Vol. 18, No. 3 (2019) 789-801
Revista Mexicana de Ingeniería Química
Ingeniería de alimentos

EFFECT OF A CORN STARCH COATING OBTAINED BY THE COMBINATION OF EXTRUSION PROCESS AND CASTING TECHNIQUE ON THE POSTHARVEST QUALITY OF TOMATO

EFECTO DE UN RECUBRIMIENTO DE ALMIDÓN DE MAÍZ OBTENIDO MEDIANTE LA COMBINACIÓN DEL PROCESO DE EXTRUSIÓN Y TÉCNICA DE CASTING SOBRE LA CALIDAD POSCOSECHA DE TOMATE

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Received: November 15, 2018; Accepted: March 8, 2019

Abstract
The aim of this work was to validate the effect of a corn starch coating (CSG) on the postharvest quality of tomato fruit (*Solanum lycopersicum* L.) cv. Imperial. To obtain the study coating, corn starch and plasticizers (sorbitol and glycerol) were processed in a twin screw extruder and casting technique was used. Three treatments in freshly harvested tomatoes were applied: control (without coating), carnauba wax (CW, commercial coating) and CSG, and were stored at 12 ± 1 °C. Weight loss, firmness, external color, pH, total soluble solids, titratable acidity, respiration rate (RR) and ethylene production (EP), were evaluated. CSG was effective to maintain the physical and chemical quality of tomatoes, recording similar or better values than those of CW. Treatment CW recorded a range of 15.85-32.15 % of less weight loss regarding to control and CSG between days 10 and 20 of storage. Whilst, CSG-covered fruit presented the lowest RR and EP compared with Control and CW. CSG obtained by a combination of extrusion-casting could be employed to maintain during 28 days the postharvest quality and extend the shelf life of tomato fruit.
Keywords: starch, coating, extrusion-casting, tomato, postharvest quality.

Resumen
El objetivo de este trabajo fue validar el efecto de un recubrimiento de almidón de maíz (RAM) sobre la calidad poscosecha de tomate (*Solanum lycopersicum* L.) cv. Imperial. Para obtener el recubrimiento de estudio, se procesaron almidón de maíz y plastificantes (sorbitol-glicerol) en un extrusor de doble tornillo y se empleó la técnica de casting. Se aplicaron tres tratamientos en tomates recién cosechados: control (sin recubrimiento), cera de carnauba (CC, recubrimiento comercial) y RAM, y fueron almacenados a 12 ± 1 °C. Se evaluó la pérdida de peso, firmeza, color externo, sólidos solubles totales, pH, acidez titulable, tasa de respiración (TR) y producción de etileno (PE). RAM fue efectivo para mantener la calidad física y química de los tomates, registrando valores similares o mejores que los de CC. El tratamiento CC registró un rango de 15.85-32.15 % de menor pérdida de peso, con respecto a control y RAM, entre los días 10 y 20 de almacenamiento. La fruta recubierta con RAM presentó la menor TR y PE, comparado con Control y CC. RAM obtenido mediante la combinación de extrusión-casting podría ser empleado para mantener durante 28 días la calidad poscosecha y extender la vida de anaquel del tomate.
Palabras clave: almidón, recubrimiento, extrusión-casting, tomate, calidad poscosecha.

1 Introduction

Tomato (*Solanum lycopersicum* L.) is a climacteric fruit that has a relatively reduced postharvest life since many processes after harvesting contribute to its quality loss. Therefore, the main factors that limit the tomato fruit storage are transpiration, ripening acceleration, senescence and fungal infection (Zapata *et al*., 2008). The storage at low temperature is reliable for freshness retention and shelf-life extension, because of it reduces the thermal decomposition and respiration rate (Ali *et al*., 2010). To control ripening, tomato is stored and distributed at 10-12 °C. At these

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https://doi.org/10.24275/uam/izt/dcbi/revmexingquim/2019v18n3/Fitch
issn-e: 2395-8472

temperature, the storage period is quite short and limits its trade to distant countries that represent a market opportunity for Mexican producers (Das *et al.*, 2013). Therefore, new strategies and technologies to maintain quality and extend shelf life of tomato are required.

The use of edible coatings (EC) is a promising technology to maintain the quality of fruits and vegetables. The EC act as barrier, having a similar effect to that promoted by controlled or modified atmospheres, controlling moisture transfer, carbon dioxide (CO_2), oxygen (O_2), lipids and flavor components (Chiumarelli and Hubinger, 2014). In addition, functional ingredients such as antioxidants, antimicrobials, nutraceuticals, flavorings and colorants, could be carried by the films (Das *et al.*, 2013; Flores-Martínez *et al.*, 2017; López-Hernández *et al.*, 2018). According to the desired food application, EC can be produced from a type of material or a mixture. The materials commonly employed in the production of EC are lipids, resins, proteins and polysaccharides (Costa-García *et al.*, 2012; López-Díaz *et al.*, 2018; Núñez-Gastélum *et al.*, 2019). Lipid-based coatings, like waxes, are the most commonly used in food industry since they are generally effective barriers to moisture, however they have certain disadvantages such as brittleness, inhomogeneity, presence of pores and cracks at the surface and they can cause anaerobic conditions at higher storage temperatures due to their low gas-permeability characteristics (Hashmi, 2014). For this reason, the use of polysaccharides was proposed to obtain EC.

