphoric acid (15 mL). The mixture was sonicated and centrifuged as described above for the determination of the total phenolic content. The extract was filtered through a polyethylene membrane with a pore size of 0.45 μ m (Millipore Corp., Bedford, MA, USA) and manually injected (20 μ L) into a HPLC system (Varian Inc., Walnut Creek, CA, USA), which was composed of a ternary pump (Solvent Delivery System Model 9012) and a UV/Vis detector (Model 9050). AA was monitored at λ =254 nm. The chromatographic system included a μ Bondapack C₁₈ (3.9 $\times$ 300 mm, 10 μ m) reversed-phase column (Waters Corp., Milford, MA, USA) that was kept at 25 °C. The mobile phase (isocratic system) was composed of 0.2 M KH₂PO₄, adjusted to a final pH value of 2.3 with 85 % *o*-phosphoric acid. The flow rate of the mobile phase was 1 mL / min. The AA quantification was performed using calibration curves that were constructed using three independent sets of dilutions of pure AA.

Capsaicinoids analysis

Pepper puree (5 g) was homogenized in methanol (25 mL). The mixture was sonicated and centrifuged as described above for total phenols. The extract was filtered and manually injected (20 μ L) into the HPLC system described above. Capsaicinoids were monitored at λ =236 nm. The chromatographic system included a Supelcosil LC-18 (4.6 $\times$ 250 mm, 5 μ m) reversed-phase column (Supelco, Bellefonte, PA, USA) that was kept at 25 °C. The mobile phase (isocratic system) was composed of water (containing 1 % of acetic acid) and acetonitrile (50:50, v/v). The flow rate of the mobile phase was 1 mL / min. Quantification of capsaicin and dihydrocapsaicin was carried out by calibration curves, which were constructed by three independent sets of dilutions of pure capsaicinoids.

β -Carotene analysis

Aliquots of pureed peppers (4 g) were homogenized in calcium carbonate (0.2 g) and methanol (15 mL). The homogenate was filtered through a Whatman paper No. 3, adding methanol until the retained solids became colorless. The methanolic extract was mixed with 50 mL of a mixture of hexane: acetone (1:1, v/v) containing 0.1 % of BHT. After vigorous stirring, 40 mL of 10 % sodium sulfate was added for phase separation. The upper layer was separated, washed several times with

water, and evaporated in a rotavapor at 35 °C. The residue was dissolved in methanol (5 mL) and manually injected (20 µL) into the HPLC system described above. The chromatographic system included an YMC C₃₀ reversed-phase column (4.6×150 mm; 3 µm) (YMC Inc., Wilmington, NC, USA). β-Carotene was monitored at λ=452 nm. A mixture of *tert*-butyl methyl ether and methanol (33:67, v/v) was used as mobile phase (isocratic system) at a flow rate of 1 mL / min. Quantification of β-carotene was carried out by calibration curves constructed by three independent sets of dilutions of pure β-carotene.

Statistical analysis

The data were analyzed using a completely randomized design. The statistical significance of the differences between treatments was determined using ANOVA followed by the Tukey-Kramer post hoc test; 0.05 was the significance limit. The data analysis was performed using JMP statistical software (SAS Institute Inc., Cary, NC, USA).

Results and discussion

In-package atmosphere

The CO₂ levels inside of the packages with 0, 1, and 2 perforations tended to increase with the storage time (Fig. 1a). However, the accumulation of CO₂ was statistically higher only for the unperforated packages and packages with 1 perforation. The CO₂ levels inside of the unperforated packages between the first and last week of storage (3.7–5.7 kPa) were very similar to those obtained recently (4–6 kPa) using the same film as packaging material (Ornelas-Paz et al. 2012). The levels of CO₂ inside of the packages with 1 and 2 perforations (0.4–2.3 kPa) were in the recommended range (0–5 kPa) for peppers (Beaudry 1999; Saltveit 2003). The O₂ levels only were significantly reduced in the unperforated packages (1.0–4.1 kPa after 1 week of storage) (Fig. 1b) and were slightly lower than those previously obtained (2–7 kPa) using the same film as packaging material (Ornelas-Paz et al. 2012). These O₂ levels were also lower than those typically recommended (3–5 kPa O₂) for peppers (Beaudry 1999; Saltveit 2003). Low O₂ and high CO₂ levels cause the beneficial effects of MAP. In general, the O₂ and CO₂ levels inside of the unperforated packages and packages with 1 perforation were similar to those reported for pepper packages constructed with patented films (González-Aguilar and Tiznado 1993; González-Aguilar et al. 2004). Our study demonstrates that films composed of recycled polymers can be successfully used as packaging material to preserve Jalapeño peppers by modified atmospheres.

