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Evaluation of a modified atmosphere packaging system in pallets to extend the shelf-life of the stored tomato at cooling temperature

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ABSTRACT

A modified atmosphere packaging (MAP) system in pallets was developed and its effect on physico-chemical and sensory characteristics and shelf-life of tomato was evaluated. Tomatoes were stored at 6 °C in cardboard boxes arranged on pallets wrapped in micro-perforated low-density polyethylene (LDPE) bags. Effects of the storage time and packaging were evaluated after 0, 7, 14, and 21 days of storage. The MAP system with pallets assessed, using a packaging atmosphere composition of 10% O_2 - 10% CO_2 and silica gel as an adsorbent, extended the shelf-life of the tomato stored at refrigeration temperature. MAP delayed color evolution and reduced the firmness loss, biosynthesis of lycopene, and decay rate of tomato. At the end of storage, 100% of the unpackaged samples showed spots while only 42.9% of MAP samples had them. In addition, the percentage of tomatoes with cracks and stretch marks was reduced from 42.9% (unpackaged tomatoes) to 14.3% (MAP tomatoes).

1. Introduction

Tomato (*Lycopersicon esculentum* Mill.) is widely grown and consumed around the world either as a fresh or as processed product such as canned tomatoes, sauce, juice, ketchup and soup (Domínguez, Lafuente, Hernández-Muñoz, & Gavara, 2016; Ninčević Grassino et al., 2020). Tomato contains about 90% water of its fresh weight, which makes it highly perishable. Half of the dry matter is constituted by reducing sugars such as fructose and glucose, among others. In addition to its nutritional quality, tomato contains various bioactive and antioxidative compounds beneficial for human health, such as carotenoids, ascorbic acid (AA), and phenolic compounds. This vegetable is the main source of lycopene, which has the highest antioxidant activity among all the antioxidants in the diet. Lycopene is the most abundant carotenoid in tomato, representing more than 80% of the total content of carotenoids in fully red ripe tomato (Fagundes et al., 2015; Kaur & Bhatia, 2016).

During tomato processing, a considerable amount of waste and by-products is generated and its effective utilization has great potential for obtaining various functional ingredients including pectin, polyphenols, and fatty acids. Tomato by-products contain higher amounts of phenolics compared to pulp which indicates that removal of peel and seed during tomato processing results in a loss of their antioxidant properties (Ninčević Grassino et al., 2020). Inclusion of 40% tomato pomace in the formulation of the goatśdiet resulted in higher milk production and improved milk quality while allowed reducing the feeding costs (Mizael et al., 2020). Tomato seeds could be used as a source of vegetable oil for edible use, but tomato seed oil (TSO) has not a widespread industrial use at present. TSO could be used as a dietary supplement of essential fatty acids in deficient diets and defatted seeds could be used for animal feed due to their high crude protein content (Giuffrè & Capocasale, 2016).

In addition to its use as a food for humans and animals, the peel, seed, and seed oil of tomato can also have a non-food use. Several researchers (Giuffrè, Capocasale, Zappia, & Poiana, 2017) suggested the possibility that biodiesel can be economically processed from TSO with characteristics that compliant with the European standard EN14124:2014. On the other hand, pectin isolated from tomato peel could be used as a natural tin corrosion inhibition. Several researchers reported that pectin acts as a more effective tin corrosion inhibitor than commercial apple pectin (Ninčević Grassino et al., 2020).

Tomato is considered a climacteric fruit and its postharvest ripening is acompanished by an increase in respiration rate and ethylene

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production. This accelerates quality loss due to physico-chemical changes including color evolution and softening (Akbudak, Akbudak, Seniz, & Eris, 2007). Firmness is a reliable quality indicator of tomato maturity (Aneesh, Kudachikar, & Ravi, 2008) and considerably affects its marketability. Firmness of tomato generally decrease with the storage time. The fruits softening is due to the breakdown of cell wall structure's carbohydrates and the increase in soluble pectin substances that results in weakening of the cell walls and reduction of the cohesive forces binding cells together (Majidi, Minaei, Almassi, & Mostofi, 2014).

Many strategies have been developed to prevent the detrimental effects of ethylene on perishable crops. Photocatalytic oxidation has proved to be an efficient technology for removing ethylene from the atmosphere surrounding ethylene-sensitive fruits and vegetables in horticultural storage chambers (Keller, Ducamp, Robert, & Keller, 2013). Recently, Basso, de Fátima Peralta Muniz Moreira, and José (2018) studied the effect of the operating conditions on the photocatalytic oxidation of ethylene in a continuous flow reactor with TiO_2, as a semiconductor material, under UV-A light and applied to cherry tomato. A continuous rate of ethylene gas production during tomato ripening of 0.3182 μmol/kg.h was observed. The reactor with a TiO_2 film thickness of 0.419 μm under an incident irradiance of 5.18 W/m^2 maintained the ethylene concentration in the gas phase close to zero and the respiration rate decreased.

Another approach to ethylene control is based on the inhibiting of its synthesis and action on horticultural commodities. Some factors, including low temperature storage, controlled atmosphere storage (CAS), modified atmosphere packaging (MAP), or application of ethylene antagonists can diminish ethylene synthesis and its effect on tomato (Sabir & Agar, 2011). However, storage temperatures below 13 °C may cause chilling injury, particularly in mature green stage (Polenta, Lucangeli, Budde, González, & Murray, 2006). On the other hand, the use of chemicals can be unsafe. 1-Methylcyclopropene (1-MCP) is a strong blocker of ethylene receptors having the advantages of leaving residues at negligible levels and non-toxic and delaying the ripening of fresh produce at a very low concentration (Sabir & Agar, 2011). Several researchers reported beneficial effects of 1-MCP on tomato (Choi & Huber, 2008; Sabir & Agar, 2011).

CAS or MAP combinated with low storage temperatures can reduce respiration and ethylene production rates, which slow down changes related to ripening and senescence. The modified atmosphere may be produced as a result of produce respiration (passive MAP) or by the addition/removal of gases from food packages (active MAP) in order to control the levels of O_2 and CO_2. In active MAP, a mixture of gases is introduced inside the package once which changes its composition over time whereas in CAS, gas levels are strictly kept at all times (Majidi et al., 2014). High CO_2 and low O_2 concentrations in MAP are usually achieved to reduce respiration and ethylene production rates. However, extremely low levels of O_2 and/or high levels of CO_2 could induce anaerobic metabolism with the possibility of off-flavors generation, physiological and microbial decay, browning, and softening. Thus, high-O_2 atmospheres have been suggested as an effective method to inhibit the growth of microorganisms and prevent undesired anoxic fermentation (Odriozola-Serrano, Oms-Oliu, Soliva-Fortuny, & Martín-Belloso, 2009).

Kaewklin, Siripatrawan, Suwanagul, and Lee (2018) investigated the feasibility of active packaging from chitosan (CS) and chitosan containing nanosized titanium dioxide (CT) to maintain quality and extend storage life of tomato. Cherry tomatoes at breaker stage were used for the experiment. Quality changes were lower in fruits packaged with the CT film than in control fruits or in fruits packaged with the CS film. It should be noted that fruits were exposed to UV light in the three treatments evaluated. The results suggested that the CT film exhibited ethylene photodegradation activity when exposed to UV light and consequently delayed the ripening process and changes in the quality of the tomatoes. The use of granular-activated carbon as a ethylene sorbent in MAP, alone or impregned with palladium as a catalyst, diminished efficiently the ethylene accumulation, thus reducing color evolution, softening, and weigh loss in Buffalo tomato (Bailén et al., 2006).