Polysaccharides-based coatings have low gases permeability, which could reduce the fruits respiration rate. The most important polysaccharide used in the formulation of EC is starch (Chiumarelli and Hubinger, 2014; López-García *et al.*, 2017). Starch-based coatings are extensively used because they are odorless, tasteless, transparent, biodegradable and good gas (CO_2 and O_2) exchange barrier. However, due to the hydrophilic character of the starch coatings, these present high water vapor permeability and solubility (Sánchez-Ortega *et al.*, 2015). To overcome these disadvantages further modification is usually necessary.

Physically modified starches could be produced, particularly, using twin-screw extruders in a continuous process obtaining a consistent product of good quality. The extruders are an excellent mixing devices which could produce highly viscous fluids such as gelatinized starch (Woggum *et al.*, 2014). Previous works indicate that, starches can suffer changes at intra and intermolecular levels by effect of the high-shear and high-temperature conditions of the extrusion process (Sagar and Merrill, 1995) which could improve the properties of the obtained products, such as, EC. Studies related with the processes to obtain coatings suggests that, probably, the casting technique (CT) is the traditional procedure applied in research areas. The CT begins from a solution containing the polymer former and a heating with excess water (Zamudio-Flores *et al.*, 2007), however using native starch the EC formation is difficult. Fitch-Vargas *et al.* (2016) found that the use of extrusion process as a pretreatment to the CT is an alternative to generate the physical starch modification to obtain EC with improved mechanical and barrier properties, and maintain the postharvest quality of fresh products. Therefore, to give continuity to this research, the aim of this work was to validate the effect of a corn starch coating obtained by a combination of extrusion process and casting technique on the postharvest quality of tomato fruit (*Solanum lycopersicum* L.) cv. Imperial.

2 Materials and methods

2.1 Materials

Corn starch was supplied by Ingredion (IL, U.S.A.), glycerol was purchased from JT Baker® (PA, U.S.A.) and sorbitol was obtained from Cedrosa S.A. de C.V. (Edo. Mexico, Mexico). Carnauba wax was supplied by Decco® (Valencia, Spain); this is a commercial coating composed by a mixture of esters of high molecular weight acid and hydroxyacids. Tomato (*Solanum lycopersicum* L.) fruits cv. Imperial at mature green stage, classified based on size, color uniformity, freedom of physical and microbial injury, were harvested during the 2016 season at a local farm in Culiacán, Sinaloa, the most important Mexico's area in tomato production.

2.2 Corn starch coating preparation

The starch coating formulation was obtained according to Fitch-Vargas *et al.* (2016). For this purpose, corn starch, glycerol, and sorbitol were used. The blend was prepared by mixing 80 % corn starch with 20 % plasticizers (sorbitol and glycerol, 79.7 and 20.3 %, respectively). The mixture was processed in a twin screw extruder (Shandong Light M&E, Model

LT32L, China) with a L/D of 18.5, screw compression ratio of 2:1, and a circular die with 19 mm of length, 42 mm of diameter and an output of 5 mm was used. The extrusion process conditions were: temperature profile = 70-90-89 °C (the 3 zones of heating were independently electrically heated, and air-cooled), and screw speed = 66 rpm. The extruded final product (thermoplastic starch) was received in water at a ratio of 1:4 to avoid retrogradation. The final product was named extruded mixture.

2.3 Coatings application

Tomatoes were washed with sodium hypochlorite solution (100 ppm) and dried under ambient conditions. Fruits were randomized into three groups, control (without coating), carnauba wax (CW, commercial coating) and corn starch coating (CSG, study coating).

Casting technique was used to obtain the CSG. For this, 300 mL of the extruded mixture were heated at 80 °C and stirred for 10 min on a plate (Fisher Scientific, Waltham, MA, U.S.A.) to get a gelatinized solution. Finally, the CSG was cooled to be applied on the fruit surface.

The coatings (CW and CSG) were applied manually, scattering 0.25 mL of solution on the entire fruit surface with a small perfectly clean cloth at 25 ± 1 °C (simulating the conditions used in the packinghouse). The fruits were kept under refrigeration at 12 ± 1 °C for a period of 28 days with a relative humidity of 90 ± 5 % for their posterior characterization. The weight loss percentage evaluation was carried out every 2 days for 28 days. The firmness, external color, total soluble solids, pH and titratable acidity were recorded every 5 days for 20 days. Whilst, RR and EP were measured in two periods; the first one immediately after harvest daily for 8 days (to record the climacteric peak), and the second one after 10 days of commercial storage at 12 ± 1 ° C during 7 days.

2.4 Physical analysis

2.4.1 Weight loss percentage

Weight loss percentage (% WL) was determined according to the methodology reported by Costa-García *et al*. (2012). The determination was performed using 10 fruits per treatment; the weight was recorded every two days with the use of a balance (Sartorius TE 4101, Gottingen, Germany). Values were expressed as % WL regarding to the initial weight, using the Eq. (1):

$$\%WL = \frac{(\text{Initial Weight} - \text{Final Weight})}{(\text{Initial Weight})} \times 100 \quad (1)$$

2.4.2 External color

External color was measured according to the methodology employed by López-Valenzuela *et al*. (2011). A reflectance colorimeter (Chroma Meter CR-200, Minolta, Osaka, Japan) with pulsed xenon arc lamp and 8 mm diameter measuring area was used, where three different points of the equatorial region of three tomato fruits per treatment were taken.

