Vol. 16, No. 1 (2017) 109-119
Revista Mexicana de Ingeniería Química

PHYSICAL, BARRIER, MECHANICAL AND MICROSTRUCTURAL PROPERTIES OF *Aloe vera*-GELATIN-GLYCEROL EDIBLE FILMS INCORPORATED WITH *Pimenta dioica* L. MERRILL ESSENTIAL OIL

PROPIEDADES FÍSICAS, DE BARRERA, MECÁNICAS Y MICROESTRUCTURALES DE PELÍCULAS COMESTIBLES A BASE DE GEL DE *Aloe vera*, GRENETINA Y GLICEROL INCORPORADOS CON ACEITE ESENCIAL DE *Pimenta dioica* L. MERRILL

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Received December 1, 2016; Accepted December 23, 2016

Abstract

Physical, barrier, mechanical and microstructural properties of an edible film based on *Aloe vera*, gelatin-glycerol with different concentrations of the essential oil of a pepper (*Pimenta dioica* L. Merrill) at 0, 0.5, 1.0, and 1.5% w / w were investigated. The optical properties showed low brightness and ΔE of 59.6. In terms of water vapor permeability, the values ranged from 2.54 $\times 10^{-9}$ ± 0.09 to 4.49 $\times 10^{-9}$ ± 0.3 (g m/Pa s m^2), due to the effect of decreased polarity in the structural matrix. In the case of the mechanical properties, an increase in the oil concentration significantly reduced the tensile strength, making the material more flexible (% E = 72 to 122), possibly due to the rearrangement of and the interaction between polysaccharides, proteins and plasticizers in the matrix. This behavior was also observed in the microstructural studies: the increased concentration of oil increased the roughness of the film (Ra = 0.222 to 2.12 mV). The results show that addition of *Pimenta dioica* oil to the film results in a film with increased WVP and resistant film qualities that favor the material for use in high-moisture food coating applications.

Keywords: edible films, *Aloe vera*, *Pimenta dioica* L. Merrill, physical and mechanical properties, microscopy techniques, optical properties.

Resumen

Se midieron las propiedades físicas, de barrera, mecánicas y microestructurales de una película comestible a base de gel de *Aloe vera*, grenetina y glicerol con diferentes concentraciones de aceite esencial de *Pimenta dioica* L. Merrill a 0, 0,5, 1,0 y 1,5% p/p. Las propiedades ópticas mostraron un brillo bajo y un ΔE de 59.6. En términos de permeabilidad al vapor de agua, los valores oscilaron entre 2.54 $\times 10^{-9}$ ± 0.09 y 4.49 $\times 10^{-9}$ ± 0.3 (g m/Pa s m^2), debido al efecto de la disminución de la polaridad en la matriz estructural. En el caso de las propiedades mecánicas, un aumento de la concentración de aceite redujo significativamente la resistencia a la tensión, haciendo que el material sea más flexible (% E = 72 a 122), posiblemente debido al reordenamiento y la interacción entre polisacáridos, proteínas y plastificantes en la matriz. El aumento de la concentración de aceite incrementó la rugosidad de la película (Ra = 0.222 a 2.12 mV). Los resultados muestran que la adición de aceite esencial de *Pimenta dioica* a la película, le confiere a ésta un aumento en la PVA, resistencia y flexibilidad, propiedades que favorecen su uso como recubrimientos comestibles.

Palabras clave: películas comestibles, *Aloe vera*, *Pimenta dioica* L. Merrill, propiedades físicas y mecánicas, técnicas de microscopía, propiedades ópticas.

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1 Introduction

Edible and biodegradable natural-polymer films offer alternatives to conventional packaging due to their excellent biodegradability, biocompatibility, edibility, and the range of their potential applications (Salmieri and Lacroix, 2006; Hernández-Carrillo *et al*., 2015; Rodriguez-Marín *et al*., 2016). They are applied as barriers to preserve and delay food deterioration (Sotelo-Boyás *et al*., 2015). Recently, researchers have developed edible films that enhance food properties such as color, texture, flavor and overall appearance (Abugoch *et al*., 2011; Bergo *et al*., 2010). Additionally, these films may operate as carriers for a range of functional ingredients, expanding their capabilities into active packaging, such as *Aloe vera*, gelatin, and the essential oil of *Pimenta dioica* L. Merril. *Aloe vera* gel films exhibit high water permeability; therefore, mixtures with diverse compounds (cellulose, gelatin, etc.) have been studied in order to improve water vapor and gas diffusion in the edible films (Saibuatong and Phisalaphong, 2010; Ramirez-Hernández *et al*., 2015).