The effectiveness of MAP in plant produces depends on the variety, ripening stage, length of storage, and temperature. Optimal temperature, humidity, and atmosphere composition conditions must be used to obtain significant benefits (Park, Sangwanangkul, & Choi, 2018). Many MAP systems for tomatoes have been designed to keep fruit between 5 °C and 10 °C (Bailén et al., 2006; Fagundes et al., 2015). Cherry tomatoes (cv. Tiny Bell) harvested at commercial maturity (H°: 57.2; firmness: 5.3 N) were stored in the dark at 7 °C for 21 days under passive MAP. Considering sensory quality, ready-to-eat cherry tomatoes packaged in PE exhibited a shelf-life of at least 21 days at that temperature (Paulsen, Barrios, & Lema, 2019). This was the packaging condition recommended for cherry tomato postharvest refrigerated storage in the study. DAquino et al. (2016) recommended moderate levels of CO_2 (around 3 kPa), O_2 not below than 12 kPa and relative humidity (RH) not higher than 90% for red-ripe cherry tomatoes stored under passive MAP at 20 °C. These conditions were achieved using a laser-perforated 30-mm-thick oriented polypropylene (OPP) film. In contrast, the packages made with the same film but without perforation, which are designed to generate benefits at low temperatures, created anaerobic conditions and hastened physico-chemical and eating quality loss.

Other researchers evaluated the packaging of a greenhouse-grown tomato on the culture medium containing compost tea under modified atmosphere (88% N_2 + 8% CO_2 + 4% O_2) in LDPE and nanosilicon-PE bags at 5 °C for 30 days. Results confirmed the extension of shelf-life and maintaining of the tomato quality in the nanosilicon-PE film until the end of storage (Tajeddin, Azadshahraki, & Darsangi, 2020). Storage under MAP of litchi fruits (cv. Gola), harvested at 90–100% red color stage, was suitable to delay its postharvest browning and to conserve biochemical attributes and antioxidative enzymes during 28 days at 5 °C (Ali et al., 2019).

UV treatment of fruit and vegetables has been reported to increase their antioxidant capacities. Vunnam et al. (2014) found that UV-C treatment enhanced the antioxidant capacity of mature red cherry tomatoes, but had no beneficial effect in reducing the % mass loss, color change, respiration rate, or in maintaining the firmness of the fruits. The best quality tomatoes, in terms of minimum changes in their physico-chemical attributes such as mass loss, respiration rate, color change, total soluble solid (TSS) content, and firmness and enhanced antioxidant capacity were achieved with UV-C + MAP, suggesting that UV-C treatment can be successfully combined with MAP thereby resulting in a produce with increased shelf-life and nutritive quality.

Pinto et al. (2020) reported that the combined technology of O_3 gas + MAP significantly reduced the yeast and mould counts in strawberries, raspberries, and blueberries, compared to samples stored in air and MAP without any pre-treatment. However, as expected, a different effect of the combined treatment on microbiological, chemical and quality parameters of different types of small fruits, stored under the same conditions, has been observed. Ozturk et al. (2019) suggested a combined treatment of MAP + methyl jasmonate (MeJA) as an effective tool for delaying quality loss and maintaining of bioactive compounds in medlar fruit (cv. İstanbul) during storage at 0 °C for 60 days. Fruits were collected at the stage of comercial maturity with 17.65% TSS, 2.35% titratable acidity (TA), and 82.66% firmness. MeJA is a plant growth regulator and it is also known to initiate the resistance mechanisms against different stresses in plants and fruits.

To our knowledge, no articles have been published on the application of MAP to tomatoes stored using pallets to extend their shelf-life. The aim of this work was to develop a MAP system with pallets and study its effect on the physico-chemical and sensory characteristics of tomato stored at refrigeration temperature.

2. Material and methods

2.1. Plant material

The influence of packaging system was studied in tomato cv. Anairis (*Lycopersicon esculentum* Mill.) with a size of 82–102 mm (GG gauge). The tomato fruit was grown in Orense (Galicia, northwest Spain; geographic coordinates: 42°17′40″N; 159 m on the sea level) and provided by an agricultural cooperative. Tomatoes were cultivated in a greenhouse under controlled conditions of temperature (day 20–23 °C, night 15 °C) and RH (60–70%). Cultivation conditions employed in growing the tomato crops were the following: a) Soil type: clayey; b) Fertilization (applied in all cases before seed was sown): 8–24–16 NPK (800 kg ha^{-1}), and KNO_3 (80 kg ha^{-1}); c) Water supply: Drip irrigation. The dimension of plants was of 1.80 m. Tomatoes were harvested in June and September for two years and were immediately taken to the facilities of the cooperative.

2.2. Packaging, storage, and sampling

Three assays were carried out changing the packaging conditions. The packaging and storage of tomato took place in the own facilities of the cooperative. After harvest, technicians of the agricultural company placed the tomatoes in cardboard boxes (50 × 30 × 17 cm) which were subsequently distributed on four pallets. Each pallet contained around ten boxes distributed in two heights. The weigh of each box was around 10 kg. One of the four pallets was used as a control (unpackaged pallet), while the rest were packaged under a modified atmosphere (packaged pallets) composed of a mixture O_2/CO_2. The use of silica gel as a moisture adsorbent was tested in the third assay. To do this, a cardboard box containing silica gel crystals (2.5 kg/pallet) and orange indicator (WG-2) was deposited on each MAP pallet. Micro-perforated LDPE bags of 60 μm thickness and 24.30 × 13.55 × 26.00 m (length × width × height) size were employed for the packaging. The permeabilities of polymer to O_2 and CO_2 at 23 °C were 3300 and 16600 cm^3/m^2/day/atm, respectively, and the water vapor transmission 1.67 g/m^2/day/atm.

A gaseous mixture of N_2/CO_2 ("Freshline 20 – Carburos Metálicos Company", Coruña, Spain) was injected into each packaging bag which allowed to displace the air and reach the desired concentrations of O_2 and CO_2. Two gas compositions were tested: 7.8% O_2/12.6% CO_2/79.6% N_2 (first assay) and 10% O_2/10% CO_2/80% N_2 (second and third assays). Once the bags were hermetically closed with a flange, pallets were stored inside a cooling chamber at 6 °C and RH around 91%. The gas composition was monitored daily by the technicians of the agricultural company using a Witt-Gasetechnik gases-meter model Oxibaby® M + for O_2/CO_2.

Samplings were carried out after 0, 7, 14, and 21 days of storage except in the second assay where the possibility of extending the time of storage of the samples up to 28 days was studied and the 7 days-sampling was not carried out.

