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ORIGINAL PAPER

Active Packaging of Cardboard to Extend the Shelf Life of Tomatoes

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Abstract In order to extend the shelf life of fresh tomatoes using biodegradable materials, an active microcorrugated cardboard tray package was tested for use with fresh Cherry tomatoes (*Lycopersicon esculentum* var. *cerasiforme*). Active packaging characteristics were achieved by coating the interior surface of the cardboard tray with polylactic acid (PLA; 3% *w*/*v*) and, after filling with tomatoes, the tray was wrapped with a low-density polyethylene (LDPE) film of 70 or 20 μm thickness and hermetically heat sealed. Uncoated trays were used as control. The trays of tomatoes were stored at 20±0.5 °C and 55±2% relative humidity, for 30 days, and the ethylene concentration in the package atmosphere was measured periodically as an indicator of ripeness. The following fruit quality parameters were also studied: weight loss, surface colour, microbial count, firmness, soluble solids and pH. It was demonstrated that the capacity of PLA to adsorb ethylene and water vapour and the thickness of the LDPE film were decisive for controlling the ethylene concentration of the package atmosphere and for preventing condensation of water vapour on the fruit and film. The active packaging configuration and storage conditions used preserved fruit quality for a month, thus extending the useful life of the tomatoes and saving refrigeration costs.

Keywords Cardboard · Active packaging · Tomato shelf life · PLA · LDPE

Introduction

The shelf life of fresh fruits and vegetables, including tomatoes, has become a factor of major importance for satisfying consumer demands in terms of quality and safety (Jagadeesh et al. 2010). Active packaging, a new concept of food packaging, was developed in response to changes in current consumption and market trends and is designed to improve fresh product quality and safety (Gontard and Guillaume 2010).

The main techniques related with active packaging are substance adsorption (e.g. oxygen, ethylene, moisture, carbon dioxide, flavours/odours) and substance release (e.g. carbon dioxide, antimicrobial agents, antioxidants and flavours; Rodríguez-Lafuente et al. 2010). Cardboard, which is one of the major raw materials used for packaging food, could serve as base material for biodegradable active packages, reinforcing their mechanical properties, improving the humidity barrier and minimising microbial contamination. Such active packages could delay the maturity of climacterics fruits by controlling the surrounding environment of the fruits, providing good yield at a relatively low cost (Taechutrakul et al. 2009). New efforts are continuously being made to obtain more environmentally friendly packaging materials, and, in this respect, polylactic acid (PLA) and cardboard are renewable and biodegradable (Rhim et al. 2007). PLA is a biopolymer that shows a certain resistance to water (Rhim and Kim 2009), so that covering the corrugated cardboard with this hydrophobic biopolymer allows better conservation of vegetable products. Because PLA is compostable and derived from renewable sources, it has

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been considered as one of the solutions for packaging materials (Rhim et al. 2007).

Ethylene (C_2H_4) accelerates respiration, leading to the ripening, softening and senescence of fruit and vegetables. Many suppliers offer C_2H_4 scavengers based on potassium permanganate ($KMnO_4$), which oxidises the ethylene to acetate and ethanol. However, $KMnO_4$ products cannot be integrated into food–contact materials, so they are only supplied in the form of sachets (Taechutrakul et al. 2009; Sammi and Masud 2009). Another type of ethylene scavenger is activated carbon, which acts as an adsorbent agent (Bailen et al. 2006), although it presents problems for use in primary packaging (Martínez-Romero et al. 2009). Ethylene-adsorbing packaging films incorporating finely dispersed minerals such as zeolite clays have been tested successfully. Nevertheless, they are opaque and not capable of adsorbing ethylene sufficiently (Zagory 1995). However, the ethylene adsorption capacity of materials such as cardboard lined with PLA has been little studied for use in active packaging. Taechutrakul et al. (2009) studied the effect of corrugated cardboard containing palm shell charcoal and activated carbon on the shelf life of Cherry tomatoes, and found that it showed potential as an ethylene absorber to delay fruit ripening. Oliveira et al. (2006) studied the ethylene sorption properties of PLA, finding the Langmuir model applicable, since sorption is closely related to the presence of the free volume in PLA. However, no studies have looked at PLA as ethylene adsorbent for use in the active packaging of fresh fruit and vegetables.