Aloe vera is used as an antioxidant, anti-inflammatory, digestion stimulant, activator of the immune system and an agent for healing. *Aloe vera* leaves contain a slimy tissue that stores water, which makes the leaves thick. This slimy, water-filled tissue has diverse names including pulp, mucilaginous tissue, mucilaginous gel, and parenchyma tissue. It is composed of degenerated cell organelles and a viscous liquid contained in the cells (Li *et al*., 2003). The mucilaginous gel contains water at a ratio of 99-99.5% and 0.56-0.66% polysaccharides and soluble sugars, followed by proteins (many of which are enzymes), amino acids, vitamins and anthraquinones (Boudreau and Beland, 2006; Liu *et al*., 2007). This gel has many applications as an ingredient in functional foods due to the biological activity of its components (Vega *et al*., 2005). The use of *Aloe vera* as an edible coating has been used in pre-harvest or postharvest treatments to maintain fruit quality attributes and to delay fungal decomposition in sweet cherries (Martínez *et al*., 2006), table grapes (Valverde *et al*., 2005; Serrano *et al*., 2006; Castillo *et al*., 2010), and nectarines (Navarro *et al*., 2011), with fairly satisfactory results with respect to the conservation of the sensory characteristics, control of respiration activity and moisture losses, and reduction of enzymatic browning and microbial growth. The *Aloe vera* coating maintained the firmness of kiwifruit slices (Benítez *et al*., 2013), and microorganism growth was reduced by 50% in coated blueberries after 25 days of storage (Vieira *et al*., 2016).

The addition of essential oils to edible films favors slower oxidation in foods and prevents microbial propagation. Some examples are edible films based on alginate and the essential oil of oregano (Benavides *et al*., 2012). Sotelo-Bóyas *et al*. (2015) report that chitosan nanoparticles added with thyme essential oil presented a significant inhibitory effect on the growth of *Pectobacterium carotovorum*. Romero-Bastida *et al*. (2011) used 1.5% cinnamon oil in banana films that presented an inhibitory effect on *Staphylococcus aureus*. Edible films rich in phenolic compounds formulated from orange and grapefruit peels (Hernández-Carrillo *et al*., 2015), and edible films based on fish protein and the essential oil of cloves (Teixeira *et al*., 2014); both studies reported microbial inhibition in gram-positive bacteria.

The selection criteria for edible films are often based on their barrier and mechanical properties, especially water vapor permeability (WVP) and elastic modulus. Due to the flexibility, antioxidant and antimicrobial properties enhanced with the incorporation of essential oils to edible films, the aim of this work was to evaluate the functionality of *Aloe vera*-gelatin-glycerol films with the incorporation of different concentrations of *Pimenta dioica* L. Merrill essential oil.

2 Materials and methods

2.1 Materials

Aloe vera gel was obtained from fresh *Aloe vera* leaves in the laboratory of Physicochemical and Alternative Packaging Materials (Instituto Tecnológico de Celaya, México) by scraping the outer epidermis. Gelatin Knox^{TM} was provided by Con Alimentos S.A de C.V (Mexico City, Mexico), Glycerol ACS (catalog number 06441) was supplied by Productos Químicos de Monterrey, S.A de C.V. (Monterrey, N.L., Mexico), polyoxyethylene sorbitan monooleate (Tween 80) was provided by Hycel de México, S.A de C.V (Zapopan, Jal., Mexico). The extraction of essential oil was performed by hydrodistillation of *Pimenta dioica* L. Merrill (Locally known as "pimienta gorda" or "pimienta de Jamaica") harvested in Tacuapan, region located in the northern part of the state of Puebla, Mexico (Geographical coordinates 20°1´3"N - 97°31´25"W).