The initial sampling was done on the control pallet and the following ones consisted of two sub-samplings, one from the control pallet and the other from a MAP pallet. A different MAP pallet was used every day of sampling. A minimum of 10 kg of tomatoes were collected from the different boxes of each pallet (unpackaged and packaged). After sampling, the tomatoes were transported to the tasting room and to the Food Technology Laboratory, both located in the Faculty of Veterinary of the University of Santiago of Compostela (Galicia, Spain) for sensory and physico-chemical analysis, respectively.

2.3. Reagents

Lycopene, β-carotene, and 2N Folin–Ciocalteau reagent were supplied from Sigma-Aldrich (St. Louis, MO, USA.). HPLC-grade *n*-hexane was acquired from Merck (Madrid, Spain). Acetone, 96% ethanol, 96% 2,6-di-tert-butyl-4-methylphenol (BHT), HPLC-grade methanol, metaphosphoric acid, sodium hydroxide (NaOH), potassium dihydrogen phosphate (KH_2PO_4), anhydrous sodium carbonate (Na_2CO_3), 85% phosphoric acid, 99% L-(+)-ascorbic acid, and HPLC-grade tetrahydrofuran (THF) were purchased from Panreac (Barcelona, Spain). 98% Gallic acid was from Acros (Geel, Belgium). Ultrapure water was obtained by a Milli-Q water purification system from Millipore (Bedford, MA, USA).

2.4. Determination of the CIE L*a*b* color parameters

Tomato color was measured with a *ColorFlex* colorimeter (HunterLab, Reston, VA, USA). Measurements were made using D_{65} illuminat and an 10° observation angle as references. Lightness (L*), a* (redness/greenness), and b* (yellowness/blueness) were registered. The hue angle was calculated as $H^\circ = \arctan(b^*/a^*)$, the saturation index or chroma as $C^* = (b^{*2} + a^{*2})^{1/2}$, and the total color difference as $\Delta E = ((L^* - Lo^*)^2 + (a^* - ao^*)^2 + (b^* - bo^*)^2)^{1/2}$. The instrument was calibrated using a standard tile (L* = 93.41; a* = −1.07; b* = +1.13). The color measurements were performed at 25 ± 1 °C on three locations of each fruit, two equatorial and one on the base. The data are presented as means of 10 fruits (Ordóñez-Santos et al., 2009).

2.5. Determination of moisture, titratable acidity, pH, and total soluble solids content

For the determination of moisture, TA, pH, and TSS content, a minimum of 10 tomatoes from each sample (unpackaged and packaged) on each sampling day were crushed.

For the moisture determination, the crushed samples were lyophilized using the Coolsafe Superior PRO 90–80 lyophilizer (SCANVAC, Stockholm, Sweden). Moisture was determined in triplicate and expressed as percentage. pH, TA, and TSS content were determined in triplicate according to the methods of the AOAC (2005). pH was determined in a homogeneous mixture of about 10 g of crushed tomato in 100 mL of deionized water with a GLP 21 Crison pH meter and a Crison 52–02 glass electrode (Crison Instruments, S.A., Barcelona, Spain). TA was determined by titration the previous mixture with 0.1 M NaOH to pH 8.1. Results were expressed as g citric acid/100 g fresh weigh (FW). The TSS content was determined using a (0–32%) Labolan 301 refractometer (Spain) and expressed as percentage (°Brix).

2.6. Determination of firmness

Tomato instrumental firmness was measured in a minimum of 10 tomatoes using a TA.XT. Plus Texture Analyzer (*Stable Micro Systems,* Surrey, UK) and expressed as Newtons (N). Puncture tests were performed by a probe with cylindrical tip (P/0.255) of 6.35 mm diameter. A speed of 2 mm s^{-1} and penetration distance of 10 mm were used to puncture the samples. A whole tomato was placed in an equatorial position on the texturometer stage for each measurement. Puncture force was measured in triplicate.

2.7. Determination of lycopene and β-carotene

Extraction was performed following Lugasi et al. (2003) and Sadler, Davis, and Dezman (1990). Briefly, 2 g crushed tomatoes were weighed in a 250-mL Erlenmeyer flask, and 50 mL of solvent (2:1:1) *n*-hexane / acetone-(2.5% w/v) BHT / 96% ethanol were added. The flask was covered with foil, and then placed in crushed ice and shaken by a magnetic stirrer for 10 min, after which 10 mL of distilled water were added and shaking was continued for a further 5 min. A 4 mL sample of the organic phase was then taken with a Pasteur pipette and filtered twice through a 0.2-μm nylon filter. All samples were analyzed in triplicate. A 20 μL aliquot of the filtrate was injected in duplicate into an HPLC apparatus equipped with a UV–VIS diode array detector, degasser, temperature stabilizer, manual injector, SunFire C18 column (5 μm, 25

× 0.46 cm), and SunFire C18 precolumn (5 μm, 2 × 0.46 cm). As mobile phase, 67:27:6 (v:v:v) methanol/THF/water (Sadler et al., 1990) was delivered at 2 mL/min, and the columns were thermostated at 30 °C.

Lycopene and β-carotene were detected at 475 and 450 nm, respectively, and quantified using calibration curves (r = 0.9983 and r = 0.9994, respectively) that had previously been constructed with the corresponding standards. Chromatographic peaks were identified by comparing the retention times with those of authentic standards. The limits of detection (LOD) were calculated as the concentration corresponding to the average signal of the blank plus 3 times the standard deviation. The values obtained were 0.074 and 0.081 μg/mL for lycopene and β-carotene, respectively. For lycopene, the analytical recovery was 101.0% and the measurement and method coefficients of variation 2.34% and 2.91%, respectively. For β-carotene, the analytical recovery was 97.4%, and the measurement and method coefficients of variation 2.41% and 2.30%, respectively.

2.8. Determination of ascorbic acid

Following Baardseth, Bjerke, Martinsen, and Skrede (2010) and Gökmen, Kahraman, Demir, and Acar (2000), 5 g of homogenized sample was weighed in a beaker and 5% (w/v) metaphosphoric acid was added in sufficient quantity to cover it. The beaker was covered with foil, placed on a magnetic stirrer, and then shaken for 15 min before being diluted to 25 mL with metaphosphoric acid. The sample was filtered through a filter paper (Filter-Lab No. 1238), and then through a 0.2 μm nylon filter, keeping it away from direct sunlight. All samples were analyzed in triplicate. A 20 μL aliquot was injected in duplicate into an HPLC apparatus equipped with a UV–VIS diode array detector, degasser, temperature stabilizer, manual injector, Spherisorb ODS2 C18 column (5 μm, 25 × 0.46 cm) and Spherisorb ODS2 C18 precolumn (5 μm, 2 × 0.46 cm). The columns were thermostated at 25 °C. A 0.2 M KH_2PO_4 solution was used as a mobile phase with a flow-rate of 0.8 mL/min. The pH of the mobile phase was adjusted to 2.4 by 85% phosphoric acid. AA was detected at 254 nm and quantified using a calibration curve (r = 0.9999) constructed with AA standards. Chromatographic peak was identified by comparing the retention time with that of an authentic standard. The LOD was 0.0122 μg/mL, the analytical recovery 97.03% and the measurement and method coefficients of variation 4.57% and 5.74%, respectively.