When combined with cold storage, modified atmosphere packaging (MAP) can increase the shelf life of fresh products and reduce economic losses due to damage, making longer transport distances possible and lowering moisture loss during storage, while ensuring a high-quality product (Robertson 2006). MAP technology can retard fresh vegetable respiration rates and extend their shelf life. However, to achieve the required modified atmosphere (RMA) in the package, it is very important to control the permeability properties of the packaging film, the respiration rate of the vegetable, and CO_2 gas and vapour release (Caleb et al. 2011). This is the reason why obtaining the desired steady-state gas composition for some fresh vegetables may require the use of macroperforated films, or a combination of microperforations and suitable permeability characteristics in the films used for wrapping the vegetable trays (Lee and Renault 1998; Rennie and Tavoularis 2009; Gontard and Guillaume 2010).

Most applications of MAP for fresh vegetables use a packaging film that allows restricted gas diffusion (ethylene, CO_2, O_2, and vapour) through the film wall. In the packaging design process, the type of material, surface area and thickness of the packaging film are selected to obtain the desired equilibrium gas composition or RMA. The types of film used include low-density polyethylene (LDPE), poly (vinyl chloride), and oriented polypropylene (Smith et al. 2003; Gontard and Guillaume 2010; Sandhya 2010). But, even after selecting the most suitable film characteristics, it is relatively difficult to achieve the RMA due to the complexity of controlling all the factors affecting the gas composition in the package, which moreover, continue to change during the commercial life of the packaged product. In fact, this is the limitation of both active and passive MAP when attempting to prolong even further the shelf life of packaged fresh fruits and vegetables (Gontard and Guillaume 2010). Active packaging can help achieve the RMA during the commercial life of fresh fruits and vegetables and thus obtain better quality, increased safety and a longer shelf life (Gontard and Guillaume 2010; Sandhya 2010).

The main objective of this study was to test active packaging based on cardboard trays coated with PLA and wrapped with LDPE film for the preservation of fresh Cherry tomatoes. The reduction of the ethylene content inside the package and its effect on extending the shelf life of tomatoes at storage temperature of 20 °C were analysed.

Materials and Methods

Experimental Design

Healthy Cherry tomato fruits (*Lycopersicon esculentum* var. *cerasiforme*), with no physical damage and harvested the day before, were supplied by SAT Duran (Mazarrón, Murcia, Spain). The fruits were selected by size and colour (colour 3 of the colour chart of Difrusa Export SA; Artés and Gómez 2003) and transported directly to the laboratory for direct packaging.

The active package consisted of cardboard trays lined with PLA (3% *w/v*) of 80 μm thickness and wrapped with LDPE films of 20 and 70 μm thickness (20 trays for each LDPE thickness). Twenty cardboard trays without PLA lining were used as control for each thickness of the LPDE wrapping film.

The lining PLA solution was prepared by mixing 3 g of PLA in 100 mL of chloroform, using a magnetic stirrer for 2 h. Using calibrated gauges and a metal bar, 2.8 mL of this PLA solution was applied to the surface of the inner wall of the microcorrugated cardboard (area of 25×12 cm). The coated cardboard was dried in an oven at 100 °C for 24 h and cooled to room temperature in desiccators at 20±0.5 °C until use. The thickness and homogeneity of the PLA coating on the cardboard samples were measured using a handheld micrometre (dial thickness gauge Nr 7301, Mitutoyo Co. Ltd., Kawasaki, Japan) with 0.005 mm accuracy. The thickness was determined (after drying) in five positions of the sample along the length of the sample strip, taking the mean values (Rhim and Kim 2009).

Tomatoes were distributed randomly in two layers within each cardboard tray, to reach a weight of 250±10 g. The trays containing the tomatoes were then wrapped with LDPE film of 20 or 70 μm thickness and thermosealed to achieve an airtight closure.