The parameters L*, a* and b* of the CIE color scale were registered, where L* represents the brightness of color and ranges from black to white with values from 0 to 100, the positive and negative value of a* indicates red and green coloration, respectively; while the value of b* indicates the change from yellow to blue (McGuire, 1992). The total color difference (ΔE) was calculated taking as reference the fruit values at day zero and using the Eq (2)

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (2)$$

2.4.3 Firmness

The firmness was evaluated according to the method reported by Mejía-Torres *et al*. (2009) with some modifications. The measurements were determined at three equidistant points of the tomato fruit slices (cut from the equatorial region) with a digital penetrometer (Chatillon DFE 100; AMETEK Inc, Largo, FL, U.S.A.) adapted with a flat tip of 11 mm in diameter. The pericarp wall, was penetrated in the tissue to a 5 mm of depth and speed of 100 mm/min. Data were expressed in Newtons (N).

2.5 Chemical analysis

2.5.1 Total soluble solids

Total soluble solids (TSS) were determined employing a refractometer (Atago, Fisher Scientific, GA, U.S.A.) and expressed as °Brix. Twelve slices per replicate were evaluated.

2.5.2 Titratable acidity and pH

Titratable acidity (TA) and pH were evaluated following the methodology of Calderón-Castro *et al*. (2018). Twenty g of tomato fruit were homogenized employing an Ultra-Turrax (IKA T18 basic Ultra-Turrax, Germany) with 100 mL of neutral distilled water and filtered. TA was determined titling 20 mL of the homogenized solution with 0.1 N NaOH (until reaching a pH value of 8.1 ± 0.2) and was expressed as citric acid percentage. Meanwhile, the pH of the tomato solution was measured with a potentiometer (Orion Research Inc., Beverly, MA, U.S.A).

2.6 Physiological analysis

2.6.1 Respiration rate and ethylene production

To measure changes in respiration rate and ethylene production, the methodology reported by López-Valenzuela *et al*. (2011) was employed. Twelve fruits per treatment were weighed and placed in three 5-liter hermetic glass jars; they were conditioned at 21 ± 1 °C (to simulate marketing conditions) and connected to a continuous flow (20 mL · min^{-1}) of humidified air. The measurements were carried out in two periods. In the first period, the physiological changes in freshly harvested fruits were evaluated daily for 8 days, while in the second period the fruits stored during 10 days at 12 ± 1 ° C were evaluated during 7 days. CO_2 and ethylene productions were monitored using a digital O_2/CO_2 analyzer (Gas control systems, Inc, Model GCS-150, MI, U.S.A.) and a digital C_2H_4 analyzer (Gas control systems, Inc, Model ICA 56, MI, U.S.A.). Ethylene production rate was expressed as ppm and the CO_2 production was correlated with the air flow and fruit weight employing the Eq. (3):

$$\frac{mLCO_2}{kg \cdot h} = \frac{([CO_2]inlet - [CO_2]outlet)(F \times 60min)}{100 \times W} \quad (3)$$

Where F = air flow (20 mL · min^{-1}); W = sample weight (kg). Using a correction factor of 1.84, corresponding to the temperature used, results were reported as mg CO_2/kg · h at 21 ± 1 °C.

2.7 Statistical analysis

For data analysis, a completely randomized factorial experimental design with 3 replicates was performed. The factors for the physical and chemical analysis were type of coating (Control, CW and CSG) and days of storage (until 20 days for external color, firmness, SST, pH and TA, and until 28 days for % WL) at 12 ± 1 °C. For physiological analysis, the factors were type of coating (Control, CW and CSG) and days of ripening at 21 ± 1 °C. Data statistical analyses were carried out through analysis of variance (ANOVA) with Statgraphics plus 6.0 (Manugistics, Rockville, MD, U.S.A.) and means were compared using Fisher's minimum significant difference (LSD) test ($P \leq 0.05$).

3 Results and discussion

3.1 Physical analysis

3.1.1 Weight loss percentage

Fig. 1 shows the % WL of tomato fruit cv. Imperial in function of the storage time (28 days). All treatments showed an increase in the % WL. Weight loss in fresh fruits and vegetables is mainly due to transpiration and respiration processes. Likewise, it is known that tomato fruit is very susceptible to water loss, because of its thin cover provides a poor resistance to mass transfer (García *et al*., 2014).

CW-covered fruit had a total % WL of 4.70 ± 0.59 and recorded a range of 15.85-32.15 % of less weight loss from 10^{th} day to 20^{th} day of storage, showing significant difference ($P \leq 0.05$) regarding the other treatments. This could be attributed to the carnauba wax hydrophobic nature (esters of acid of high molecular weight and hydroxyacids) which produce an effective barrier to moisture. Similar results were obtained by Saucedo-Pompa *et al*. (2009) who found a value of % WL of 4.9 in avocado using a coating of candelilla wax with ellagic acid. Similarly, Baldwin *et al*. (1999) used two waxes in mango, one based on a mixture of hydroxypropyl cellulose and other from carnauba, obtaining weight losses of 3.8 and 2.4 %, respectively.