2.9. Determination of total phenolic content

Phenolics were extracted (Oboh, 2005) by treating 30 mg of lyophilized sample with 20 mL of 70% (v/v) acetone at 4 °C, vortexed, allowed to stand at 4 °C for about 12 h, and then filtered. TPC was determined in triplicate using the Folin–Ciocalteau reagent (Singleton, Orthofer, & Lamuela-Raventós, 1999) as follows: a mixture of 2 mL of filtered solution and 10 mL of 0.2 N Folin–Ciocalteau reagent was vortexed and allowed to stand for 3 min, then neutralized with 8 mL of 7.5% (w/v) sodium carbonate, again vortexed for 20 s, and incubated for 90 min at 25 °C. Absorbance at 760 nm was measured in a UV–VIS spectrophotometer, and TPC determined from a calibration curve (r = 0.9977) that had previously been constructed with gallic acid standards. All samples were analyzed in triplicate. The method and measurement coefficients of variation were 3.2% and 2.50%, respectively. TPC was expressed as mg GAE/100 g FW.

2.10. Sensory evaluation

The sensory analysis was performed by a panel of ten trained tasters who evaluated pairs of samples, unpackaged and packaged fruits, using the tasting sheet previously elaborated by Ordóñez-Santos et al. (2009), following the methodology described in ISO 8586:2012. Three number codes were used to name samples, thus avoiding their identification by tasters. Each taster received a whole tomato of each sample. Sixteen sensory descriptors were evaluated. A 2-point scale (presence/absence) was used for color uniformity, spots, detachment of the viscous part, and off-aromas and results were expressed as percentages. A 10–cm unstructured scale was employed for the rest of descriptors including external and internal color intensities, external and internal odor intensities, firmness, juiciness, consistency, resilience to skin chewing, sweetness, acid flavour, salty flavour, and flavour persistency. The tasters could also indicate any other alteration observed in the samples using the item "*other alterations*" included in the tasting sheet.

2.11. Statistical analysis

Sensory and physico-chemical results were subjected to two-way analysis of variance (ANOVA) with interaction (t*P). Sources of variation were packaging (yes/non) and storage time (7, 14, and 21 days). The *t*-Student test was used to compare means between the two first samplings (0–7 or 0–14 days). Pearsońs chi-squared test was applied on the descriptors evaluated by a 2-point scale. All analyses were performed using SPSS 17.0 for Windows (SPSS Inc., Chicago, Ill., U.S.A.).

3. Results and discussion

3.1. First assay

Tomato harvested was divided into two groups because fruits attained different stages of maturation, green and mature. Tables 1 and 2 show the values of the physico-chemical parameters determined in control and MAP samples for tomatoes at green and mature stages, respectively, together with the corresponding statistical results.

During this first assay, high condensation of water vapor was observed inside the packaging bags covering the MAP pallets. This is most likely caused by the development of high RH within the bags due to the low water vapor permeability of the packaging material. These conditions are unsuitable because microbial proliferation might be produced thus reducing quality and safety of the produce (Singh, Giri, & Kotwaliwale, 2014).

At the beginning of storage (day 0), the values of TA and pH for tomato at the mature and green stages were similar. TA tended to decrease during the storage time with the consequent increase in pH regardless of its maturation stage and conservation method, although tasters did not detect significant differences in the acid taste over time. Changes in TA seem to be slower in ripe tomato because the *t*-Student test did not show significant differences between the samplings at 0 and 7 days. The effects of the packaging factor on pH and TA were only significant for green tomato with higher values of pH and lower values of TA in MAP tomato at the end of storage. In accordance with these results, at sensory level, MAP green tomato obtained lower scores of acid taste (3.1–3.6) than control tomato (3.7–4.9) in all samplings although in this case the effect of packaging factor on the sensory descriptor was not significant.

Domínguez et al. (2016) did not find significant changes in TA during storage of tomato (cv. Delizia) at breaker stage neither in unpackaged nor MAP samples. Majidi et al. (2014) reported that MAP and especially CAS slowed down the diminishing trend of TA in tomatoes (cv. Super jeff) at mature-green stage. The use of 1-MCP or the 1-MCP + MAP combination showed a possitive effect in tomatoes (cv. Perla) at the pink and light red stages by delaying changes in TA during storage. However, such an effect on TA was not observed when MAP was used alone (Sabir & Agar, 2011).

TSS content is considered as an important index of ripening in tomatoes. Changes in TSS during the natural maturation process are attributed to the hydrolysis of the starch which is converted into sugar (Kaewklin et al., 2018). The initial TSS content in tomato was higher in mature (4.50%) than green (3.67%) fruits. No significant changes in TSS during storage were observed in green tomato. However, a significant increase in TSS after 7 days of storage was detected in control and MAP

Table 1
Effect of the storage time and MAP on the physico-chemical parameters of green tomato (first assay).

	Day 0	Day 7		Day 14		Day 21		Two-way ANOVA with interaction			*t*-Student test (0–7 days)	
	Control	Control	MAP	Control	MAP	Control	MAP	t	P	t*P	Control	MAP
pH	4.37	4.33	4.48	4.36	4.48	4.50	4.56	***	***	ns	ns	*
TA (g citric acid/100 g FW)	0.43	0.40	0.36	0.35	0.36	0.35	0.22	***	***	***	**	*
TSS content (%)	3.67	5.00	4.17	4.43	5.00	4.73	4.10	ns	ns	**	ns	ns
Moisture (%)	93.39	93.46	93.64	93.51	94.01	93.99	94.20	–	–	–	–	–
Firmness (N)	28.99	29.46	31.32	29.4	23.56	30.87	23.46	ns	ns	ns	ns	ns
Lycopene (mg/100 g FW)	7.69	3.19	6.03	2.72	2.81	3.49	5.71	**	**	ns	*	ns
β-Carotene (mg/100 g FW)	4.34	2.40	3.19	2.66	3.25	2.66	3.56	ns	ns	ns	*	**
L*	37.48	37.36	36.16	38.27	36.24	37.57	36.70	ns	*	ns	ns	ns
a*	0.61	2.98	2.18	3.08	4.41	3.96	3.70	ns	ns	ns	ns	ns
b*	19.22	18.81	19.23	16.13	17.09	18.87	18.97	ns	ns	ns	ns	ns
C*	20.16	19.9	20.03	16.13	18.33	20.14	20.11	***	ns	ns	ns	ns
H°	88.23	81.90	84.16	80.77	76.47	78.35	79.48	ns	ns	ns	ns	ns
ΔE	–	6.50	5.97	6.75	6.65	7.33	6.62	ns	ns	ns	–	–
AA (mg/100 g FW)	14.32	19.83	23.97	21.13	21.84	19.95	16.60	ns	ns	*	ns	**
TPC (mg GAE/100 g FW)	66.35	64.55	64.82	54.63	65.05	58.28	53.91	**	ns	*	ns	ns

TA: titratable acidity; TSS: total soluble solid; FW: fresh weight; AA: ascorbic acid; TPC total phenolic content; t: time; P: packaging; MAP: modified atmosphere packaging; ns = not significant; (*) $p \leq 0.05$; (**) $p \leq 0.01$; (***) $p \leq 0.001$

Table 2
Effect of the storage time and MAP on the physico-chemical parameters of ripe tomato (first assay).