Fig. 1 CO₂ (a) and O₂ (b) concentrations inside of the packages of peppers during postharvest storage. Values represent the mean of 3 individual measurements±the standard error. C-23 °C: Unpacked peppers stored at 23 °C; C-7 °C: Unpacked peppers stored at 7 °C; 4P-7 °C: Peppers packed in bags with 4 perforations and stored at 7 °C; 3P-7 °C: Peppers packed in bags with 3 perforations and stored at 7 °C; 2P-7 °C: Peppers packed in bags with 2 perforations and stored at 7 °C; 1P-7 °C: Peppers packed in bags with 1 perforation and stored at 7 °C; 0P-7 °C: Peppers packed in unperforated bags and stored at 7 °C

Effect of MAP on tristimulus color

The tristimulus color of the peppers was not affected by MAP (Fig. 2a, b, and c). In contrast, the storage temperature highly influenced the a* and b* values (Fig. 2b and c). At 23 °C, the a* values increased during the first four weeks of storage and then remained constant during the rest of storage. In these peppers, the b* values increased during the first three weeks of storage and then decreased (Fig. 2c). The green color of the unpacked peppers began to change during the second week of storage at 23 °C, gradually developing a red color as the storage time increased. Similarly, Gómez-Ladrón de Guevara and Pardo-González (1996) observed large increases in a* values during the change from the green stage of ripening to the reddish stage, followed by a constant interval during the rest of the ripening process (red stages) in 13 pepper genotypes. They also observed a descending pattern of the b* values during the last stages of ripening of peppers (Gómez-Ladrón de Guevara and Pardo-González 1996). The red color in

peppers is caused by the concomitant biosynthesis of some carotenoids during ripening (Hornero-Méndez et al. 2000). The yellow-carotenoids fraction (zeaxanthin, violaxanthin, antheraxanthin, β -cryptoxanthin, and β -carotene) diminishes while the red-carotenoids fraction increases (capsanthin, capsanthin 5.6-epoxide, and capsorubin) during ripening, with the yellow-carotenoids acting as precursors to the red-carotenoids (Hornero-Méndez et al. 2000; Deli et al. 2001).

Fig. 2 Changes of L* (a), a* (b) and b* (c) values (tristimulus color) in Jalapeño peppers during postharvest storage. The values represent the means of 60 individual measurements $\pm$ the standard error. See Fig. 1 for the treatment assignments

In our study, minor changes in color were observed in refrigerated peppers (Fig. 2a, b, and c), as was reported by Manolopoulou et al. (2010). The perforation level did not affect the tristimulus color of the peppers (Fig. 2a, b, and c). Similarly, Kosson (2003) did not find color differences between peppers without packaging and peppers maintained in unperforated bags and perforated bags in refrigeration. Carotenoids biosynthesis in fruits and vegetables, including peppers, is reduced or inhibited by refrigeration (Yahia and Ornelas-Paz 2010). On the other hand, chlorophyllase is only active at temperatures from 10 to 75 °C; therefore, we infer that the activity of chlorophyll-degrading enzymes was low or nonexistent in refrigerated peppers, favoring the stability of the green color (Arkus et al. 2005). Some studies have demonstrated that chlorophyll fluorescence (Fv/Fm) shows minimal changes in unpacked and packed (unperforated and perforated bags) peppers during refrigerated storage (Kosson 2003).