Control and CSG-covered fruit had similar behaviors during all storage time, presenting a final % WL of 4.80 ± 0.45 and 4.68 ± 0.86, respectively. This could be result of the hydrophilic nature of the CSG components and the extrusion process. According to Maran *et al*. (2013) the plasticizers addition increases the water vapor permeability by reducing intermolecular bonds among the polymer chains. López-Chavez *et al*. (2017) found that as the plasticizer content increased in nanocomposite films of starch, clay and glycerol, the water vapor permeability was higher. Moreover, Fitch-Vargas *et al*. (2016) reported that extrusion process could increase the water diffusion through the film, because it can produce hydrolyzed starches that have the ability to interact with the molecules of water, producing thus, an increment in the permeability. However, since day 22, all the treatments recorded similar values.

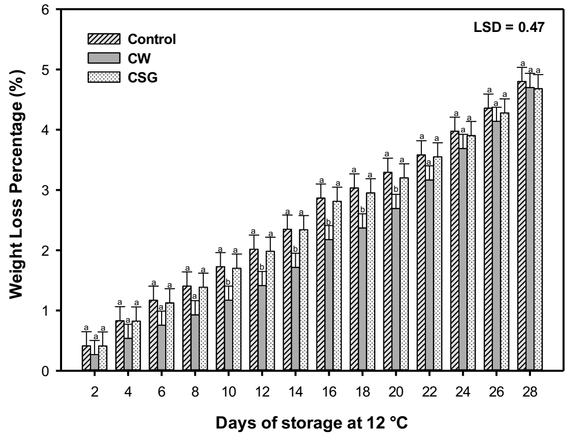

Fig. 1. Weight loss percentage (%) of tomato fruit cv. Imperial stored for 28 days at 12 ± 1 °C. Each point represents the mean of 10 replicates. Different letters show significant differences among treatments ($P \leq 0.05$) according to the least significant difference (LSD) by Fisher's test. CW = carnauba wax, CSG = corn starch coating.

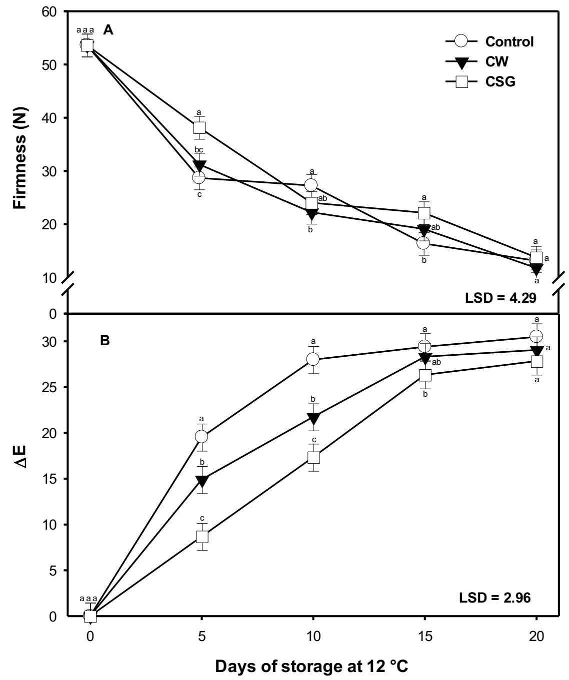

Fig. 2. Firmness (A) and external color (ΔE, B) changes of tomato fruit cv. Imperial stored for 20 days at 12 ± 1 °C. Each point represents the mean of 10 replicates. Different letters show significant differences among treatments ($P \leq 0.05$) according to the least significant difference (LSD) by Fisher's test. CW = carnauba wax, CSG = corn starch coating.

This could be due to the environment pressure differential (at relative humidity of 95 ± 1 °C) which avoided a higher weight loss in Control and CSG. Likewise, CW could have lost its capacity of water retention, due to a possible rupture in the coating structure. Weight loss limit of tomatoes for its marketing must not exceed 7.0 % of its original weight (Navarro-López *et al*., 2012), taking this into consideration, the results obtained for all treatments are still acceptable.

Damasceno *et al*. (2003) used coatings of native tapioca starch in tomato, reporting less weight loss on the coated fruit (2.9 %) compared to the uncoated fruit (3.1 %). Meanwhile, Chiumarelli *et al*. (2010) studied the effect of a coating of cassava starch and glycerol in mango, reporting that starch helped to reduce moisture loss obtaining a value of 4.1 %, but when this was combined with glycerol, the % WL increased to 5.0. Our results are similar to those obtained in these works.

3.1.2 Firmness

The firmness results of tomato fruit are shown in Fig. 2A. The average value of firmness at day zero of assessment was 53.70 ± 7.53 N. Firmness loss was recorded in all treatments during storage time, showing a marked decline the first 5 days; the CSG-covered fruit presented the highest value (38.2 ± 7.80 N). Ramos-García *et al*. (2018) reported that tomatoes covered by chitosan films with lemon essential oil presented higher firmness at harvest regarding to the red-ripe fruits. Tissue softening is attributed to the degradation of pectins, cell wall main components, as a result of the enzymatic activity of pectinesterase and polygalacturonase. Also, water loss could be a result of the cell modification, which has been considered an important factor for firmness changes in fruits and vegetables (Aguilar-Méndez *et al*., 2008).