	Day 0	Day 7		Day 14		Day 21		Two-way ANOVA with interaction			*t*-Student test (0–7 days)	
	Control	Control	MAP	Control	MAP	Control	MAP	t	P	t*P	Control	MAP
pH	4.28	4.29	4.26	4.43	4.43	4.35	4.62	***	ns	***	ns	ns
TA (g citric acid/100 g FW)	0.42	0.39	0.39	0.34	0.36	0.37	0.22	***	ns	***	ns	ns
TSS content (%)	4.50	5.67	6.00	4.83	6.17	5.07	4.93	ns	ns	ns	*	**
Moisture (%)	93.29	93.30	93.27	93.77	93.39	92.31	94.35	–	–	–	–	–
Firmness (N)	18.68	22.92	20.13	19.10	12.53	21.40	12.75	ns	**	ns	ns	ns
Lycopene (mg/100 g FW)	37.83	38.76	58.15	29.14	48.14	24.05	31.77	***	***	**	ns	*
β-Carotene (mg/100 g FW)	5.55	5.01	6.56	4.47	5.83	5.18	5.39	ns	***	*	ns	ns
L*	30.58	29.97	29.70	29.85	30.71	29.91	29.67	ns	ns	ns	ns	ns
a*	13.80	15.92	16.24	13.93	14.39	14.30	13.16	ns	ns	ns	*	*
b*	16.64	14.78	14.58	14.14	15.45	14.78	13.84	ns	ns	ns	ns	ns
C*	21.96	21.85	22.05	20.01	21.43	20.67	19.29	*	ns	ns	ns	ns
H°	50.95	43.23	41.72	45.52	47.53	46.29	47.30	ns	ns	ns	*	*
ΔE	–	4.57	4.91	4.65	4.35	3.58	4.97	ns	ns	ns	–	–
AA (mg/100 g FW)	13.96	21.88	16.02	26.67	23.73	20.10	19.59	**	*	ns	*	ns
TPC (mg GAE/100 g FW)	62.88	69.60	71.39	89.12	71.28	63.23	53.37	***	***	***	**	**

TA: titratable acidity; TSS: total soluble solids; FW: fresh weight; AA: ascorbic acid; TPC total phenolic content; t: time; P: packaging; MAP: modified atmosphere packaging; ns = not significant; (*) $p \leq 0.05$; (**) $p \leq 0.01$; (***) $p \leq 0.001$

mature tomato although tasters did not detect significant differences in the "sweetness" descriptor. Domínguez et al. (2016) found no significant changes in TSS over storage time neither in control nor MAP tomato (cv. Delizia). However, Sabir and Agar (2011) reported a TSS increase in tomato (cv. Perla) during the storage regardless of the treatment used (control, 1-MCP, MAP, or 1-MCP + MAP). Results obtained by other researchers (Akbudak et al., 2007) showed that the use of MAP in light-red cherry tomato (cvs. Alona and Naomi) slowed down the increase of TSS during storage.

The initial instrumental firmness was, as expected, higher in the green (28.99 N) than ripe (18.68 N) tomatoes. Consistent with this result, the average score given by tasters to firmness was higher in green (8.6) than ripe tomato (6.3). In our study, these values did not change significantly with the storage time. The effect of packaging factor was only significant in matured tomatoes; the values of puncture force and firmness score were lower in fruits stored using MAP which could be attributed to the high condensation of water vapor inside the packaging bags which caused the softening of the fruits.

The initial values of H° and a* in matured tomatoes were 50.95 and 13.80, respectively. In green tomatoes, the values were 88.23 and 0.61, respectively. These differences indicate tomato color development, from green to red, during ripening. Sabir and Agar (2011) reported H° values in tomato (cv. Perla) at pink and light red stages of 88.08 and 72.27, respectively. Domínguez et al. (2016) found H° values of 93.11 and 48.12 in Delizia (breaker stage) and Pitenza (red) tomato, respectively.

In mature tomato, H° significantly decreased after 7 days of storage in both unpackaged and packaged fruits whereas a* significantly increased after the same time period indicating that tomato adquired a slightly more intense red color. In accordance with these results, the average score given by the tasters to the external color intensity at the beginning of storage (3.0), significantly increased after 7 days to 6.3 and 8.2 in unpackaged and packaged fruits, respectively. In the same way, the internal color intensity (4.3) increased to 5.9 and 8.1, respectively. Minor changes in the color parameters were found in green tomatoes.

The pigments in tomatoes include mostly chlorophyll *a*, chlorophyll *b*, β-carotene, and lycopene (Fagundes et al., 2015), which are metabolized during the ripening of tomatoes. The initial amounts of β-carotene in green and mature tomato were 4.34 and 5.55 mg/100 g FW, respectively. β-Carotene in green tomato significantly decreased in both unpackaged and packaged fruits after 7 days of storage and then it remained without significant changes. β-Carotene in ripe tomato was affected by MAP with the higher amounts of the pigment being found in packaged fruits.

The initial amount of lycopene in mature fruits (37.83 mg/100 g FW) was much higher than that found in green fruits (7.69 mg/100 g FW), a result consistent with the tomato color analysis. Biosynthesis of lycopene was observed in packaged ripe tomato after 7 days of storage and then a decline occurred. Instead, lycopene tended to decrease with the

time of storage in the unpackaged fruits. The highest lycopene content detected in packaged fruits was in agreement with the greatest scores given by the tasters to the internal and external color intensities. Biosynthesis of lycopene was not observed in control or MAP green tomato. On the contrary, it decreased significantly after 7 days of storage in control fruits.

The initial content of AA was not significantly modified in the green tomato, but it did change in the mature one, both over time, with values higher than the initial values after 21 days of storage, and depending on the method of conservation, with the values being slightly lower in the case of packaged tomato throughout the storage time. Sabir and Agar (2011) studied the AA changes with the storage time in tomato (cv. Perla) at two maturation stages and using different treatments (control, MAP, 1-MCP, and 1-MCP + MAP). At pink stage, AA slighly increased although no significant differences among treatments were found. At light red stage, AA content uneven increased. The lowest changes were observed with 1-MCP or 1-MCP + MAP.

In the study carried out by Kaewklin et al. (2018) comparing the CS and CT packaging films for storage of cherry tomato (breaker stage) under MAP + UV light, AA increased when fruits reached the pink stage and then declined slightly as the fruit attained the red stage. Control fruits with UV exposure shows a similar behavior. Control samples and samples packaged with CS reached the highest contents of AA after 3 days of storage, while samples packaged with CT reached it after 7 days of storage. Results suggested that the CT film could delay ripening process of the tomato fruits. The possible cause for the decrease in AA at the red stage of tomato ripening can be its utilization as respiratory substrate in the ripening process or its conversion to sugars during ripening. Kaur and Bhatia (2016) studied the effect of different packaging materials (HDPE, LDPE, and PP) on the AA content in tomatoes (Punjab Upma and Punjab Ratta) at pink stage and observed that AA increased up to day 14 for both varieties, and then declined afterwards in open trays as well as in all the packaging modes. AA enhancement rate was more under open trays as compared to packaged tomatoes.