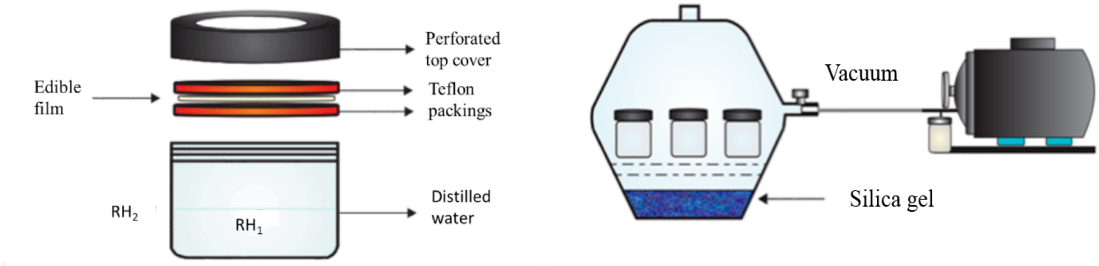

Fig. 1. Schematic representation of the cells and system used to determine the water vapor permeability.

2.2 *Methods*

2.2.1 Film preparation

Aloe vera mucilage was milled by adding 0.1% w/w of polyoxyethylene sorbitan monooleate, weighed and centrifuged at 2880 ×g for 40 minutes. The supernatant was separated, filtered, and placed in a circulator bath at 40 ± 2 °C, and 2 % w/w gelatin and 0.4 % w/w glycerol were slowly added, with stirring over 20 minutes. Later, the essential oil was added and homogenized at 304.2 ×g for 3 minutes using a T25 digital Ultra Turrax disperser (IKA Works, Inc., Wilmington, USA). The concentrations of essential oil tested were 0.5, 1.0, and 1.5 % w/w. Finally, 8 mL of the filmogenic suspension was distributed in petri dishes (9 cm in diameter) and allowed to dry at room temperature for 48 h.

2.2.2 Thickness

The film thickness (mm) was measured using a handheld digital micrometer (F1000/30-3, Käfer Messuhrenfabrik GmbH & Co., Villingen-Schwenningen, Germany) with a resolution of 0.001 mm. Measurements were performed at ten different film locations and the mean thickness value was used to calculate the permeability and mechanical properties of the films.

2.2.3 Color properties

Color values of the films were determined using a colorimeter (CR-400, Minolta, Konica Ramsey, NJ, USA). The color scale was used for measuring color values: L*, the lightness variable; a*, from green to blue; and b*, from yellow to red. The total color difference (ΔE) was calculated using Eq. (1):

$$\Delta E = \left(\sqrt{\Delta a^2 + \Delta b^2 + \Delta L^2}\right) \quad (1)$$

where $\Delta L = L^*_{standard} - L^*_{sample}$, $\Delta a = a^*_{standard} - a^*_{sample}$ and $\Delta b = b^*_{standard} - b^*_{sample}$. The standard plate (calibration plate $L^* = 94.90$ $a^* = -0.45$ $b^* = 3.93$) was used as a standard. Five measurements were collected on each film, one at the center and four around the perimeter.

2.2.4 Water vapor permeability

The water vapor permeability (WVP) of the films was determined gravimetrically, using a modified ASTM E00996-00 (ASTM, 2000a) procedure. The cup had an internal diameter of 3.5 cm and an external diameter of 4 cm and was 5 cm deep. The cup was filled with 27 mL of distilled water to generate a 100% relative humidity and was covered by the film. The cup was placed in a desiccator containing silica gel to provide 10-12% RH. Changes in the weight of the cup were measured to the nearest 0.018 mg. The tests were conducted in triplicate, and the water vapor permeability was calculated using Eq. (2):

$$WVP = \frac{\Delta m \cdot x}{A \cdot t \cdot \Delta P};\left(\frac{g \cdot m}{Pa \cdot s \cdot m^2}\right) \quad (2)$$

where Δm = mass change over time (g); x = thickness (m); t = time (s); A = film area (m^2) and ΔP = partial vapor pressure difference of the atmosphere with silica gel and pure water (3167 Pa at 25 °C), as shown in Figure 1.

2.2.5 Mechanical properties

All mechanical properties of the films were determined by a texture analyzer (TA-XT plus, Stable Micro Systems LTD, Surrey, UK), using a modified ASTM D882-00 (ASTM, 2000b; Rodriguez-Marín *et al*., 2016) procedure. The films were cut into 1 x 8 cm strips for testing. The measurements were performed using a crosshead velocity of 0.5 mm s^{-1} with an exposed area 1 x 6 cm for each film strip. Four strips were prepared from each film. Tensile stress was plotted versus elongation to give a stress-strain curve and Young´s modulus is the ratio between the strength of a film and its deformation before it breaks.

At higher values of E, the film will be stiffer and more fragile (Gordon, 2013). The final tensile strength (TS, in MPa), elongation at break (%E) and elastic modulus (EM, in MPa) of the films were also reported.