Using a factorial design (2×2), with the factors PLA coating (with and without) and wrapping LDPE film thickness (20 and 70 μm), 80 trays of tomatoes were prepared, with 20 packages for each treatment. All containers were placed in a thermostatic chamber at 20±0.5 °C and 55±2% relative humidity (RH). Samples were taken periodically from three trays per treatment from days 0 to 30 of storage. Analyses were performed in triplicate, determining: ethylene, weight loss, colour, firmness, soluble solids, pH and microbiological count of bacteria, yeasts and moulds in each tray.

Ethylene Determination

The ethylene composition of the package atmosphere was measured using a gas chromatograph (GC), with a Thermo Trace Gas 2000 FID detector (Thermo Finnigan, Milan, Italy) and ethylene GS-Q capillary column (J&W Scientific, Agilent Technologies Inc., USA). For this, 1 mL of gas was extracted from the package atmosphere with a syringe through a silicone septum attached to the wall of the wrapping film of the tray, and 0.5 mL was injected into the GC. The gases used were helium, hydrogen, nitrogen and air at a pressure of 4 bar. The flow rate of hydrogen was 35 mL/min, air flow was 350 mL/min and nitrogen flow 30 mL/min, at a working temperature of 250 °C. Helium was used as carrier gas (16 mL/min; Serrano et al. 2005; Bailen et al. 2006). The standard of ethylene was a mixture of four components: CO_2 (2±0.04%), O_2 (10±0.1%), C_2H_4 (1±0 μL/L), and N_2 (the rest). The results (mean±SE) are expressed as microlitre per litre (ethylene/interior atmosphere). After the ethylene gas analysis, the packages were opened and the tomatoes were used for physical, chemical and microbiological tests.

Weight Loss, Count of Microorganisms, Colour, Firmness, pH and Total Soluble Solids

Weight loss percentage was determined as the difference between the initial weight of the containers with tomatoes and the corresponding weight after the period of storage (n=4), using a balance with an accuracy of ±0.1 g (Gram Precision Series BH, Taiwan).

For quantification of the microorganisms, approximately 25 g of tomatoes were homogenised in 250 mL of sterile saline in a Masticator (IUL Instruments, Spain) to prepare decimal dilutions for plating. To count total mesophilic microflora, dilutions of the homogenate were plated by the pouring method in plate count agar (Cultimar, Spain). To count moulds and yeasts, the same medium was used, adding 0.1 g/L of chloramphenicol (n=9). The plates for counting the total microflora were incubated at 31±1 °C for 72 h and the plates for yeast and mould counts were incubated at 25 °C for 5–7 days. The results are expressed as the logarithms of colony-forming unit per gramme of tomatoes (Log CFU/g; Serrano et al. 2005; Rodríguez-Lafuente et al. 2010).

The surface colour of each of the tomatoes was measured with a colorimeter (Konica Minolta Co. Ltd., Japan) using a D65 light source. Three readings were made at five equidistant points (n=15) for each replica, obtaining the parameters: L lightness, a the balance between green and red, and b the balance between yellow and blue as described in Bailen et al. (2006). The a/b ratio was calculated as an index of maturation.

Firmness was measured with an FT 011, 0–11 lb, penetrometer (Facchini, Alfonsine, Italy), to determine the resistance of the fruit to penetration with a rod of 8.0 mm diameter for soft fruits. The rod was placed perpendicularly on the tomato and the fruit was pressed to cause a gradual visible cut, at which point the measurement was recorded (OECD 2009).

To determine pH and soluble solids, small portions of juice were obtained by squeezing the tomatoes, using a pH metre Crison GLP 21 (Crison Instruments, SA, Barcelona, Spain) and a Digital Hand-held “Pocket” Refractometer PAL-1 (Atago Co., Ltd., Tokyo, Japan). The values are expressed as °Brix.

Statistical analysis

All measurements were made for each sample in triplicate. Sources of variation were the time of storage and treatments. Means comparison was performed ($p<0.05$) by Duncan's multiple range test and by analysis of variance. All analyses were performed using the Statgraphic Plus package version 5.1 (Statpoint Technologies, Inc., Warrengton, VA).