TPC tended to decrease with the storage time in green tomato but no significant differences were observed between unpackaged and packaged fruits. In unpackaged ripe tomato, TPC significantly increased after 7 days of storage in unpackaged fruits and continued to increase until 14 days of storage and then decreased reaching values similar to the initial ones. Pinheiro, Alegria, Abreu, Gonçalves, and Silva (2013) reported a TPC increase in tomato (cv. Zinac) at mature-green stage during the 30 days of storage. Toor and Savage (2006) noticed an increase of TPC in tomato at light-red stage (cv. Tradiro) until the 8th storage day, followed by a slight decrease until the end of storage time (10 days). In general, the increase of phenolics content is associated with ripening development, especially with the increase of the phenylalanine ammonia-lyase (PAL) enzyme activity, which plays an important role in phenolics compounds synthesis (Alothman, Kaur, Fazilah, Bhat, & Karim, 2010). In our study, accumulation of TPC was reduced when the tomatoes were stored under modified atmosphere. At the end of sorage, TPC was significantly lower in MAP than control fruits.

In this first assay, the tasters indicated the presence of cracks and stretch marks from the beginning of storage as well as rot after 21 days of storage in both packaged and unpackaged ripe fruits.

3.2. Second assay

In this second assay, a different packaging atmosphere composition was evaluated with a sample of homogenous tomatoes at their point of maturity. Results obtained are shown in Table 3. High condensation of water vapor was again observed inside the packaging bags covering the pallets, as happened in the first assay.

TA of tomato in this second assay did not vary significantly over time even when there were differences in its value at the end of storage between the control and MAP samples, with TA being lower in the latter, as it happened in the first assay. The pH variations, although significant, were very small. Tasters did not detect significant changes in the acid taste neither with the storage time nor the method of conservation.

An increase in the TSS content was observed in both control and MAP samples after 14 days of storage although such an increase was not significant. Control fruits had significantly higher TSS content than those MAP at the end of storage. At the sensory level, “sweetness” did not change significantly over time or with the method of storage.

The initial instrumental firmness decreased over time in both control and MAP fruits although the variations observed were not significant. Moreover, a significant effect of the packaging was not found. However, a noticeable and significant decline of the firmness scores in both control and MAP tomato was obtained at 14 days of storage with no significant differences between both types of fruits.

Initial H° and a* were 70.70 and 6.34, respectively (Table 3) and significantly decreased (52.97°) and increased (19.83°), respectively, in unpackaged tomato after 14 days of storage. In addition, the initial average score of the external color intensity (2.2) significantly increased (7.4) after the same time period. A lower a* increase was observed in MAP tomato after 14 days of storage, although such a change was not significant. Moreover, no significant changes in H° or external and internal color intensites were observed in packaged fruits during storage. As for C* and L*, significantly increased after 14 days of storage in both unpackaged and packaged fuits.

Overall, packaged tomatoes shown the highest values of L*, b*, C*,

Table 3
Effect of the storage time and MAP on the physico-chemical parameters of tomato (second assay).

	Day 0	Day 14		Day 21		Two-way ANOVA with interaction			*t*-Student test (0–14 days)	
	Control	Control	MAP	Control	MAP	t	P	t*P	Control	MAP
pH	4.49	4.41	4.38	4.35	4.66	***	***	***	ns	ns
TA (g citric acid/100 g FW)	0.26	0.25	0.29	0.36	0.19	ns	***	***	ns	*
TSS content (%)	4.07	4.33	4.43	4.40	4.00	***	***	***	ns	ns
Moisture (%)	94.59	94.15	94.04	94.07	94.16	–	–	–	–	–
Firmness (N)	28.17	23.79	26.70	20.61	20.30	ns	ns	ns	ns	ns
Lycopene (mg/100 g FW)	5.56	7.53	5.39	8.07	6.44	ns	ns	ns	ns	ns
β-Carotene (mg/100 g FW)	2.38	2.91	2.38	2.18	2.31	*	ns	*	*	ns
L*	34.40	37.19	42.96	29.94	39.26	***	***	*	*	**
a*	6.34	19.83	11.64	11.47	13.43	*	ns	**	***	ns
b*	17.2	25.96	31.25	15.29	29.00	***	***	**	***	***
C*	19.38	32.92	34.28	19.45	33.05	***	***	**	***	***
H°	70.70	52.97	70.57	53.31	66.60	ns	***	ns	*	ns
ΔE	–	17.42	19.61	8.59	18.01	***	***	**	–	–
AA (mg/100 g FW)	21.41	21.41	18.67	20.74	15.73	***	***	***	ns	ns
TPC (mg GAE/100 g FW)	55.15	59.41	51.73	64.77	60.69	**	ns	*	*	ns

TA: titratable acidity; TSS: total soluble solids; FW: fresh weight; AA: ascorbic acid; TPC total phenolic content; t: time; P: packaging; MAP: modified atmosphere packaging; ns = not significant; (*) $p \leq 0.05$; (**) $p \leq 0.01$; (***) $p \leq 0.001$

and H° during the storage time. Unpackaged tomatoes had the most reddish color, consistent with the highest intensity of color (external and internal) at sensory level. Consistent with the results obtained, the packaging factor had a significant effect on the color uniformity at 14 days of storage, according to the Pearsońchi-squared test. Tasters indicated that 87.5% of the unpackaged samples had a uniform red–orange color whereas 87.5% of the MAP samples still had greenish-yellowish areas. This fact seems to be related to the faster ripening of unpackaged tomato.

The delay in the color change of the MAP tomato could be attributed to the decrease in the metabolic process responsible for the degradation of chlorophyll pigments and synthesis of lycopene and β-carotene during storage (Aneesh et al., 2008). Results were similar to those obtained by other researchers. Domínguez et al. (2016) indicated that MAP delayed the color evolution (H°) in the Delizia and Pitenza cultivars but the effect was more evident in the less mature cultivar. Sabir and Agar (2011) reported than 1-MCP and, especially, 1-MCP + MAP significantly slowed down H° changes in tomato (cv. Perla). Cherry tomatoes stored under modified atmosphere (5% O_2 + 5% CO_2) showed significant changes in all color parameters during storage for 21 days, but such changes were more pronounced in control samples. A slight L* decline in MAP tomato was associated to a modest amount of browning (Fagundes et al. (2015).

β-Carotene significantly increased in unpackaged tomato after 14 days of storage and then decreased. Biosynthesis of lycopene was also observed after the same period of time, but in this case the change was not significant. In packaged tomato, no changes were observed over time in any of the pigments, being the packaging factor not significant.

Modified atmospheres including either reduced O_2 or elevated CO_2 are usually considered to inhibit carotenoids biosynthesis. Odriozola-Serrano et al. (2009) found a marked decrease in total carotenoids over storage time (21 days) in fresh-cut tomatoes under MAP with 2.5 kPa of O_2 + 5 kPa of CO_2 or 10 kPa of O_2 + 5 kPa of CO_2. Domínguez et al. (2016) reported reduced biosynthesis of lycopene in MAP tomato (cvs. Delizia and Pitenza) which agreed with the results obtained by Fagundes et al. (2015) in cherry tomato (cv. Josefina). Kaur and Bhatia (2016) reported a continous increase of lycopene through the ripening process of two varieties of tomato harvested at pink stage (Punjab Upma and Punjab Ratta) and stored in air or under different packaging material in ambient conditions. This augmentation was corresponded to an increase in the red color as indicated by an increase in a* value with storage time. However, packaged fruits showed lesser and slow accumulation of lycopene. An immediate decline in total chlorophyll content and a steady increase in total carotenoid content during the ripening were also observed for both varieties and MAP slowed down both processes of degradation and biosynthesis, respectively.