Effect of MAP on pepper firmness

Peppers that had been stored under refrigeration were statistically more firm than those that were maintained at 23 °C (Fig. 3). Similarly, González et al. (2005) demonstrated that the postharvest softening of peppers is slowed by refrigeration. Lownds et al. (1994) demonstrated that the flaccidity increased in nine pepper cultivars as the storage temperature increased (8–20 °C). On the other hand, the firmness of the packed peppers was significantly higher than that of the unpacked peppers (Fig. 3), which agreed with previous studies (Ornelas-Paz et al. 2012). In this work, the pepper firmness was independent of the perforation level (Fig. 3). Meir et al. (1995) demonstrated that the firmness of peppers that had been maintained in bags perforated at several levels (0–72

Fig. 3 Firmness of Jalapeño peppers during postharvest storage. The values represent the means of 60 individual measurements $\pm$ the standard error. See Fig. 1 for the treatment assignments

holes of 6 mm in diameter) was similar during storage at 7.5 °C. Interestingly, firmness loss was highly correlated with weight loss ($r=-0.93-0.98$). Therefore, we infer that firmness preservation is modulated mainly by postharvest weight loss, which depends on storage temperature rather than the O_2/CO_2 levels inside of the packages. In general, the firmness of the packed peppers during storage followed a trend similar to that reported for peppers packed within patented polyethylene films (Howard and Hernández-Brenes 1998; González-Aguilar et al. 2004).

Effect of MAP on the postharvest weight loss

The weight loss increased continuously for the unpacked peppers as the storage time advanced (Fig. 4). The final weight losses for the unpacked peppers were 82.6 % and 20.2 % at 23 °C and 7 °C, respectively. In contrast, the weight loss for the packed peppers was below 3 % by the end of storage (Fig. 4). MAP diminished the weight loss between 6 and 26 times, compared with the control groups. Lownds et al. (1994) demonstrated that packaging with perforated bags (20 holes of 1 mm in diameter) reduced the postharvest weight loss by up to 20 times in several pepper genotypes. Unperforated bags composed of RLDPE and varying in thickness reduced the weight loss in Jalapeño peppers up to 37 times (Ornelas-Paz et al. 2012). In our study, the weight losses were independent of the perforation level (Fig. 4). Similarly, Meir et al. (1995) demonstrated that the weight loss was similar in peppers that have been packed in bags perforated at several levels and stored at 7.5 °C. The surface area: volume ratio and the epicuticular wax quantity of the pepper fruits were linked to the rate of postharvest water loss; however, other factors could be involved in this phenomenon (e.g., initial water content, surface area, surface morphology, and fruit weight) (Kissinger

Fig. 4 Weight loss of Jalapeño peppers during refrigerated storage. The values represent the means of 15 individual measurements $\pm$ the standard error. See Fig. 1 for the treatment assignments

et al. 2005). In our study, the increases in weight loss were highly correlated with softening.

Accumulation of fermentative metabolites

Ethanol was detected only in the peppers packed in unperforated bags and bags with 1 perforation (Fig. 5a). The ethanol content in the peppers that had been packed in unperforated bags was significantly higher than that of the peppers packed with bags with 1 perforation. The maximum ethanol content (187.4 nL / g) was detected in peppers packed in unperforated bags at the fifth week of storage. The acetaldehyde content increased in peppers that had been packed in unperforated bags, but decreased during last week of storage (Fig. 5b). The acetaldehyde levels were similar in peppers from the other treatments. The highest content of acetaldehyde (42.0 nL / g) was also detected in peppers packed in unperforated bags at the fifth week of storage. In general, the maximum levels of ethanol and acetaldehyde in the tested peppers were low. Similarly, Imahori et al. (2002) demonstrated that the ethanol and acetaldehyde levels in intact

Fig. 5 Accumulation of ethanol (a) and acetaldehyde (b) (fermentative metabolites) in Jalapeño peppers during postharvest storage. The values represent the means of 15 individual measurements $\pm$ the standard error. See Fig. 1 for the treatment assignments

peppers remained very low under a 1 kPa O₂ atmosphere. Luo and Miktself (1996) did not detect ethanol in green Bell peppers that had been stored at low O₂ levels for 4 weeks. The levels of ethanol and acetaldehyde that were found in this study were considerably lower than those reported for Bell peppers that had been packed in patented bags composed of LDPE and Saran (González-Aguilar et al. 2004).