Results and Discussion

Behaviour of Ethylene in the Package

In all cases, ethylene showed maximum concentration inside the packages of tomatoes after the first day of storage. This behaviour is consistent with the results obtained by other authors (Bailen et al. 2006) and it is due to the fact that the greatest release of ethylene in tomatoes occurs shortly after separation from the plant, when fruits contain a high internal concentration of ethylene. It has been demonstrated that tomato skin is an effective barrier to ethylene and is about 1,000 times less permeable to gas exchange than cracked skin. When the tomato is harvested, the ethylene is quickly released from inside the fruit through the scar area of union with the plant (Cameron and Yang 1982). As Fig. 1 shows, the concentration of ethylene in the packages decreased after the first day and reached a minimum value at day 14. This decrease was probably due to the adsorption of ethylene by the PLA coating of the cardboard tray, since PLA-lined packages (wrapped with LDPE film of 70 μm) showed a significantly ($P<0.05$) lower ethylene concentration (0.543 μL/L) than the corresponding uncoated trays used as control (1.127 μL/L), during the storage period. In all the trays coated with PLA and wrapped with the 70 μm LDPE film, a significant ($P<0.05$) increase in ethylene concentration was observed in the third week of storage, when the value reached (1.245 μL/L) was more than double that reached the previous week. This ethylene increase can be explained by the adsorption of water vapour by the PLA coating, leading to the release of ethylene adsorbed in the same PLA coating (Oliveira et al. 2006). At the same time, ethylene-producing microorganisms may cause the supplementary production of ethylene, as might the tomatoes due to microbial stress, making ethylene release through the thick LDPE film wall more difficult. The lowest value detected for ethylene concentration in the PLA-coated trays wrapped with thick LDPE film was 0.54 μL/L in the second week of storage, when the condensation of water vapour was not perceptible. Nevertheless, it may be necessary to further reduce ethylene to increase the shelf life since there is biological action on tomato at concentrations of only 0.1 μL/L (Wills and Warton 2000). In the case of PLA-coated cardboard trays wrapped with thin LDPE film (20 μm), the ethylene concentration was always five- to sevenfold lower than in trays wrapped with thick LDPE film throughout the storage time. However, no great differences were found between the trays wrapped with thin LDPE film, whether or not they were coated with PLA. These results underline the great influence of the thickness of the LDPE film on the rate of ethylene and water vapour release through the film wall for achieving the RMA during the shelf life of fresh tomatoes and at a storage temperature of 20 °C.

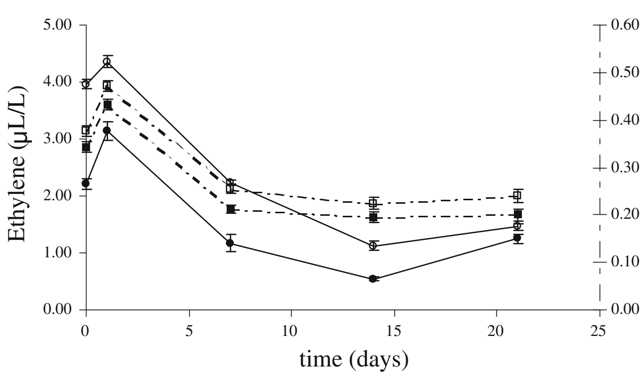

Fig. 1 Evolution of the ethylene concentration within the package of cherry tomatoes based on cardboard trays with and without PLA coating and wrapped in thick LDPE film of 70 μm thickness (*left axis*) or thin LDPE film of 20 μm thickness (*right axis*), during storage at 20±0.5 °C and 55±2% RH. *Empty circle* uncoated and thick LDPE film, *empty square* uncoated and thin LDPE film, *filled circle* PLA coated and thick LDPE film, *filled square* PLA coated and thin LDPE film

The capacity of the PLA coating to absorb ethylene and water is largely responsible for the positive results obtained for tomato quality preservation as demonstrated primarily by colour evolution during storage. Tomatoes packaged in PLA-coated cardboard trays with both types of wrapping films showed higher fruit quality than the fruit stored in the corresponding uncoated packages used as control.