CSG-covered fruit presented significant difference ($P \leq 0.05$) compared to Control and CW-covered fruit on 5th day. Since day 10, no statistical differences ($P > 0.05$) among the 3 treatments were observed, however CSG-covered fruit showed the highest values on 15th day of storage. Fruits of Control, CW and CSG treatments obtained final values of 13.12 ± 2.48, 11.80 ± 3.47 and 13.80 ± 2.30 N, respectively. The final firmness loss percentages regarding to the initial day were 75.56, 78.02 and 74.33 % for Control, CW and CSG-covered fruits, respectively.

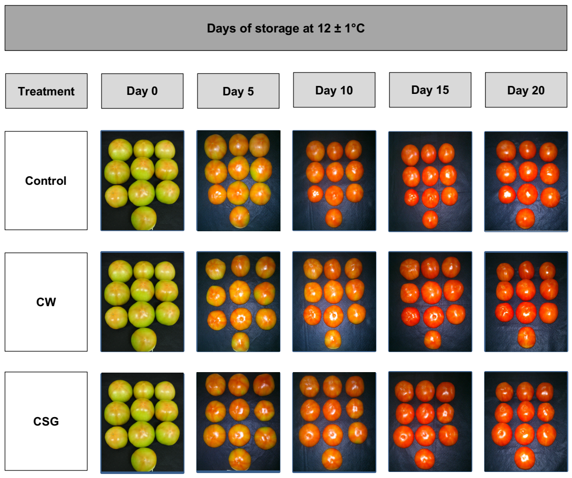

Fig. 3. Visual color changes during storage for 20 days at 12 ± 1 °C of tomato fruit cv. Imperial. CW = carnauba wax, CSG = corn starch coating.

According to Costa-García *et al.* (2012) edible coatings based on polysaccharides can modify the atmosphere that surround the fruits and vegetables, consequently, decrease their respiration rate due to the selectivity of gas permeability. Therefore, the results obtained for CSG-covered fruit may be due to the inhibition of ethylene production (as it is shown in Fig. 4) caused by the increment of CO_2 level and decrement of O_2 in the internal atmosphere of tomato fruit, which could have helped to decrease the enzymatic activity of pectinesterase and polygalacturonase. Likewise, the extrusion process could have helped to improve the interactions among corn starch, sorbitol and glycerol, improving the barrier properties of the coating.

Similar results were obtained by Achipiz *et al.* (2013) when developed coatings employing potato starch, aloe vera and carnauba wax in guavas. Also, Barco-Hernández *et al.* (2011) studied the effect of modified cassava starch-based coating on tomato, getting acceptable levels of firmness at day 22 of storage, while Damasceno *et al.* (2003) obtained similar results with unmodified cassava starch coatings.

3.1.3 External color

External color is an important quality index for consumers. Fig. 2B presents the external color changes in tomato cv. Imperial stored for 20 days at 12 ± 1 °C. Values of ΔE near to zero indicate that fruits did not show large color changes with regard to the initial values, while values above 10 are indicative of coloration differences (López-Valenzuela *et al.*, 2011; Damasceno *et al.*, 2003).

Control fruit showed the higher ΔE obtaining a final value of 30.48 ± 1.88. CW-covered fruit presented a final value of 29.06 ± 1.89, showing significant difference ($P \leq 0.05$) with the other treatments on days 5 and 10. Meanwhile, CSG-covered fruit recorded the lower ΔE with a final value of 27.85 ± 0.84, showing statistical difference ($P \leq 0.05$) with CW-covered fruit on days 5 and 10 and regarding to Control from day 5 until 20, obtaining thus, the best results during all storage period.

In Fig. 3 it is appreciated that there were no problems of coloration during the ripening process, reaching all treatments at 15^{th} day the desired red color of the tomato fruit. The ripening of tomato fruit is a complex process, genetically programmed which ends in dramatic fruit color changes. The carotenoids synthesis, mainly β-carotene and lycopene, are associated with the change of fruit color from green to red as chloroplasts are converted to chromoplasts resulting in the characteristic ripe tomato fruit red pigmentation (Mejía-Torres *et al.*, 2009). Nevertheless, this process could be delayed to prolong the tomato fruit postharvest life. The use of edible coatings is an alternative to change the ripening process. The modification of the fruit internal atmosphere caused by the coatings, produces high CO_2 and low O_2 levels affecting the maturation process and delaying the red color of tomatoes (Zapata *et al.*, 2008; Dávila-Aviña *et al.*, 2011).

Extrusion process can destroy the semi-crystalline structure of starch, either complete or partially. These molecular changes could have favored the interactions among the components of CSG (starch, sorbitol and glycerol), obtaining a compact matrix that exerts a selective gases diffusion resistance over the pores of the fruit surface resulting in a modified atmosphere (high CO_2 and low O_2 levels). These results are similar to those obtained by Trujillo-Navarro *et al.* (2012) who used a coating of cassava starch and potato with potassium sorbate and citric acid in mango fruits, getting minor differences in color because of the atmosphere created between the coating and the sample surface, preventing chlorophyll degradation due to the low concentration of O_2. On the other hand, Franco *et al.* (2017) with edible coatings based on modified starches (oxidized and acetylated) in strawberries, did not observe any difference in external color, which they consider of great importance since this response is a fundamental attribute in the fruit acquisition.

