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POTENTIAL USE OF AN EDIBLE CANDELILLA WAX-BASED COATING TO EXTEND THE SHELF LIFE OF PASSION FRUIT

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ABSTRACT

Passion fruit (*Passiflora edulis* f. *flavicarpa* Degener) is not widely traded due to its short shelf life. Edible coatings can be used to extend the postharvest life of fruits. The objective of this study was to develop a candelilla wax-based coating (*Euphorbia antisyphilitica* Zucc) for the preservation of passion fruit. Three coating formulations (C1, C2, and C3) were made with pectin, glycerol, and candelilla wax and applied by immersion. Weight loss and changes in physical appearance were used to assess shelf life under two storage conditions: room temperature (32 °C/6 days) and refrigeration (6.6 °C/32 days). Uncoated fruit in both storage conditions served as controls. Furthermore, a physicochemical characterization of the coatings was performed. Coated fruit at room temperature showed an improvement in weight retention compared to controls, but no differences in physical appearance were observed. In fruits stored under refrigeration, only C2 had less weight loss compared to the control, while C3 maintained a better physical appearance. In terms of coating characterization, C3 presented the lowest moisture content and thickness. C1 obtained the highest density value, while C1 also had the highest water vapor permeability rate (TPVA) value. The application of the C2 coating was effective in preserving the fruit for a longer period of time, and this coating has the lowest TPVA value, which is related to the decrease in weight loss in the fruit.

Keywords: *Euphorbia antisyphilitica* Zucc, *Passiflora edulis* f. *flavicarpa* fruit preservation, postharvest losses, films, water vapor permeability.

INTRODUCTION

Globally, approximately 25 % of the food produced annually for human consumption is lost or wasted. This is equivalent to about 1.3 billion Mg of food, with fruits and vegetables accounting for half of the losses (Benítez, 2022). Perishable fruit losses imply a decrease in income for both farmers and consumers. Yellow passion fruit (*Passiflora edulis* f. *flavicarpa* Degener) is an example of a perishable fruit that is not widely traded due to its short shelf life. Passion fruit is native to southern Brazil and has spread widely throughout South America, Africa, and Asia. In Mexico, passion fruit is currently grown mainly in the states of Veracruz, Jalisco, Nayarit, and Sinaloa (Pérez-Valadez, 2014). Passion fruit is traditionally used in the production of soft drinks, food creams, crystallized sweets, liqueurs, candies, nectars, jellies, concentrates, in the juice industry, and, to a lesser extent, it is marketed as fresh fruit, possibly due to its short shelf life (Taborda *et al*., 2021). One of the main causes is post-harvest weight loss due to dehydration during storage (Duan *et al*., 2011).

An alternative in the preservation of minimally processed fruits is the use of edible coatings. This is a thin layer of edible materials made from biopolymers such as pectin and starches, proteins such as whey or soy, lipids such as waxes, additives, and bioactive compounds that can then be applied to the food in liquid form (Maan *et al*., 2021). In recent years, the use of edible coatings has played an important role in the food industry, proving to be effective in preserving fruits and vegetables and extending their shelf life. These form a semi-permeable barrier to gases such as O_2 and CO_2, creating a modified atmosphere inside that reduces transpiration and slows the ripening process (Saucedo-Pompa *et al*., 2009). Candelilla wax (*Euphorbia antisyphilitica* Zucc) is an important source of natural and edible lipids that has been used in the formulation of edible coatings, demonstrating its effectiveness as an ingredient to prolong shelf life in fruits and vegetables in combination with other materials (Aguirre-Joya *et al*., 2019According to its chemical properties, candelilla wax contains fatty and organic components with hydrophobic capacity, which in the plant protects the stems from hot and cold temperatures (Aranda-Ledesma *et al*., 2022). Because of its hydrophobic property, candelilla wax has proven useful in the development of films and coatings with low water vapor permeability values. The use of a film based on candelilla wax and other components significantly reduces changes in appearance, solids content, pH, water, and weight loss (Saucedo-Pompa *et al*., 2009). The objective of this study was to develop a candelilla wax-based coating for the preservation of passion fruit.

MATERIALS AND METHODS

Reagents

Food grade citrus pectin was purchased from Droguería Cosmopolita (Mexico City, Mexico). Glycerol (CTR Scientific) and candelilla wax were provided by the Chemistry and Biochemistry Laboratory of the Universidad Autónoma de Nuevo León, Facultad de Agronomía.