Tomato Fruit Quality Parameters

Figure 2 indicates the evolution of weight loss for tomatoes during the 30 days of storage at 20±0.5 °C and 55±2% RH. In all cases, weight loss was directly proportional to the storage time, and less than 3.5% at the end of the storage period. The weight loss in tomatoes was greatest for uncoated cardboard trays wrapped with thin LDPE film, and lowest for the PLA-coated trays wrapped with thick LDPE film. In studies of different systems for preserving fresh tomatoes, other authors (Artés et al. 1998; Bailen et al. 2006) have found weight losses of 1–4%. The observed loss of water from the tomato fruit did not affect quality, which remained optimal throughout the storage time, with tomatoes maintaining their good appearance of freshness and firmness, and a low microbial count. These quality results suggest that the loss of water in tomatoes was sufficiently controlled by keeping both RH and microbial growth within the package low.

The trays wrapped in thick LDPE film showed greater retention of water vapour from the third week of storage onwards (Fig. 2), resulting in lower weight losses in the

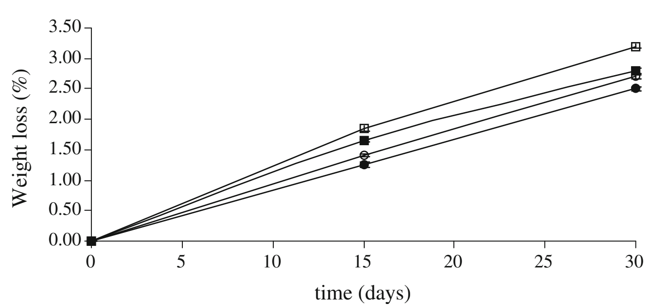

Fig. 2 Weight loss in cherry tomatoes packaged in cardboard trays, with or without PLA coating and wrapped in thin and thick (20 and 70 μm) LDPE film, during storage at 20±0.5 °C and 55±2% RH. *Empty circle* uncoated and thick LDPE film, *empty square* uncoated and thin LDPE film, *filled circle* PLA coated and thick LDPE film, *filled square* PLA coated and thin LDPE film

tomatoes. However, the higher RH within the package caused an increase in microbial growth on the tomato fruits packaged in uncoated trays. This situation led to the rejection (due to the poor appearance of the fruit) of 5% of the tomatoes in trays coated with PLA, and 20% in uncoated trays due to alterations of a microbial origin (Table 1). Packages wrapped with thin LDPE film caused no rejection of fruit as a result of bacterial growth or moisture condensation in any trays during storage, probably due to the better release of water vapour through the thin film wall.

Figures 3 and 4 show the development of yeasts, moulds and bacteria on tomatoes during storage at 20±0.5 °C and 55±2% RH. Microbial proliferation was significantly lower ($P<0.05$) in tomatoes packaged in trays wrapped with thin LDPE film regardless of the coating, a result that was closely related to the moisture content of the container. Nevertheless, all the counts were below 10^4 CFU/g, meeting the standards set for the sanitary conditions of tomatoes (Rodríguez-Lafuente et al. 2010). These results obtained for microbial contamination and quality in tomatoes packaged in PLA-lined cardboard trays after storage for 30 days at 20 °C point to the advantage of using this kind of active packaging. However this packaging system is also very interesting from an energy-saving point of view, because it is possible to obtain a longer shelf life by maintaining the required quality at a temperature much higher than the 8–12 °C storage temperatures recommended for tomatoes (Artés et al. 1998). Some authors, like Siripatrawan and Assatarakul (2009), propose an even lower storage temperature of 5 °C. But postharvest environmental conditions need to be considered carefully when evaluating particular bioactive compounds in fresh tomatoes, because room temperature stored tomatoes can show a significant increase in their lycopene content (Javanmardia and Kubota 2006).

These findings contrast with those obtained by Rodríguez-Lafuente et al. (2010), who evaluated a new active paraffin coating for paper and cardboard for antimicrobial protection (using cinnamon bark and oregano essential oil as antimicrobial agents) and decay retardation in the active packaging of Cherry tomatoes. However, their studied storage time was only 10 days, and ethylene control was not considered.