Table 1. Total soluble solids, pH and titratable acidity of tomato fruit cv. Imperial stored for 20 days at 12 ± 1 °C.

Days of storage at 12 ± 1 °C	**Treatments Control**	**CW**	**CSG**
TSS (° Brix)			
0	4.48 ± 0.13^{a}	4.48 ± 0.13^{a}	4.48 ± 0.13^{a}
5	4.90 ± 0.06^{a}	5.08 ± 0.18^{a}	4.98 ± 0.27^{a}
10	5.28 ± 0.07^{a}	5.40 ± 0.14^{a}	5.28 ± 0.10^{a}
15	4.80 ± 0.06^{a}	3.80 ± 0.13^{a}	4.10 ± 0.45^{b}
20	4.45 ± 0.34^{a}	4.00 ± 0.06^{c}	4.15 ± 0.14^{bc}
pH			
0	4.44 ± 0.09^{a}	4.44 ± 0.09^{a}	4.44 ± 0.09^{a}
5	4.46 ± 0.09^{a}	4.48 ± 0.11^{a}	4.46 ± 0.04^{a}
10	4.50 ± 0.03^{a}	4.50 ± 0.04^{a}	4.46 ± 0.02^{a}
15	4.42 ± 0.03^{a}	4.46 ± 0.02^{a}	4.36 ± 0.06^{b}
20	4.68 ± 0.07^{a}	4.68 ± 0.05^{a}	4.60 ± 0.06^{a}
TA (% citric acid)			
0	0.41 ± 0.01^{a}	0.41 ± 0.01^{a}	0.41 ± 0.01^{a}
5	0.28 ± 0.01^{a}	0.26 ± 0.02^{b}	0.28 ± 0.02^{a}
10	0.24 ± 0.01^{a}	0.25 ± 0.01^{ab}	0.27 ± 0.01^{a}
15	0.26 ± 0.01^{a}	0.24 ± 0.02^{b}	0.26 ± 0.01^{a}
20	0.22 ± 0.01^{ab}	0.21 ± 0.01^{b}	0.24 ± 0.02^{a}

Different letters (a, b, c) in same row (treatments) represent statistical difference ($P \leq 0.05$) according to LSD (TSS,$_{LSD}$ = 0.32, pH,$_{LSD}$ = 0.098 and TA,$_{LSD}$ = 0.022) by Fisher's test. CW = carnauba wax, CSG = corn starch coating, TSS = total soluble solids, TA = titratable acidity

3.2 Chemical analysis

3.2.1 Total soluble solids

The initial TSS content at the harvest time was 4.48 ± 0.13 °Brix (Table 1). The highest values on the TSS content of tomato fruit were obtained at 10th day of storage, meanwhile at days 15 and 20 a decrease was registered. This suggest that at initial stages of fruit ripening, starch was degraded and TSS increased, but once the fruit reached a progressive ripening stage, TSS decreased because of an increment in the respiration rate (López-Valenzuela *et al*., 2011). In addition, McGlasson (2003) reported that values between 4 and 6 °Brix are acceptable for a good tomato flavor.

No significant differences ($P > 0.05$) in TSS were found among the treatments from day 0 to 10 (Table 1). Similar results were obtained by Santos *et al*. (2016) with coatings of starch and carvacrol on minimally processed pumpkin. On the other hand, Achipiz *et al*. (2013) developed coatings of potato starch, aloe vera and carnauba wax on guava, obtaining lower values of TSS for coated fruit, which was attributed to a lower respiration rate. Amaya *et al*. (2010) employed cassava starch coatings and wax on tomato; they observed a smaller increase in TSS content compared to the uncoated fruit. While, Barco-Hernández *et al*. (2011) and Garcia *et al*. (1998) found similar results to those obtained in this work in tomatoes and strawberries, respectively.

3.2.2 pH

The results obtained for pH in tomato fruit cv. Imperial stored at 12 ± 1 ° C for 20 days are shown in Table 1; the initial value was 4.44 ± 0.09. All treatments recorded a similar behavior at the first 10 days of storage, while at the 15th day, CSG-covered fruit showed significant difference ($P \leq 0.05$) regarding to Control and CW-covered fruits. At 20th day, no statistical differences ($P > 0.05$) among the 3 treatments were observed. Likewise, at the end of the assessment a marked pH increase was observed for all the fruits, which may be related to the biochemical reactions that are associated with respiratory process, where organic acids are consumed and converted to sugars.

The use of the extrusion process as a pretreatment to the casting technique could have helped to obtain coatings (CSG treatment) with better gas barrier properties due to the physical modification of starch which allowed to improve the interactions among the components of the polymeric matrix (corn starch, sorbitol and glycerol). Damasceno *et al*. (2003) studied the effect of cassava starch coating on postharvest quality of tomato, obtaining lower pH values in the coated fruit regarding to the control fruit. Furthermore, Garcia *et al*. (1998) applied corn starch coatings with sorbitol or glycerol in strawberries, reporting lower pH values in those coatings that contained sorbitol, which may be due to that this plasticizer has greater ability to form compact networks with good mechanical and barrier properties helping to create a better atmosphere in the fruit.