2.2.6 Environmental scanning electronic microscopy (ESEM)

The microstructure of the films was observed using a scanning electron microscope (Philips XL-30, Andover, MA, USA) to visualize the overall morphology of the film surfaces. Films of 4 x 4 mm were fixed on the sample holder with double sided carbon tape, without a metallic conductive cover, and observed using the ESEM system. Micrographs were captured at 100x magnification in gray-scale using a voltage of 25 kV and stored in TIFF format. The cross-section of films was observed using a scanning electron microscope (JSM-6510LV, JEOL Ltd., Tokyo, Japan); the film samples were fractured, then mounted on the specimen holder with double sided adhesive carbon tape. After gold coating using a Denton Vacuum Desk V (HP) sputter coater (Denton Vacuum LLC, Moorestown, NJ, USA), the image was captured using an accelerating voltage of 30 kV.

2.2.7 Atomic force microscopy (AFM)

AFM allows the analysis of the surface topography at nanometer levels and makes possible the creation of 3-D models showing the microstructure of the sample at minor scale. AFM (diMultimode V, Veeco, Santa Barbara, CA, USA) was used in the tapping mode with silicon probes (RTESP Bruker cantilevers) with a resonance frequency of 256 x 256 pixels. The roughness was calculated using the root square deviation of the heights (Rq, Eq. 4), and the arithmetic average of the absolute values of the height deviations (Ra, Eq. 5) of the edible film images using the software NanoScope Analysis 1.20 (Veeco, Santa Barbara, CA, USA).

$$Rq = \sqrt{\frac{\Sigma(Zi)^2}{N}} \tag{3}$$

$$Ra = \frac{1}{N}\sum_{i=1}^{N}|Zi| \tag{4}$$

In these equations, Zi is the height deviation from the mean of the heights, and N is the number of points in the image.

2.2.8 Statistical analysis

The data were presented as the mean ± standard deviation of each treatment. We performed a factorial design of experiments with a fully randomized design using analysis of variance (ANOVA) using SAS software (Version 8, Statistical Analysis System Institute Inc., Cary, NC, USA). Differences between the mean values of the measured film properties were compared by applying Tukey multiple range tests and a p-value < 0.05 was considered significant.

3 Results and discussion

3.1 Water vapor permeability properties

Table 1 shows the average values of the thicknesses of the edible films. The thickness is directly proportional to the increase in concentration of the essential oil, and the values varied between 37 and 52 μm. This behavior is due to intermolecular rearrangement of the matrix components by the incorporation of the essential oil, as has been described by Pelissari *et al*. (2009), with films produced with chitosan and the essential oil of oregano (*Origanum vulgare L.*), and Ghasemlou *et al*. (2013), with films formulated with corn starch and the essential oil of *Zataria multiflora Boiss*. Recently, Dashipour *et al*. (2015) confirmed this behavior in films made with carboxymethyl cellulose and the essential oil *Zataria multiflora Boiss* by observing that increasing the concentration of the essential oil in the edible films increased the material thickness.

The values of water vapor permeability ranged from $2.54 \times 10^{-9} \pm 0.09$ to $4.49 \times 10^{-9} \pm 0.3$ (g m / Pa s m^2), a high permeability compared to other polymer matrices. The addition of the essential oil extends the structural matrix of the edible film; therefore, the water vapor permeability increased by 76%. Similar behavior was reported for edible films formulated with fish gelatin and the essential oil of bergamot (Ahmad *et al*., 2012); in edible films based on pectin with lime essential oil (Sanchez-Aldana *et al*., 2014) and in edible films based on fish gelatin and chitosan with oregano essential oil (Hosseini *et al*., 2015). This could be due to the interaction that could be carried out between phenolic compounds present in the extract (Sanchez-Aldana *et al*., 2014).

Table 1. Effect of *Pimenta dioica* essential oil concentrations (% w/w) on water vapor permeability (WVP) of *Aloe vera* edible film.

Films	Essential oil (% w/w)	Thickness[1] (μm)	WVP[1] x 10^{-9} $(g \cdot m/Pa \cdot s \cdot m^2)$
Control	0	37 ± 3^{a}	2.54 ± 0.09^{a}
Allspice oil	0.5	44 ± 5^{b}	3.20 ± 0.4^{b}
Allspice oil	1.0	47 ± 6^{b}	3.75 ± 0.2^{b}
Allspice oil	1.5	52 ± 4^{bc}	4.49 ± 0.3^{c}

Means in same column for essential oil and control with different letters are significantly different at $p < 0.05$.
[1]Thickness and WVP data are mean values ± standard deviations.