Collection and preparation of plant material

Passion fruit was obtained from the local market in Ciudad Valles, San Luis Potosí, Mexico, in the month of May 2018. Once the fruits were acquired, a selection was made taking into account the following parameters: the yellow color characteristic of ripening, smooth texture, and absence of physical damage such as bruises and cuts on the peel. The selected fruits were subjected to a disinfection treatment in a chlorinated solution (50 ppm) for 15 min and then dried with the aid of a conventional fan.

Coating preparation

Three formulations were prepared at different concentrations of each component to prepare the coatings (Table 1). For the preparation of the solutions, the pectin was dissolved in distilled water at room temperature. It was heated to 80 °C and homogenized for 10 s. Subsequently, the solution was heated to 80 °C again for 15 min and the candelilla wax was added, homogenizing the mixture for 3 min. The same heating and homogenization cycle was performed without heating, heating to 80 °C and homogenizing for 2 min, then the mixture was heated again to 80 °C and homogenized for 1 min. Finally, the emulsion was subjected to a cooling period until it reached 40 °C, the glycerol was added, and the mixture was homogenized for 3 min. (Figure 1).

Table 1. Coating formulation.

Coating	Coding	Pectin*	Glycerol*	Cadelilla wax*
1	C1	0.50	0.16	0.07
2	C2	1.00	0.32	0.14
3	C3	1.50	0.48	0.21

*% (w/v)

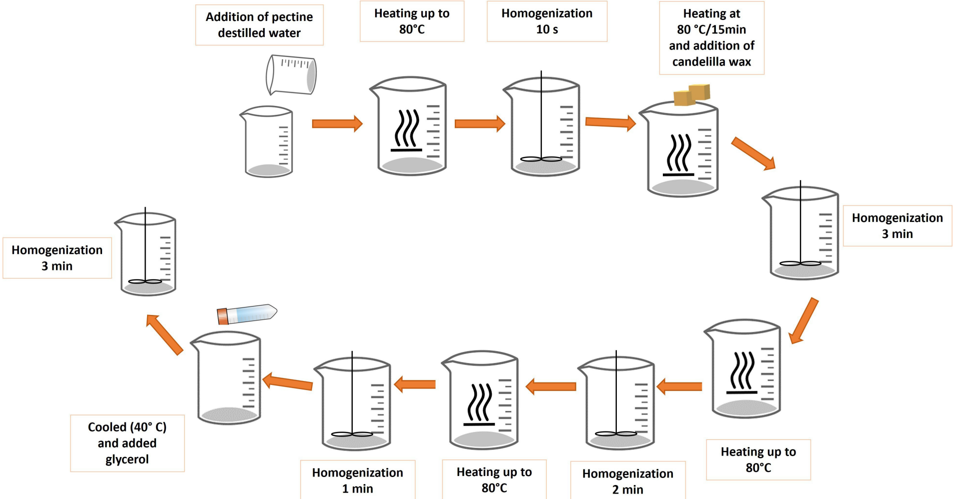

Figure 1. General scheme for coating preparation.

Application of coatings on fruits

For the application of the coatings, the fruits were immersed for 1 min in the different solutions. Subsequently, they were dried at room temperature with the aid of a fan. The process was carried out twice, forming a double layer of coating on each fruit. Each coating was applied in duplicate.

Life testing

Shelf-life tests were conducted under two different storage conditions: ambient (32 °C, 52 % RH) for 6 days and refrigerated (6.6 °C, 23 % HR) for 32 days, the period until the fruit showed microorganism damage. The percentage weight loss of passion fruit was determined by weighing it on an analytic scale. Changes in physical appearance were recorded with photographic evidence (Saucedo-Pompa *et al*., 2009).

Characterization of the films

To characterize the moisture, thickness, density, and water vapor permeability, each formulation was used to make a film by pouring 28 mL into a Petri dish. These were dried at 50 °C for 24 h. The films were removed and characterized immediately after drying. All experiments were carried out in triplicate.

Moisture

The films were cut into 21 mm diameter circles. Subsequently, they were placed in an aluminum container at constant weight and placed in an oven at 105 ± 2 °C for 24 hours. At the end of the drying time, the sample was weighed, and the humidity was calculated using the following formula (Zhang and Han, 2006).

$$\text{Humidity } \% = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

Thickness

The thickness of the films was measured randomly at 20 points using a digital micrometer No. 293-561 Mitutoyo (Japan). Subsequently, the mean was determined and defined as the thickness of the coatings (Bourbon *et al*., 2011).