Effect of MAP on the bioactive compounds content

A few studies have addressed the effects of preservation technologies on the composition of bioactive compounds in

Fig. 6 Content of total phenols (a), ascorbic acid (b), and β -carotene (c) in Jalapeño peppers during postharvest storage. The values represent the means of 9 individual measurements $\pm$ the standard error. See Fig. 1 for the treatment assignments

pepper genotypes with low commercial value (Ruiz-Cruz et al. 2010; Ornelas-Paz et al. 2012). In this study, the initial content of total phenols in the peppers was 844.9 $\mu\text{g GAE/g}$ (Fig. 6a), which is in the range (200–7820 $\mu\text{g/g}$) reported for Mexican peppers (Lee et al. 1995; Howard et al. 2000). The content of these compounds increased until the fifth week of storage in the unpacked peppers that had been stored at 23 °C, and then, the content decreased (Fig. 6a). The maximum concentration of total phenols in this experimental group was 2595.2 $\mu\text{g GAE/g}$. The phenolic content was not significantly altered by storage time in the refrigerated peppers (Fig. 6a). Similarly, MAP of fresh-cut Jalapeño peppers (using patented LDPE bags) prevented changes in the phenolic content during refrigerated storage for 4 weeks (Ruiz-Cruz et al. 2010). These differences between the refrigerated and unrefrigerated experimental groups could be linked to dehydration and ripening, based on the observed changes in color, firmness, and weight loss during storage (Fig. 2, 3 and 4). Chuah et al. (2008) found that the phenolic content was higher in green peppers than in yellow or red peppers. On the other hand, the increase in the

Fig. 7 Content of capsaicin (a) and dihydrocapsaicin (b) in Jalapeño peppers during postharvest storage. The values represent the means of 9 individual measurements $\pm$ the standard error. See Fig. 1 for the treatment assignments

phenolic content of peppers after heat processing has been linked to dehydration (Ornelas-Paz et al. 2010).

Peppers are also a good source of AA (vitamin C) (Ornelas-Paz et al. 2013). In the present work, the initial AA content in the peppers was 444.9 $\mu\text{g/g}$ (Fig. 6b), which is similar to the AA content that was previously reported for Jalapeño peppers (Ornelas-Paz et al. 2012). The initial AA content was also similar to that of Jalapeño peppers *cv.* Mitla (489 $\mu\text{g/g}$) and is in the reported range for Mexican peppers (306 and 3438 $\mu\text{g/g}$) (Lee et al. 1995; Ornelas-Paz et al. 2013). The AA content increased continuously in the unpacked peppers that had been stored at 23 °C (Fig. 6b), reaching a content of 3098.4 $\mu\text{g/g}$ by the end of storage. We infer that this increase was caused by postharvest dehydration and ripening. Ornelas-Paz et al. (2013) demonstrated that the content of AA in Jalapeño peppers depended on the ripening stage, with a lower AA content in the green stage than in the red stage. Similar findings were reported by others (Howard et al. 2000). The higher levels of AA found at advanced stages of ripening might be related to increased levels of glucose, which is the precursor of AA (Chuah et al. 2008). In our work, the AA content was similar in all experimental groups that had been refrigerated and was independent of MAP (Fig. 6b). Similarly, Pankotai et al. (2007) demonstrated that the vitamin C contents in unpacked and packed (unperforated and perforated bags) peppers were similar during refrigerated storage. Koide and Shi (2007) reported only minor changes in AA content in intact green peppers that had been packed in several films (polylactic acid and LDPE films) and refrigerated. Similar findings have been reported for fresh-cut Bell peppers stored in MAP and refrigeration (González-Aguilar et al. 2004).