Table 2. Effect of *Pimenta dioica* essential oil concentrations (% w/w) on color parameters of *Aloe vera* edible film.

Essential oil (% w/w)	*a**	*b**	*L**	*ΔE**
0	1.170 ± 0.01^{a}	7.110 ± 0.03^{a}	79.080 ± 0.001^{d}	58.14 ± 1.18^{a}
0.5	1.477 ± 0.01^{a}	6.793 ± 0.04^{a}	79.140 ± 0.026^{c}	61.04 ± 0.71^{a}
1.0	1.370 ± 0.20^{ab}	7.013 ± 0.37^{a}	79.177 ± 0.005^{b}	59.84 ± 1.80^{a}
1.5	0.467 ± 0.10^{c}	6.037 ± 0.04^{b}	79.250 ± 0.020^{a}	59.61 ± 1.10^{a}

*a**, *b**, *L**, *ΔE** data are mean values ± standard deviations.
Means in same column for control and essential oil with different letters are significantly different at $p < 0.05$.

Table 3. Effect of different concentrations (% w/w) of *Pimenta dioica* essential oil on mechanical properties of edible *Aloe vera* film.[1]

Essential oil (% w/w)	Tensile strength[1] (MPa)	Elongation[1] (%)	Elastic modulus[1] (MPa)
0	11.72 ± 1.01^{a}	72.37 ± 0.26^{a}	166.78 ± 0.52^{a}
0.5	11.63 ± 0.48^{b}	57.86 ± 0.00^{b}	80.96 ± 0.33^{b}
1.0	10.27 ± 0.70^{bc}	87.93 ± 0.00^{c}	34.13 ± 0.49^{bc}
1.5	10.08 ± 0.62^{c}	122.56 ± 0.00^{d}	34.11 ± 0.43^{c}

Means in same column for control and essential oil with different letters are significantly different at $p < 0.05$.
[1]TS, E and WVP data are mean values ± standard deviations.

3.2 Color properties

Table 2 shows the color parameters *L*, *a*, and *b* and the total color difference (Δ*E*) values for the *Aloe vera* film with added *Pimenta dioica* essential oil. The L* (brightness) parameter showed a significant difference with a range of values from 79.080 to 79.250. The color values were not different. In general, the essential oil of pepper (*Pimenta dioica* L. Merrill) incorporated into the edible film formulated with the *Aloe vera* gel caused a slight change in the brightness of the material. This fact can be attributed to the gel extraction method, interactions between the components of the polymeric matrix and the content of anthraquinones in the gel. Anthraquinones are eliminated by separating the epidermis mucilage without damaging the vascular bundles by avoiding contact with air or light because otherwise an obscure appearance occurs (Hussain *et al*., 2008); similar behavior has been reported by Vieira *et al*. (2016) in edible films of chitosan and *Aloe vera* gel.

3.3 Mechanical properties

Table 3 depicts the effect of the essential oil concentration on the mechanical properties of the films. It was observed the film with 1.5% w/w produced a higher percentage of deformation at 122.56%, while at 0.5% w/w only a 72.37% deformation is obtained. The Young's modulus also decreased, resulting in a film that was 80% more flexible than the control film. Mechanical properties of the films were characterized by measuring the tensile strength (TS) and elongation at break, which are key indicators of film strength and flexibility. Increased concentrations of the essential oil of pepper (*Pimenta dioica* L. Merrill) in films with *Aloe vera* decreased the tensile strength (TS) and simultaneously increased the flexibility of the film. This behavior has been reported by Ghasemlou *et al*. (2013) for films made with corn starch and *Zataria multiflora* essential oil and with edible films formulated with chitosan, fish gelatin and the essential oil of *Origanum vulgare* L.