Density

To perform this determination, 2 x 2 cm pieces of the film were cut and weighed on an analytical balance and the density was determined with the following formula (Sánchez-Aldana *et al*., 2015).

$$\text{Density} = \frac{\text{Sample weight}}{\text{Thickness} \times \text{Sample area}} \times 100$$

Water vapor permeability

It was performed according to the ASTM E96-00 gravimetric method (Choi and Han, 2001). The film was placed in an acrylic container with drying material inside a desiccator, adding 400 mL of distilled water and a small fan running to keep the system temperature 22 °C. The film was weighed at 10 min intervals for 40 min. The following formulas were used to determine the amount of water transferred:

$$VTVA = \frac{\frac{gH_2O}{t}}{A}$$

where VTVA is the water vapor transmission rate, gH_2O is the weight loss in g, t is the time in h, and A is the film area in m^2.

$$TPVA = \frac{VTVA * X}{\Delta P}$$

where TPVA is the water vapor permeability rate, X is the film thickness in m, and ΔP is the pressure difference in Pa.

Statistical analysis

Results are expressed as mean ± standard deviation. Results were analyzed by analysis of variance (ANOVA) and comparison of means with Tukey's test ($p < 0.05$). Analyses were performed with Statistica version 12 software.

RESULTS AND DISCUSSION

Life testing

Fruit weight loss (Figure 2) stored at room temperature did not show significant differences ($p < 0.05$) between treatments but did show significant differences with respect to time. At room temperature, the control group lost 26.06 % of its weight at day 6, while the coated fruit lost between 18.35 and 25.22 % of its initial weight.

This weight loss in the fruit is due to the natural ripening cycle being delayed by the barrier properties of the coatings. All climacteric fruits continue their respiration and weight loss processes since harvest (Barreiro and Sandoval, 2006). Transpiration and ethylene release are some of the causes of weight loss in fruits, along with CO_2 (Ulloa, 2007). Ethylene is responsible for ripening, and, consequently, respiration and transpiration. By reducing the access to oxygen in fruits, the metabolic processes after cutting are reduced, as is the expulsion of CO_2, water, and ethylene production; however, when there is insufficient oxygen, by-products such as alcohols, aldehydes, and ketones begin to form, giving bad taste to the food (Barreiro and Sandoval, 2006.

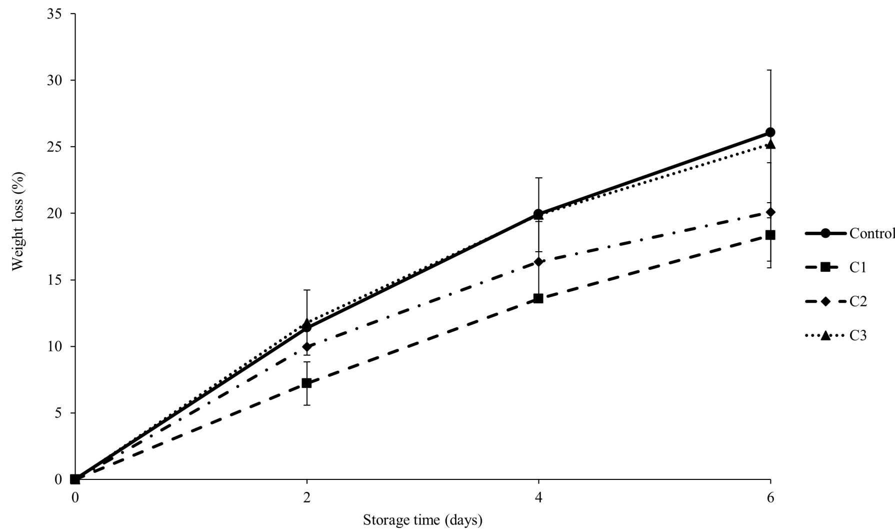

Figure 2. Passion fruit weight loss graph (treatments and controls) stored at room temperature (32 °C, 52 % RH).

According to Barreiro and Sandoval (2006), passion fruit is one of the highest ethylene-producing fruits known, with an ethylene production rate ranging over 100 uL kg^{-1} h^{-1} of C_2H_4 at 20 °C at maximum climacteric. Furthermore, passion fruit has a sensitivity to weight loss of 5 % for every 10 °C (de la Cruz *et al*., 2010). Lower weight loss was observed in fruits with coatings C1 and C2 stored at room temperature due to the migration of moisture and gases such as ethylene due to the ability of candelilla wax, pectin, and glycerol combined, on the reduction of permeability, because candelilla wax as a lipid compound reduces dehydration due to its low polarity, providing a hydrophobic layer (Oregel-Zamudio *et al*., 2016).