The variation of parameter *a*/*b*, indicating colour changes in tomato skin during storage, is shown in Fig. 5. Up to the end of the first 2 weeks of storage, there was a significant increase in the *a*/*b* ratio in all cases due to the increase in *a*, although the ratio decreased significantly during the second fortnight due to an increase in the values of *b*. The red colour of tomatoes is due to the replacement of degraded chlorophylls by carotenoids (orange and red) indicating increasing ripening (Artés and Gómez 2003). In general, the peak of ripeness was reached after 2 weeks of storage, although the tomatoes in trays wrapped with thick LDPE film had significantly ($P<0.05$) higher *a*/*b* ratios than those wrapped in thin LDPE film, pointing to faster ripening. In this report, the best behaviour was presented by the tomatoes stored in PLA-coated cardboard trays wrapped in thin LDPE film. So, there was a significant influence of the PLA coating on the value of the colour parameter *a*/*b*, especially in the trays wrapped with thin LDPE film, where the PLA lining absorbed part of the ethylene, contributing to delay maturation. Despite these changes in the *a*/*b* ratio, the tomatoes retained an acceptable red colour between levels 3 and 9 of the Tomato Colour Chart from Difrusa (Artés and Gómez 2003), in the active packaging and storage conditions studied.

Table 1 Defective fruit rejected because of microbial damage in cherry tomatoes packaged in cardboard trays with and without PLA coating and wrapped in LDPE film of 70μm thickness

Coating	7 days	14 days	21 days	Total
Uncoated	–	2	2	4
PLA 3%	–	0	1	1

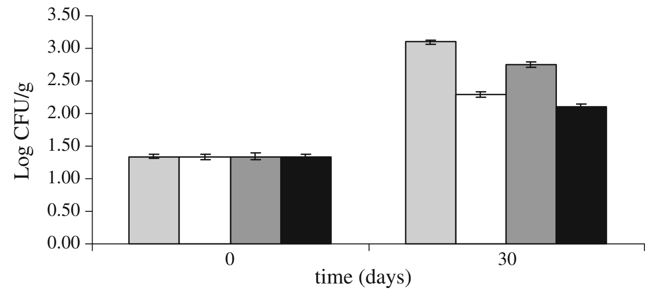

Fig. 3 Growth of bacteria in cherry tomatoes packaged in cardboard trays, with or without PLA coating and wrapped in thin and thick (20 and 70 μm) LDPE film, during storage at 20±0.5 °C and 55±2% RH. *Light grey* uncoated and LDPE thick, *white* uncoated and LDPE thin, *dark grey* PLA 3% coated and LDPE thick, *black* PLA 3% coated and LDPE thin

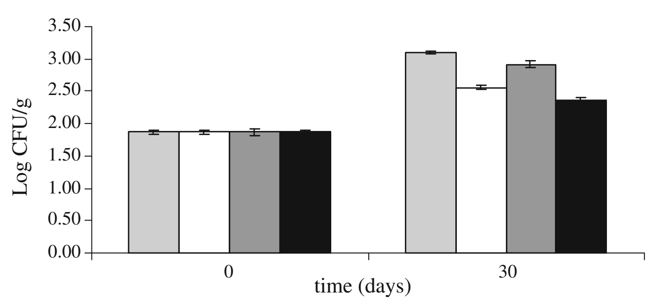

Fig. 4 Growth of moulds and yeasts in cherry tomatoes packaged in cardboard trays, with or without PLA coating and wrapped in thin and thick (20 and 70 μm) LDPE film, during storage at 20±0.5 °C and 55±2% RH. *Light grey* uncoated and LDPE thick, *white* uncoated and LDPE thin, *dark grey* PLA 3% coated and LDPE thick, *black* PLA 3% coated and LDPE thin