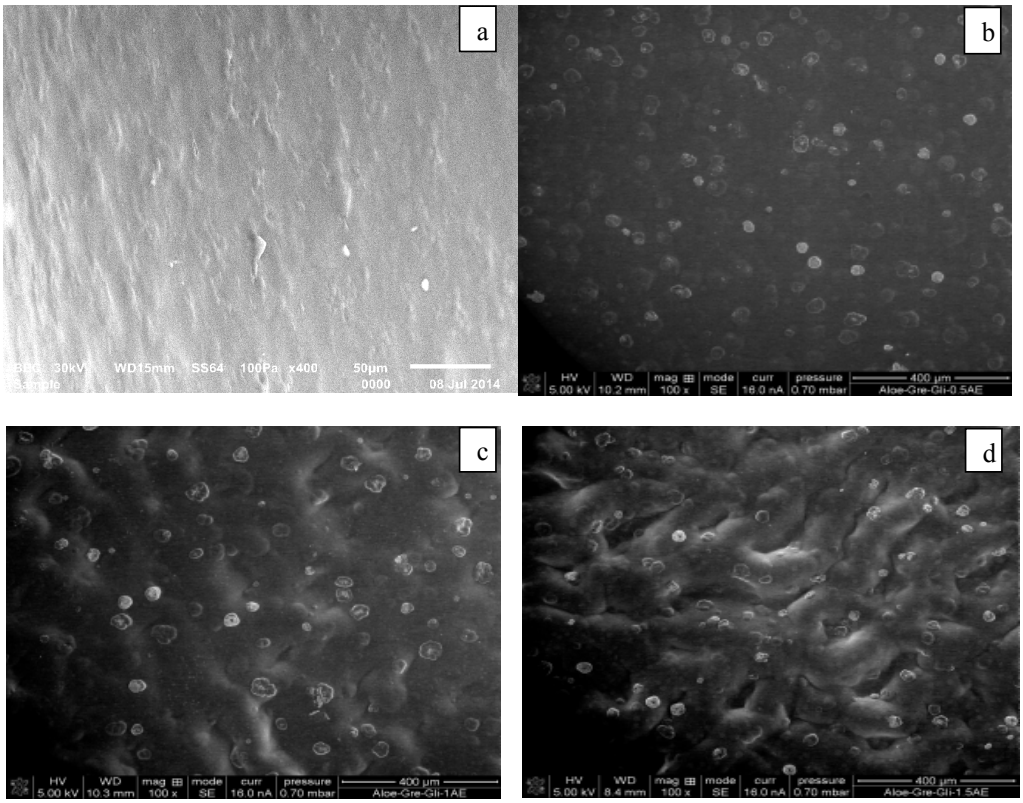

Fig. 2. Scanning electron microscopic images obtained by ESEM (100x). (a) *Aloe vera*-Gelatin-Glycerol film; (b) *Aloe vera*-Gelatin-Glycerol-0.5% EO film; (c) *Aloe vera*-Gelatin-Glycerol-1% EO film and (d) *Aloe vera*-Gelatin-Glycerol-1.5% EO film.

In addition, Choi *et al*. (2016) tested edible films formulated with hydroxypropyl methylcellulose and oregano and bergamot essential oils, observing a similar trend. It has been reported that the incorporation of essential oils in a continuous polymeric matrix reduced its tensile strength due to structural discontinuities caused by the oil (Sanchez-Gonzalez *et al*., 2011.); which became flexible (Suppakul *et al*., 2003) with a decrease of Young's modulus (EM). The addition of essential oils in a continuous polymeric matrix reduced its tensile strength due to the structural discontinuities caused by the oil phase (Sanchez-Gonzalez *et al*., 2011), which in turn became more flexible (Suppakul *et al*., 2003), as the value of Young's modulus decreased. This behavior was also observed in this study.

3.4 Film microstructure

A microscopic study of the structural arrangement of the different components in the dried film matrices contributes to better understanding of the physical, mechanical, barrier and optical properties. Fig. 2 shows micrographs of the *Aloe vera*-gelatin-based films with and without the essential oil, which show appreciable differences as a function of the film composition. The effect of drying process and the structural interaction between biopolymers are also evident in ESEM images. The control film shows a smooth microstructure, while the films that incorporated the highest concentration of essential oils had a rougher film microstructure. The interaction of biopolymers in the mixture, i.e., the polysaccharide chains and the globular and amorphous matrix of *Aloe vera*, were reinforced structurally by the gelatin protein and glycerol, causing an increase in stiffness within the matrix. This behavior was also reported by Nonsee *et al*. (2011) in films of hydroxypropyl methylcellulose and clove essential oil. Similar behavior was also reported by Shojaee-Aliabadi *et al*. (2014) in films of κ-carrageenan and the essential oil of *Mentha pulegium*, and recently by Choi *et al*. (2016) in films with oregano essential oil.