The results obtained are similar to those reported by de la Cruz *et al*. (2010), who conducted storage studies at 35 °C of fruit from three passion fruit cultivars from the state of Veracruz at different altitudes and reported weight losses of up to 49 % on day 10. This leads us to evaluate the combination of a conventional preservation method, such as refrigeration, and the various coatings developed.

When stored under refrigeration (Figure 3), weight loss did not differ ($p < 0.05$) between treatments. The fruit with C2 coating lost 25.49 % of its weight, being the only one that showed an improvement in comparison to the control, which showed 35 % weight loss. However, fruits with coatings C1 and C3 showed a weight loss of 37.52 and 47.19 %, respectively, compared to the initial day. This weight loss greater than that of the control occurred from day 4 of storage.

The result obtained in C3 coincides with Ruiz-Martínez *et al.* (2020), who reported that in candelilla wax, whey protein and glycerol coatings had greater weight losses in tomatoes than the controls, which could be due to the formation of a less complex matrix on the surface of the fruit that exposed the whey protein and glycerol,

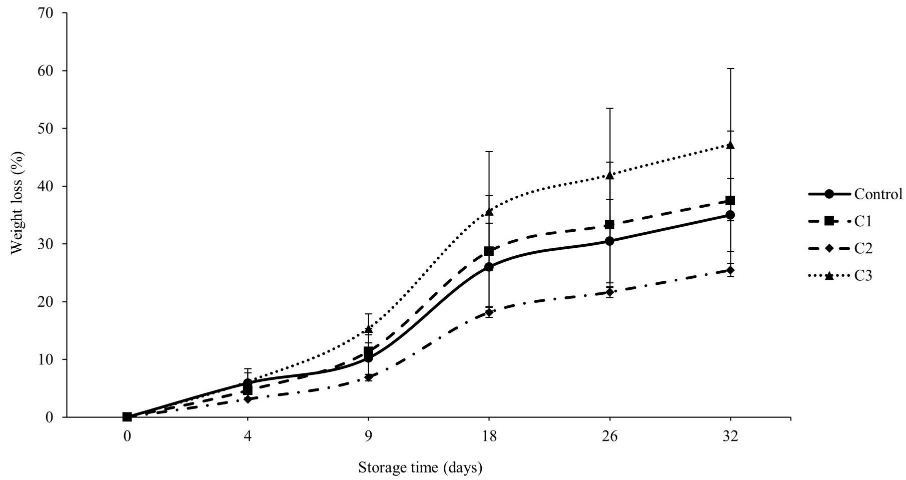

Figure 3. Passion fruit weight loss graph (treatments and controls) stored under refrigeration (6.6 °C, 23 % RH).

which allowed water molecules to flow from the interior to the exterior due to their hydrophilic character, causing the fruits to lose weight. This same situation could occur in the coatings used in passion fruit, but with glycerol and pectin, which are hydrophilic compounds.

On the other hand, it has been observed that increasing plasticizer concentration leads to a proportional increase in water permeability in chitosan and gelatin coatings (Vázquez-Briones and Guerrero-Beltrán, 2013), and the use of two layers of glycerol coating may be a reason for higher permeability. Furthermore, the thickness of the coating causes an accumulation of ethylene (C_2H_4) in the tissues, increasing the rate of respiration and increasing the permeability of the cell membrane, allowing greater exchange of oxygen and end products of respiration, resulting in weight loss (Barreiro and Sandoval, 2006). Although low temperatures are useful for preserving food and reducing ethylene production, they were only useful for coating C2. Low temperatures were not efficient in coatings C1 and C3, which could be due to the fact that formulation C1 may have contained a smaller amount of the material required to avoid gas migration due to a lower percentage of candelilla (0.07) and glycerol (0.16) than that required for this fruit.

Ascencio-Arteaga *et al.* (2022) obtained better results in the percentage of weight loss for mulberry coatings, with candelilla wax at 0.4 % and glycerol at 0.3 %, similar to the C2 coating of this research, which did obtain a positive result by modifying the exchange of gases between the fruit and the exterior. In contrast, for glycerol concentrations, the C3 coating was higher than that reported by Ascencio-Arteaga *et al*. (2022). Furthermore, the fruit may have suffered cold damage during refrigerated storage, such as tissue rupture, water loss, and ripening process disorders (Barreiro and Sandoval, 2006).