Islam, Lee, Mele, Choi, and Kang (2019) studied the effect of fruit size (large, medium, and small) on quality, shelf-life, and microbial activity of MAP cherry tomato (cv. Unicorn). After 20 days of storage at 5 °C, the lycopene content increased regardless of the fruits size in both control and MAP fruits although the effect was smaller in the large fruits. Therefore, the large tomatoes contained less lycopene than the other sizes and this can be due to their slower ripening. As a result, levels of lycopene depended on the level of ripeness of the fruits. In addition, accumulation of lycopene was lesser in MAP fruits of various sizes as compared as control fruits. Different results were reported by Sabir and Agar (2011) who found that 1-MCP or 1-MCP + MAP treatments strongly reduced the lycopene accumulation in tomato (cv. Perla) while MAP alone was not effective.

The AA content maintained quite stable during storage of control samples but tended to decline in the MAP fruits. TPC increased significantly over time but no significant differences were found between the packaging and non-packaging of the samples.

In this second assay, MAP tomato had a significantly higher percentage of fruits with spots (62.5%) than control tomato (12.5%) after 14 days of storage maybe caused by the condensation problems indicated earlier. Results are shown in Fig. 1. In the item “other alterations”, tasters indicated the presence of mechanical damage and rot in both unpackaged and MAP tomato after 14 days of storage as occurred in the first assay. Results showed that the decay of the packaged fruits was accelerated when compared to control fruits; therefore, the 28 days-sampling was not carried out.

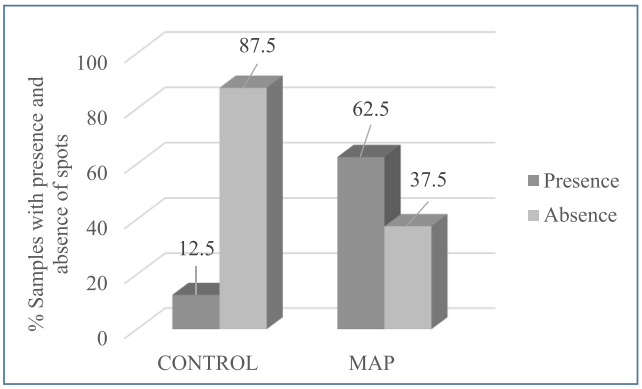

Fig. 1. Percentage of samples with presence/absence of spots in control and MAP tomato after 14 days of storage (second assay).

3.3. Third assay

The packaging conditions used in the first two assays were not the most suitable. Based on these results, silica gel was used as an adsorbent in this third assay which considerably reduced condensation of water vapor which was concentrated mainly in the areas of the pallet furthest from box containing adsorbent.

Table 4 shows the physico-chemical data obtained, together with the corresponding statistical results, for the control and MAP tomato after 0, 7, 14 and 21 days of storage in the third assay carried out.

TA in tomato tended to decrease during storage, the packaging factor being not significant. As for the TSS content, unpackaged tomato presented a slightly higher content of TSS than the packaged one during the first two weeks of storage which indicated that the process of maturation was slower when tomato was stored under modified atmosphere. However, these small differences were not reflected in the greater sweetness of the unpackaged tomato. It is considered that tomato with optimal aroma and flavour must have pH of 4–5 and TSS content of 4–6 °Brix. In general, the values obtained in the three assays were within these ranges.

The puncture force and firmness score significantly decreased in unpackaged tomato after 7 days of storage as expected due to the softening of the fruits during the ripening process. However, no loss of firmness of the MAP tomatoes was observed during the entire storage time, indicating the beneficious effect of the use of silica gel. MAP also reduced the loss of firmness in other tomato cultivars, as reported by other researchers (Aneesh et al., 2008; Domínguez et al., 2016; Fagundes et al., 2015; Vunnam et al., 2014). It has been proved that the modified atmospheres decrease the activity of the pectinesterase and poligaracturonase enzymes involved in the cell wall degradation (Domínguez et al., 2016). It was also suggested that high CO_2 concentration results in suppression of the degradation of protopectin to soluble pectin thus reducing fruit softening (Majidi et al., 2014). Studies carried out by Majidi et al. (2014) concluded that CAS is better than MAP in maintaining firmness of tomato (cv. Super Jeff), but both storage systems were better than the conventional cold storage.

Park et al. (2018) also observed condensation of water vapor when tomatoes (cv. Defunis) were bulk packaged in PE bags and cold-stored, as in our study. However, the use of Xtend MA/MH (modified atmosphere/modify humidity) prevented condensation while maintaining high RH (~95%).

The tomatoes harvested for this assay were quite green in accordance

Table 4
Effect of the storage time and MAP on the physico-chemical parameters of tomato (third assay).

	Day 0	Day 7		Day 14		Day 21		Two-way ANOVA with interaction			*t*-Student test (days 0–7)	
	Control	Control	MAP	Control	MAP	Control	MAP	t	P	t*P	Control	MAP
pH	4.20	3.81	3.60	4.02	4.04	4.25	4.26	***	ns	***	***	***
TA (g citric acid/100 g FW)	0.44	0.41	0.41	0.44	0.35	0.34	0.36	**	ns	ns	ns	ns
TSS content (%)	4.23	4.63	4.13	4.97	4.43	4.30	4.40	ns	*	ns	ns	ns
Moisture (%)	93.50	93.61	94.27	93.67	94.22	93.59	93.89	–	–	–	–	–
Firmness (N)	28.98	25.03	23.06	20.90	25.16	26.63	19.28	ns	ns	ns	**	ns
Lycopene (mg/100 g FW)	3.60	6.21	2.56	6.84	4.32	6.44	5,54	ns	**	ns	*	ns
β-Carotene (mg/100 g FW)	2.21	3.31	2.40	3.10	3.14	3.06	3.38	ns	ns	ns	*	ns
L*	44.00	42.98	39.81	40.89	40.47	42.65	40,46	ns	*	ns	ns	***
a*	1.92	6.46	8.76	8.83	5.44	9.59	6.16	ns	ns	ns	ns	ns
b*	30.71	30.98	29.65	29.68	29.35	29.60	32.09	ns	ns	ns	ns	ns
C*	31.53	32.92	32.76	31.95	31.00	31.64	33.69	ns	ns	ns	ns	ns
H°	86.81	79.77	79.63	74.27	85.74	72.59	80.25	ns	ns	ns	ns	ns
ΔE	–	10.35	13.54	10.93	10.20	10.87	10.61	ns	ns	ns	–	–
AA (mg/100 g FW)	18.52	21.55	16.90	20.78	16.95	16.95	15.56	***	***	*	*	ns
TPC (mg GAE/100 g FW)	61.58	58.23	57.64	60.34	51.92	63.34	62.25	***	**	ns	ns	ns

TA: titratable acidity; TSS: total soluble solids; FW: fresh weight; AA: ascorbic acid; TPC total phenolic content; t: time; P: packaging; MAP: modified atmosphere packaging; ns = not significant; (*) $p \leq 0.05$; (**) $p \leq 0.01$; (***) $p \leq 0.001$

with their values of H° (86.81°) and a* (1.92). Therefore, only small changes in the color parameters were found in agreement with the results from the first harvesting. In the same way, packaged tomatoes shown significantly higher L* than unpackaged fruits over storage time.