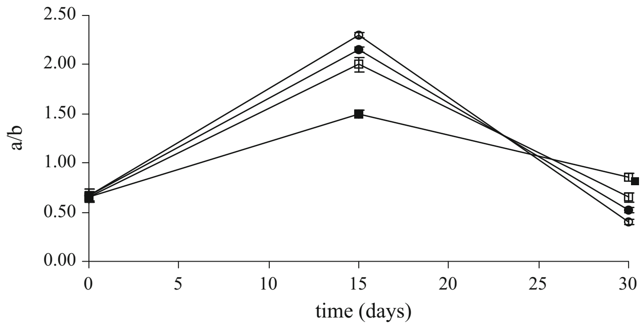

Fig. 5 Changes in colour of cherry tomatoes packaged in cardboard trays, with or without PLA coating and wrapped in thin and thick (20 and 70 μm) LDPE film, during storage at 20±0.5 °C and 55±2% RH. *Empty circle* uncoated and thick LDPE film, *empty square* uncoated and thin LDPE film, *filled circle* PLA coated and thick LDPE film, *filled square* PLA coated and thin LDPE film

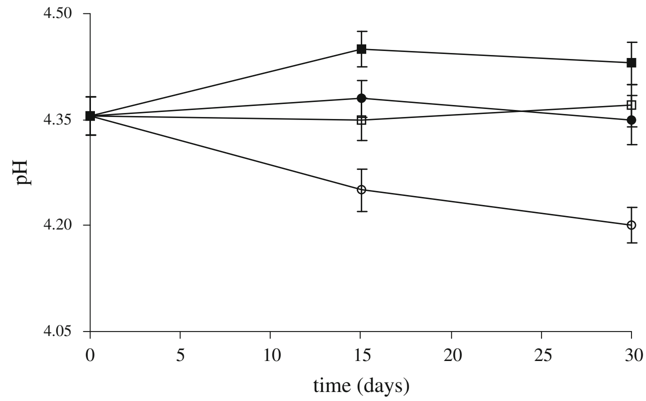

Fig. 7 Changes in pH of cherry tomatoes packaged in cardboard trays, with or without PLA coating and wrapped in thin and thick (20 and 70 μm) LDPE film during storage at 20±0.5 °C and 55±2% RH. *Empty circle* uncoated and thick LDPE film, *empty square* uncoated and thin LDPE film, *filled circle* PLA coated and thick LDPE film, *filled square* PLA coated and thin LDPE film

The firmness of Cherry tomatoes was significantly lower ($P<0.05$) after 30 days of storage at 20±0.5 °C and 55±2% RH (Fig. 6), except for those packaged in PLA-coated trays wrapped in thin LDPE film, which presented no significant differences. The firmness of tomatoes was significantly higher when they were packaged in trays wrapped with thin LDPE film, compared to tomatoes wrapped with thick LDPE film ($P<0.05$) for the same type of packing tray. These results demonstrate the positive effect of low concentrations of ethylene and water vapour on the firmness and other quality parameters of tomato during storage.

Figures 7 and 8 show the evolution of pH and soluble solids in tomatoes during storage in the different packaging systems studied. In general, the change in pH during storage was very small but significant ($p<0.05$), ranging from 4.20 to 4.45 between the different packaging systems. Tomatoes packaged in PLA-coated trays showed less variation in pH (between 4.35 and 4.43) than those packaged in uncoated trays (between 4.20 and 4.37). It is interesting to note the small variation observed in the pH of tomatoes packed in trays wrapped with thin LDPE film, with values ranging between 4.37 and 4.43.

The values of soluble solids in tomatoes packaged in cardboard trays wrapped with thin LDPE film presented no significant changes during the storage time (between 7.40 and 7.45). This observation confirms the interest of this kind of active packaging using thin LDPE film for maintaining the quality of tomatoes during storage. These results agree with those obtained by Srinivasa et al. (2006) in a study of tomatoes in cardboard trays. However, they found some degree of deterioration in tomatoes wrapped with LDPE film of 25 μm after 21 days of storage (at 27 °C) related with shrivelling, blemishes and shine, but there were no significant changes in pH and soluble solids compared with cardboard trays wrapped in chitosan film. These authors did not consider the use of PLA coating.