3.2.3 Titratable acidity

The average value of TA of tomato at the harvest time was 0.41 ± 0.01 % citric acid (Table 1). At 5th day, TA presented a considerably decrease of 31.70, 36.58 and 31.70 % for Control, CW and CSG, respectively. It is known that organic acids are substrate for many reactions catalyzed by enzymes while aerobic respiration is carrying out by the vegetable cells; therefore, a TA reduction is the result of the ripening process.

Control fruit presented statistically significant difference ($P \leq 0.05$) regarding to CW between 5^{th} and 15^{th} day, and with CSG-covered fruit on 10^{th} day. At the end of the assessment, no significant differences ($P > 0.05$) were observed among the treatments (Table 1). During all storage time, it was observed similar behaviors in the treatments. Nevertheless, highest citric acid percentages were obtained for CSG-covered fruit in 20 days. Latest could be related with a decrease in tomatoes respiration rate. It is known that the ripening process can be delayed by the use of starch edible coatings due to they provide a semipermeable membrane around the fruit, decreasing the respiration rate and avoiding the utilization of organic acids.

Similar results were reported by Amaya *et al*. (2010) who formulated starch coatings derived from yuca with acetic acid, citric acid, glycerol, and essential cinnamon oil. They observed that tomatoes without coating showed a lower citric acid percentage. Also, Achipiz *et al*. (2013) reported a decrease on TA percentage in guava with potato starch-based coating; this is due to a lower respiration rate and therefore a less consume of backup substrate. In addition to, Calderón-Castro *et al*. (2018) observed the similar behavior on mango with coatings of high amylose starch obtained by a combination of extrusion process and casting technique.

3.3 Physiological analysis

3.3.1 Respiration rate

Fig. 4A shows the respiration rate of tomato fruits cv. Imperial evaluated during 8 days of storage at 21 ± 1 °C after harvest. All treatments showed a typical respiration curve of climacteric fruits with an initial increase in CO_2 production until reach a maximum and a subsequent decline. All fruits showed the maximum production of CO_2 on the third day of the assessment. Control fruit reached a final value of 10.13 ± 2.45 mg CO_2/kg·h, while CW-covered and CSG-covered fruits registered values of 8.39 ± 1.02 and 7.26 ± 0.79 mg CO_2/kg·h, respectively.

After 10 days of ripening (Fig. 4B), the respiration rate of tomato fruits was evaluated at 21 ± 1 °C for 7 days. At the beginning of the assessment, were obtained values of 5.88 ± 0.35, 5.98 ± 0.32 and 4.18 ± 0.34 mg CO_2/kg h for Control, CW-covered and CSG-covered fruits, respectively. At the remaining period, it was observed a decrease in respiration rate for all treatments. According to the results, Control fruit showed the higher respiration rates while CW-covered fruit recorded low rates in some stages of the evaluation, meanwhile, CSG-covered fruit obtained the lower production of CO_2 during the 20 days of analysis.

The main effect generated by the coating layer on the skin of the fruit is the resistance to gas diffusion, by blocking the fruit surface pores, carrying out a modification of its internal atmosphere with a relative high concentration of CO_2 and low O_2 (Bai *et al*., 2003). Ribeiro *et al*. (2007) mention that the cohesion coefficient of starch films is high, resulting in high forces of attraction among the polymer molecules, forming a good gas barrier. On the other hand, it is known that sorbitol has greater ability to interact with other molecules due to the number of hydroxyl groups present on its structure (Garcia *et al*., 1998).