The initial β-carotene content significantly increased in control samples after 7 days of storage, remaining later without significant changes. β-Carotene in packaged fruits slightly increased during storage, although changes in its content were not significant.

As for lycopene, its initial amount was 3.60 mg/100 g FW. Large biosynthesis of lycopene was found in control samples at 7 days of storage (6.21 mg/100 g FW); then significant changes over time were not found. MAP delayed biosynthesis of this carotenoid. Lycopene tended to increase in packaged fruits from 7 days of storage reaching the value of 5.54 mg/100 g FW at the end of storage, although differences were not significant.

The initial AA content in unpakaged fruits significantly increased after 7 days of storage and then declined reaching lower values than the initial ones at the end of storage. Domínguez et al. (2016) observed a AA decline in tomato (cvs. Pitenza and Delizia) after few days harvesting and then a notable increase in the more mature cultivar.

AA in MAP tomatoes decreased over time showing lower concentrations than those in control tomatoes in all sampling days as occurred in the second assay when the same packaging atmosphere was used. Other researchers reported a beneficial effect of MAP on the AA content which can be related to the O_2 concentrations inside the packages. Hence, the higher amount of O_2 in the bag's headspace, the greater decrease in vitamin C content. In a study conducted by Fagundes et al. (2015), MAP (5% O_2 + 5% CO_2) reduced degradation of AA in cherry tomato stored for 21 days at 5 °C. Odriozola-Serrano et al. (2009) studied the effect of different initial in-package O_2 and CO_2 concentrations (2.5 kPa of O_2 + 5 kPa of CO_2, 10 kPa of O_2 + 5 kPa of CO_2, and 21, 60, and 80 kPa of O_2) on the vitamin C content in fresh-cut tomatoes (cv. Bola) stored at 4 °C for 21 days. A substantial degradation of vitamin C over the storage time was observed under ≥ 10 kPa of O_2 and the most dramatic effect was under 80 kPa. Instead tomatoes slices stored under 2.5 kPa of O_2 + 5 kPa of CO_2 kept their initial vitamin C content over storage time.

Islam, Mele, Park, Kim, and Kang (2017) studied the effect of surface sterilization with ClO_2 gas on the postharvest quality and shelf-life of MAP tomato (cv. Dafnis). Fruits were previously dipped in fungal suspension and, afterward, treated with ClO_2 at different concentrations and times (1 ppm/6h, 1 ppm/12 h, 1 ppm/24 h, 5 ppm/6h; and 5 ppm/12 h). The authors found that the treatment with 5 ppm/12 h yielded the highest firmness, TA, and vitamin C content. Control fruits (untreated with ClO_2) had the lower values of these parameters. The higher TA and vitamin C content in fruits treated with ClO_2 may occur due to reducing fungal and bacterial decay that helps to reduce the vitamin C oxidation as compared to control fruits.

TPC was significantly higher in unpackaged than MAP tomato. The storage factor was significant although a clear trend depending on the time was not observed. Different results were obtained by other researchers who found higher TPC in MAP than control tomato (cv. Delizia) and considered that the high CO_2 accumulation might be involved (Domínguez et al., 2016).

In this third assay, significant differences in the descriptor "spots" between unpackaged and packaged tomato were observed at 21 days of storage. 100% of the unpackaged fruits showed spots while only 42.9% of packaged fruits had them. Results are shown in Fig. 2A. This indicates that silica gel was effective in reducing moisture accumulation inside packaging bags, thus decreasing condensation and decay rate of tomato. In "other alterations", the tasters indicated the presence of cracks/stretch marks in 42.9% of the unpackaged fruits versus 14.3% in MAP fruits, at the end of storage (Fig. 2B). In the three assays carried out, tasters did not detect the presence of off-aromas in tomato throughout the storage time neither in unpackaged nor packaged fruits.

4. Conclusions

The MAP system with pallets assessed, using a packaging atmosphere composition of 10% O_2 - 10% CO_2 and silica gel as an adsorbent, extended the shelf-life of the tomato stored at refrigeration temperature. Silica gel considerably diminished the accumulation of moisture inside the packaging bags, thus preventing water vapor condensation and premature spoilage of tomato. MAP delayed color evolution and reduced the firmness loss, biosynthesis of lycopene, and the decay rate of tomato. Nevertheless, it would be interesting to evaluate other materials for the packaging bags with higher water vapor permeability as an alternative to the use of silica gel.

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CRediT authorship contribution statement

Vanesa Olveira-Bouzas: Methodology, Investigation. **Consuelo Pita-Calvo:** Formal analysis, Writing - original draft, Writing - review & editing. **Mª Lourdes Vázquez-Odériz:** Conceptualization, Visualization, Writing - review & editing. **Mª Ángeles Romero-Rodríguez:** Project

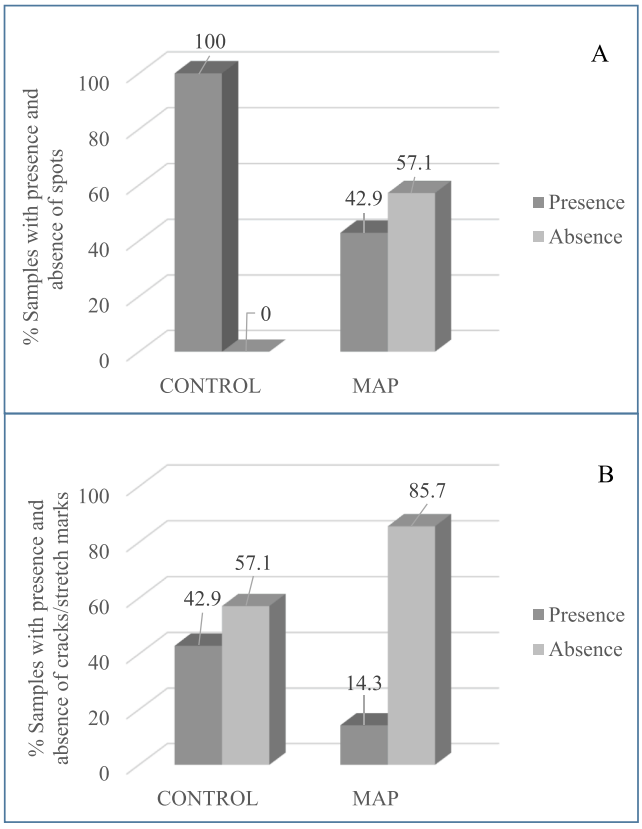

Fig. 2. Percentage of samples with presence/absence of (A) spots and (B) cracks/stretch marks in control and MAP tomato after 21 days of storage (third assay).

administration, Resources, Funding acquisition, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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