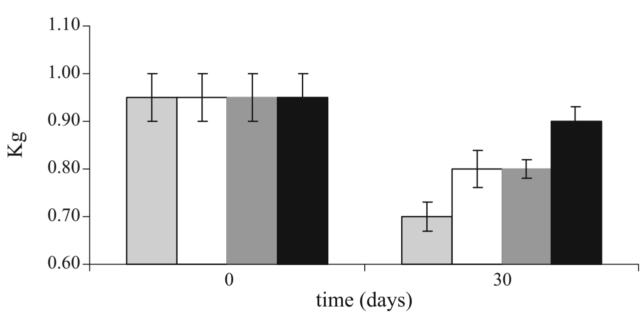

Fig. 6 Changes in the firmness of cherry tomatoes packaged in cardboard trays, with or without PLA coating and wrapped in thin and thick (20 and 70 μm) LDPE film during storage at 20±0.5 °C and 55±2% RH. *Light grey* uncoated and LDPE thick, *white* uncoated and LDPE thin, *dark grey* PLA 3% coated and LDPE thick, *black* PLA 3% coated and LDPE thin

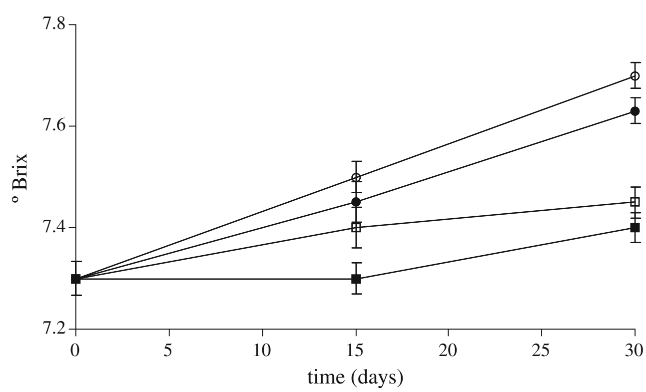

Fig. 8 Changes in soluble solids of cherry tomatoes packaged in cardboard trays, with or without PLA coating, and wrapped in thin and thick (20 and 70 μm) LDPE film, during storage at 20±0.5 °C and 55±2% RH. *Empty circle* uncoated and thick LDPE film, *empty square* uncoated and thin LDPE film, *filled circle* PLA coated and thick LDPE film, *filled square* PLA coated and thin LDPE film

According to Artés et al. (1998), tomato fruits held at a constant 20 °C or 9 °C, or intermittently warmed, increase pectolytic enzyme activity, accompanied by fall in respiration rates and ethylene production. These authors concluded that intermittent warming is more beneficial than intermittent cooling because of pitting development at 2 °C in intermittently cooled fruit. They therefore recommended low storage temperatures (between 9 °C and 12 °C) and intermittent warming, but did not consider active packaging systems.

This work highlights the interest of using active packaging systems as ethylene scavengers for tomatoes, in this case cardboard trays coated with PLA, and an appropriate selection of wrapping film (material and thickness) to maintain the RMA throughout the shelf life of the product.

Conclusions

This study has shown that the PLA coating on the inside of the cardboard tray has a very significant effect on the adsorption of ethylene and water vapour, and can be used in active packaging systems to regulate both factors. In the early stages of storage, there is a little production of water vapour and a high production of ethylene, which is adsorbed in the PLA layer. In later stages, ethylene production in tomatoes falls and water vapour production increases, so that ethylene may be exchanged for water vapour in the PLA layer, allowing the progressive exit of small amounts of ethylene through the wall of the thin LDPE film.

In conclusion, passive modified atmosphere packaging in combination with active packaging using PLA-coated cardboard trays wrapped with thin LDPE film significantly extends the shelf life of fresh tomatoes. This is a good solution for fresh tomato packaging compared with packaging systems using trays wrapped with perforated films because the active package is closed and microbial recontamination by pathogens is avoided. Therefore, microbial safety is better, while ethylene concentration inside the package is controlled at the same time. In addition, with the studied active packaging system, there is a considerable saving of energy during the storage and distribution of fresh tomatoes, as the storage temperature is 20 °C, much higher than the storage temperatures usually used with MAP

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