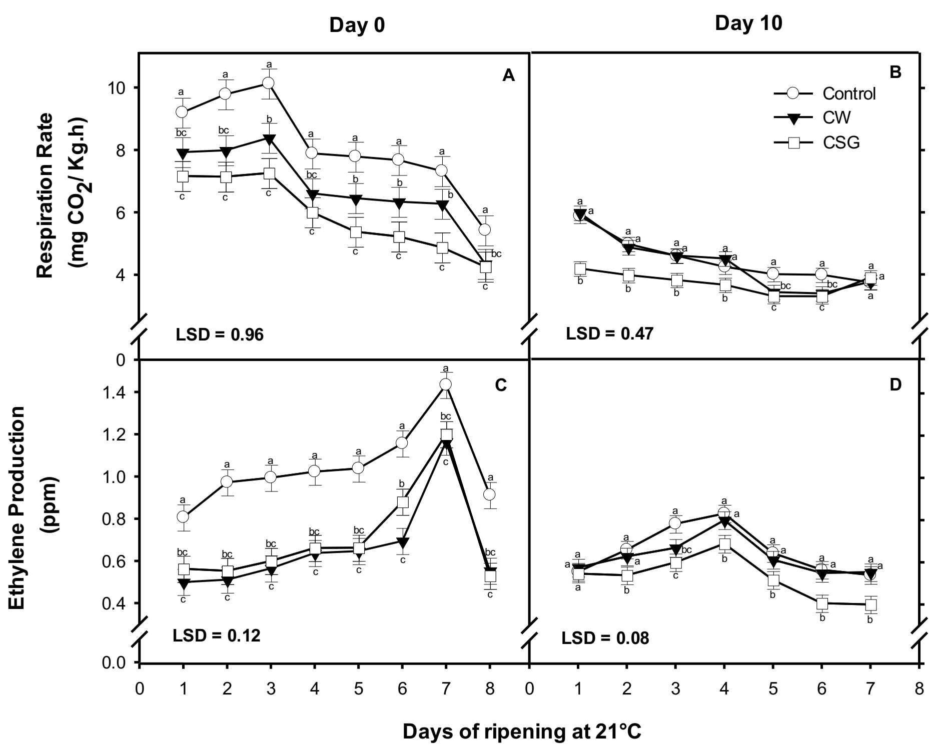

Fig. 4. Respiration and ethylene production rates during ripening at 21 ± 1 °C of tomato fruit cv. Imperial after harvest (day 0, A and C) and after 10 days (B and D) of storage at 12 ± 1 °C. Each point represents the mean of 12 replicates. Different letters show significant differences among treatments ($P \leq 0.05$) according to the least significant difference (LSD) by Fisher's test. CW = carnauba wax, CSG = corn starch coating.

For this reason, sorbitol may have contributed to the formation of a greater number of links with the different components (starch and glycerol) of the polymeric matrix, obtaining good barrier properties. Likewise, the extrusion process could have favored the interaction among the components of CSG obtaining a compact matrix. Therefore, the application of edible coatings from a mixture of corn starch with sorbitol and glycerol obtained by the combination of extrusion process and casting technique may be an alternative to modify the internal atmosphere of fruits and vegetables.

Similar results have been reported by Chiumarelli *et al*. (2010) and Amaya *et al*. (2010) with coatings of cassava starch in mango and tomato, respectively; and Achipiz *et al*. (2013) with coatings of potato starch, aloe vera and carnauba wax on guava.

3.3.2 Ethylene production

Fig. 4C shows the results for ethylene production in tomato cv. Imperial evaluated after harvest at 21 ± 1 °C for 8 days. Ethylene production showed a climacteric pattern, reaching a maximum production at the 7th day with values of 1.43 ± 0.21, 1.16 ± 0.20 and 1.20 ± 0.18 ppm for Control, CW-covered and CSG-covered fruits, respectively. Throughout the ripening period, Control fruit presented statistical differences ($P \leq 0.05$) compared with the other treatments. Fruit with 10 days of storage (Fig. 4D), unlike the freshly harvested fruits showed the maximum ethylene production at day 4, which could be product of the ripening process where an earlier biosynthesis of this phytohormone is stimulated. At this point, were obtained values of 0.83 ± 0.13, 0.80 ± 0.19 and 0.68 ± 0.10 ppm for Control, CW-covered and CSG-covered fruits, respectively. Furthermore, it can be observed in Fig. 4D that there was no metabolic inhibition in any of the treatments. After the assessment, CSG-covered fruit was the one that had the lowest ethylene production reaching a final value of 0.40 ± 0.07 ppm, showing statistical difference ($P \leq 0.05$) regarding to the other 2 treatments at 6^{th} and 7^{th} day.

Starch edible coatings provide a barrier against gases controlling the enzymatic activity and maintaining the postharvest quality of coated fruits during storage (Ali *et al*., 2010). Likewise, it is known that physical treatments, like extrusion process, generally produce changes in the packing arrangements of starch polymer molecules within granules (BeMiller and Huber, 2015). Latest assumes that by effect of the starch physical modification and the improvement of interactions, the CSG treatment could be generating a better gas barrier (with high levels of CO_2 and low levels of O_2 inside the fruit). Therefore, the high internal concentration of CO_2 could be responsible for the ethylene production inhibition. Initially, it was postulated that CO_2 could produce certain effects on ethylene biosynthesis due to competition that it had for the ethylene receptor (Barco-Hernández *et al*., 2011). By contrast, other works suggests that the effect of CO_2 on ethylene biosynthesis probably is in the Aminocyclopropane1-carboxylic acid (ACC) synthase enzyme, decreasing the conversion of S-adenosylmethionine (SAM) to ACC (de Wild *et al*., 2005).

Similar results were reported by Dávila-Aviña *et al*. (2011) who used mineral oil wax on tomato cv. Grandela observing lower ethylene production in the coated fruit compared to uncoated fruit. While Zapata *et al*. (2008) applied a coating of zein on tomatoes, recording a delay in the ripening processes, since the coating could act as a physical barrier causing a delay in the onset of climacteric peaks of ethylene production and respiration rate.

Conclusions

The results of this study indicate that CSG-covered fruit was the most effective treatment to maintain the chemical and physical quality of tomato cv. Imperial stored at 12 ± 1 °C. With regard to water loss, CW-covered fruit showed the best results, however at the end of the evaluation no significant differences were observed among the treatments. Meanwhile in physiological analysis, CSG treatment generated a decrease in respiration and ethylene production rates after harvest and 10 days of storage at 12 ± 1 °C. Therefore, edible coatings from a corn starch, sorbitol, and glycerol, obtained by a combination of extrusion process and casting technique, could be an useful alternative for extending the shelf life and the period of marketing of tomato cv. Imperial.

Acknowledgements

The authors thank to CONACYT and Universidad Autónoma de Sinaloa for providing financial support for the development of this research.

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