The initial β -carotene content in the peppers was 2.9 $\mu\text{g/g}$ (Fig. 6c), which is similar to the β -carotene content reported previously (2.1 $\mu\text{g/g}$) for the same pepper genotype (Ornelas-Paz et al. 2013). Similar values (3–5 $\mu\text{g/g}$) have been reported for green Jalapeño peppers by others (Mejia et al. 1988; Wall et al. 2001). These values are also in the typical range reported (0.11–166 $\mu\text{g/g}$) for both pungent and non-pungent peppers (Wall et al. 2001; Matsufuji et al. 2007). In our study, the β -carotene content increased almost 15-fold during the storage in the peppers that had been maintained at 23 °C (Fig. 6c). Because these peppers developed a red color during storage, we infer that such increment should be caused by the ripening process or postharvest weight loss (dehydration). Some studies have demonstrated that the β -carotene content in peppers is higher at the red stage of ripening than at the green or yellow stages (Matsufuji et al. 2007; Ornelas-Paz et al. 2013). Recently, Ornelas-Paz et al. (2013) observed increases in β -carotene content in heat-treated green Jalapeño peppers and other green peppers, and these increases were attributed to the weight loss during processing. The β -carotene content was not altered in unpacked and packed peppers that had been maintained in refrigeration (Fig. 6c), as

reported previously for several fruits (Yahia and Ornelas-Paz 2010). Some studies have demonstrated that MAP alters the postharvest content of carotenoids in Jalapeño peppers; however, our work showed that the differences in the O_2/CO_2 levels inside of the bags at different perforation levels were insufficient to detect variations in the β -carotene content of peppers (Howard and Hernández-Brenes 1998).

The initial contents of capsaicin (Fig. 7a) and dihydrocapsaicin (Fig. 7b) were 110.7 $\mu\text{g/g}$ and 37.4 $\mu\text{g/g}$, respectively. This capsaicin content was similar to that reported for Jalapeño peppers (145.9–204.2 $\mu\text{g/g}$) in previous studies (Krajewska and Powers 1987; Ornelas-Paz et al. 2010). However, the initial content of dihydrocapsaicin was lower than that typically reported for this pepper genotype (123.6–165.2 $\mu\text{g/g}$) (Krajewska and Powers 1987; Ornelas-Paz et al. 2010). The capsaicin content was higher than that of dihydrocapsaicin (Fig. 7a and b), as reported for the dried raw-fruits of other Mexican pepper genotypes (Krajewska and Powers 1987; Cisneros-Pineda et al. 2007).

The capsaicin and dihydrocapsaicin contents were affected by storage temperature but not by MAP (Fig. 7a and b). The capsaicinoid content was significantly higher in the peppers that had been stored at 23 °C. In these peppers, the capsaicinoid content increased gradually during storage and remained virtually unchanged in refrigerated peppers (Fig. 7a and b). Similarly, the capsaicinoid content in packed (perforated polyethylene bags) Habanero peppers was stable during refrigerated storage, but such content increased continuously during a post-storage period of 15 days at 22 °C (González et al. 2005). The increasing content of capsaicinoids in peppers maintained at 23 °C could be attributed to the ripening and dehydration processes that occurred during storage. Several studies have demonstrated that the capsaicinoid content is higher in ripe than in unripe peppers (Cisneros-Pineda et al. 2007; Ornelas-Paz et al. 2010). The dehydration of peppers has been slightly linked to capsaicinoid increase (Ornelas-Paz et al. 2010).

Conclusions

Unperforated bags and bags with 1 and 2 perforations led to different atmospheres. The best modified atmosphere was obtained with unperforated bags. MAP inhibited loss of weight, firmness and bioactive compounds during storage, independently of the perforation level. Fermentative metabolites did not accumulate significantly in packaged peppers. The tested films permitted the cost-effective preservation of the quality of the Jalapeño peppers for 6 weeks under refrigeration. However, the migration of compounds from the packaging material to the peppers must be studied before the commercial use of the tested films can be recommended.

Acknowledgments This research was fully funded by the Fondo Sectorial de Investigación para la Educación (Investigación Básica SEP-CONACYT; Project Clave: 103391). The authors would like to thank Ana Lourdes Ramos and Emilio Ochoa-Reyes for their technical assistance.

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