Transpiration and weight loss of passion fruit is related to the amount of peel in the fruit, which, as reported by de la Cruz *et al.* (2010), is determined by altitude. In their study, the fruits with the least amount of skin and the lowest transpiration and weight loss were those grown at a higher altitude (1200 m). However, the fruits in this study were collected from the local market, result of backyard planting in the Huasteca Potosina, where fertilization and irrigation are not carried out, particularly in the municipality of Aquismón, San Luis Potosí, which is located at an altitude of 100 m.

In comparison to the refrigerated control, the coating C2 prevented further dehydration. On the contrary, formulation C3 contains a higher concentration of pectin, candelilla wax and glycerol, compared to the other formulations, being this the one that showed negative results compared to the control, the weight loss may be attributed to the increase of glycerol in the coatings or it may be due to the pressure inside the fruit caused by the coating that may also affect if it is too dense (Vázquez-Briones and Guerrero-Beltrán, 2013). Therefore, the coating C2 at refrigeration temperature had a longer shelf life in the fruit.

Regarding the changes in the physical appearance of the fruits (Figure 4), coatings C1 and C2 prolonged the characteristic coloration of the fruit at sight for a longer time, as well as a lower roughness in the peel, in addition to acquiring shine due to the candelilla wax (Bucio *et al*., 2021). However, a color change at room temperature was observed in the C3 coatings, because the external changes in fruit appearance are related to climacterium, which causes changes in fruit pigments. Even after the climacterium has risen, it continues to deteriorate, with changes in characteristics such as external color, texture, and maturity, as well as flavor and aging.

Changes in texture occur during ripening as proto-pectin is converted to soluble pectin and by starch hydrolysis, and once the peak is reached, the metabolic processes continue, causing further changes in the fruit. Additionally, because coatings C1 and C2 contained less glycerol than C3, they retained their appearance better due to the concentration of the plasticizer, which may have resulted in higher ethylene production and, in turn, an acceleration of fruit deterioration by metabolic processes (Barreiro and Sandoval, 2006).

Characterization of the films

As for the characterization of the films (moisture, thickness, density, and permeability) (Table 2), films C1 and C3 showed no difference ($p < 0.05$), and C2 had the highest moisture percentage (26.77 %). Oregel-Zamudio *et al.* (2016) reported a moisture content of 16.43 % in coatings based on candelilla, guar gum, and glycerol. Minimum moisture content of up to 8.48 % has been reported in films based on rice starch, carrageenan, stearic acid, and glycerol (Thakur *et al*., 2016). Films based on mango peel flour and glycerol report a humidity of 3.11 % (Torres-León *et al*., 2018). However, it has not been reported that coatings must have a specific moisture content for application to food (Oregel-Zamudio *et al.*, 2016), despite the fact that low moisture content favors moisture-sensitive food packaging (Zhang *et al*., 2020).

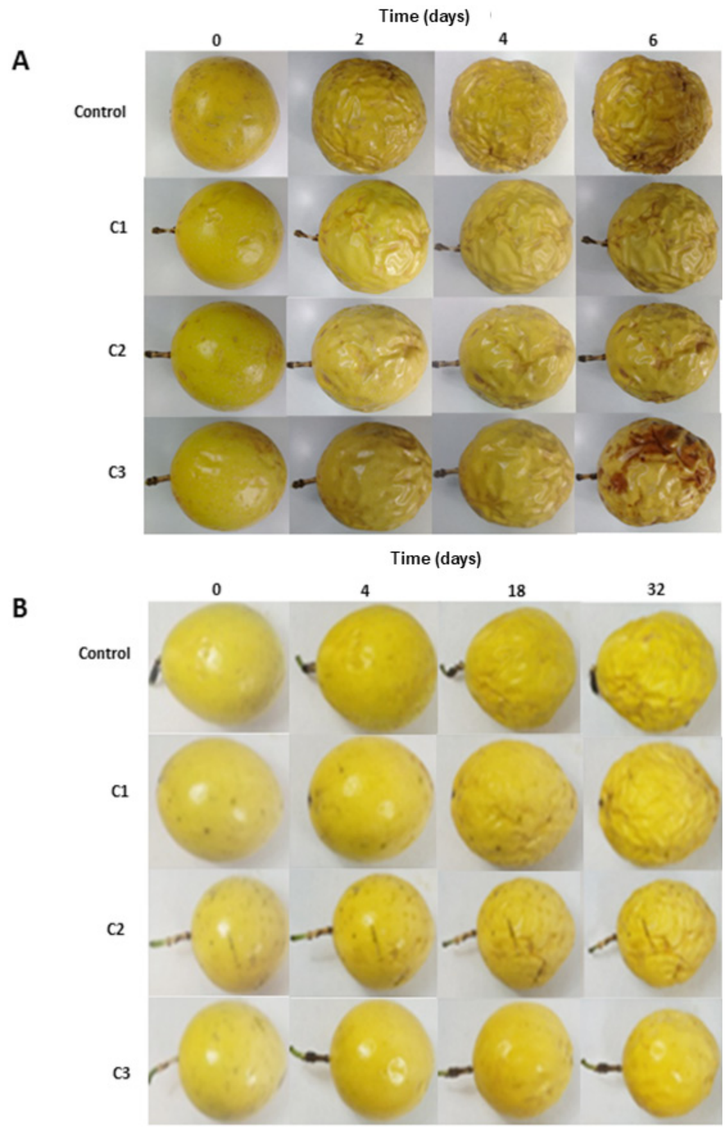

Figure 4. Changes in fruit physical appearance. A: Fruit stored at room temperature (32 °C, 52 % HR); B: Fruit stored in refrigeration (6.6 °C, 23 % RH).

Table 2. Film characterization.

Coating	Moisture (%)	Thickness (μm)	Density (g mL^{-1})	TPVA (g h^{-1} m^{-1} Pa^{-1})
C1	18.60 ± 3.44 a	96.6 ± 0.9 a	0.88 ± 0.04 a	4.17 ± 0.25 a
C2	26.77 ± 4.36 b	95.7 ± 0.4 a	0.54 ± 0.03 b	1.60 ± 0.33 b
C3	12.45 ± 3.72 a	63.8 ± 0.8 b	0.45 ± 0.04 c	2.04 ± 0.05 b

abc: Values measured by column with different letters show statistically significant differences ($p < 0.05$).

Another evaluated characteristic of the films was the thickness. In this parameter, C1 and C2 films had the highest thickness values, being greater than 95 μm without statistical difference ($p < 0.05$), while C3 was the thinnest film with a value of 63.8 μm. Aguirre-Joya *et al.* (2018) obtained thinner films of up to 10 μm using the same components but different concentrations. On the other hand, films based on cashew gum and polyvinyl alcohol showed a thickness of 200 μm (Moreira *et al*., 2020). Oregel-Zamudio *et al.* (2016) reported that a thicker coating (73 μm) allows a lower water vapor permeability rate. However, in this study, the C1 and C2 coatings had similar thickness values but different TPVA values.

In terms of density, all formulations showed differences ($p < 0.05$), with C1 having the highest density and C3 the lowest. An inverse relationship is observed between density and the number of solutes in the formulation, with the less dense coating containing the most solutes in its composition. This relationship may be due to the water-holding capacity of the solutes. Density is an important property as it ensures film stability and helps maintain product integrity (Dhanapal *et al*., 2012). Other candelilla wax-based films have reported densities lower than 0.2 g cm^{-3} (Oregel-Zamudio *et al*., 2016). This suggests that it is possible to create less dense films that have less of an influence on the barrier properties of the fruit.

Coatings C2 and C3 showed no difference ($p < 0.05$) in TPVA with the lowest value. Coating C1 had a high TPVA value of 4.17 g h^{-1} m^{-1} Pa^{-1}. Water vapor permeability of materials is one of the most important properties of edible coatings and films in food packaging, due to the importance of water in spoilage reactions that directly influence the shelf life of food products (Bourbon *et al*., 2011). Therefore, the lower the water vapor permeability value, the better the barrier property (Du *et al*., 2016). This is supported by the fact that the C2 coating had the lowest TPVA value and also had the lowest weight loss in fruit stored at ambient and refrigerated temperatures, indicating that there is a direct relationship between TPVA and weight loss of coated fruit. The main materials used in the production of edible coatings are polysaccharides and proteins, which are hydrophilic compounds that in some cases cannot control the loss of moisture from food, so the main alternative is the use of lipid substances such as waxes that better meet this barrier property (Lin and Zhao, 2007).

CONCLUSIONS

The use of coatings had a positive effect on the preservation of passion fruit with formulation C2 in both room temperature and refrigeration storage compared to the uncoated control, reducing weight loss and maintaining a good physical appearance. Passion fruit cultivation in the Huasteca Potosina region could be boosted by using preservation techniques such as edible coatings. The coating characterization indicates a clear relationship between water vapor permeability rate and fruit weight loss, making it the most relevant coating characteristic.

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