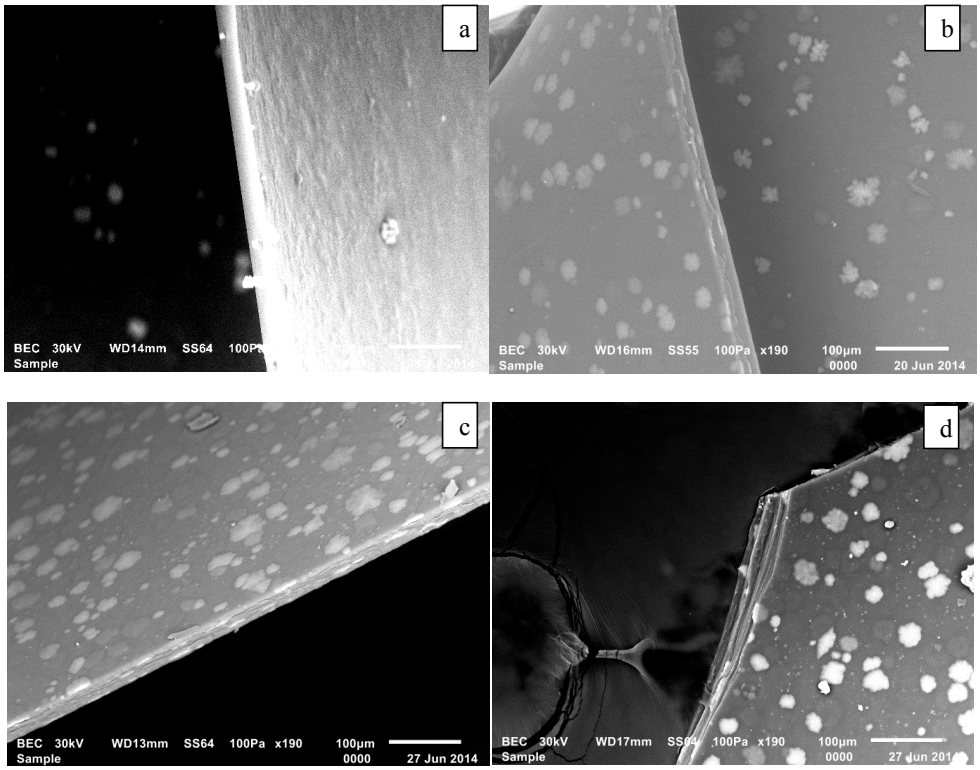

Fig. 3. Scanning electron microscopic of cross-section obtained by SEM-LV (100x). (a) *Aloe vera*-Gelatin-Glycerol; (b) *Aloe vera*-Gelatin-Glycerol-0.5% EO film; (c) *Aloe vera*-Gelatin-Glycerol-1% EO film and (d) *Aloe vera*-Gelatin-Glycerol-1.5% EO film.

Fig. 3 shows cross-sectional micrographs of *Aloe vera*-gelatin based films, which exhibit significant differences as a function of film composition. A smooth and continuous microstructure was observed in the control film, while the emulsified films showed discontinuities associated with the essential oil droplets embedded in the polymeric matrix. At lower concentrations, emulsified films show a smaller oil-droplet size. However, a coarser microstructure was observed in the films that incorporated the highest concentration of essential oils because the higher lipid content favors the flocculation rate (Sánchez-González *et al*., 2011).

3.5 Surface morphology

Atomic force microscopy (AFM) is a powerful tool for studying surfaces and has been used to provide qualitative and quantitative information regarding the topography of biopolymers at the nanometer scale that are often inaccessible by any other experimental techniques. AFM allows for the determination of roughness parameters that can be calculated for the film surface. According to the AFM images (Fig. 4), an increase in the essential oil concentration in the edible film modified the surface morphology with a rough appearance, while the control film exhibited a smoother surface. The presence of the essential oil appears to favor an increased surface roughness, which is probably due to the higher lipid content (Sánchez-González *et al*., 2011). These results agree with those reported by Shojaee-Aliabadi *et al*. (2014) for films prepared from κ-carrageenan and essential oils (*Zataria multiflora* and *Mentha pulegium*). Other similar results were reported by Ma *et al*. (2012) for edible films of gelatin and olive oil and Hosseini *et al*. (2015) for edible films of chitosan and fish gelatin with oregano essential oil.

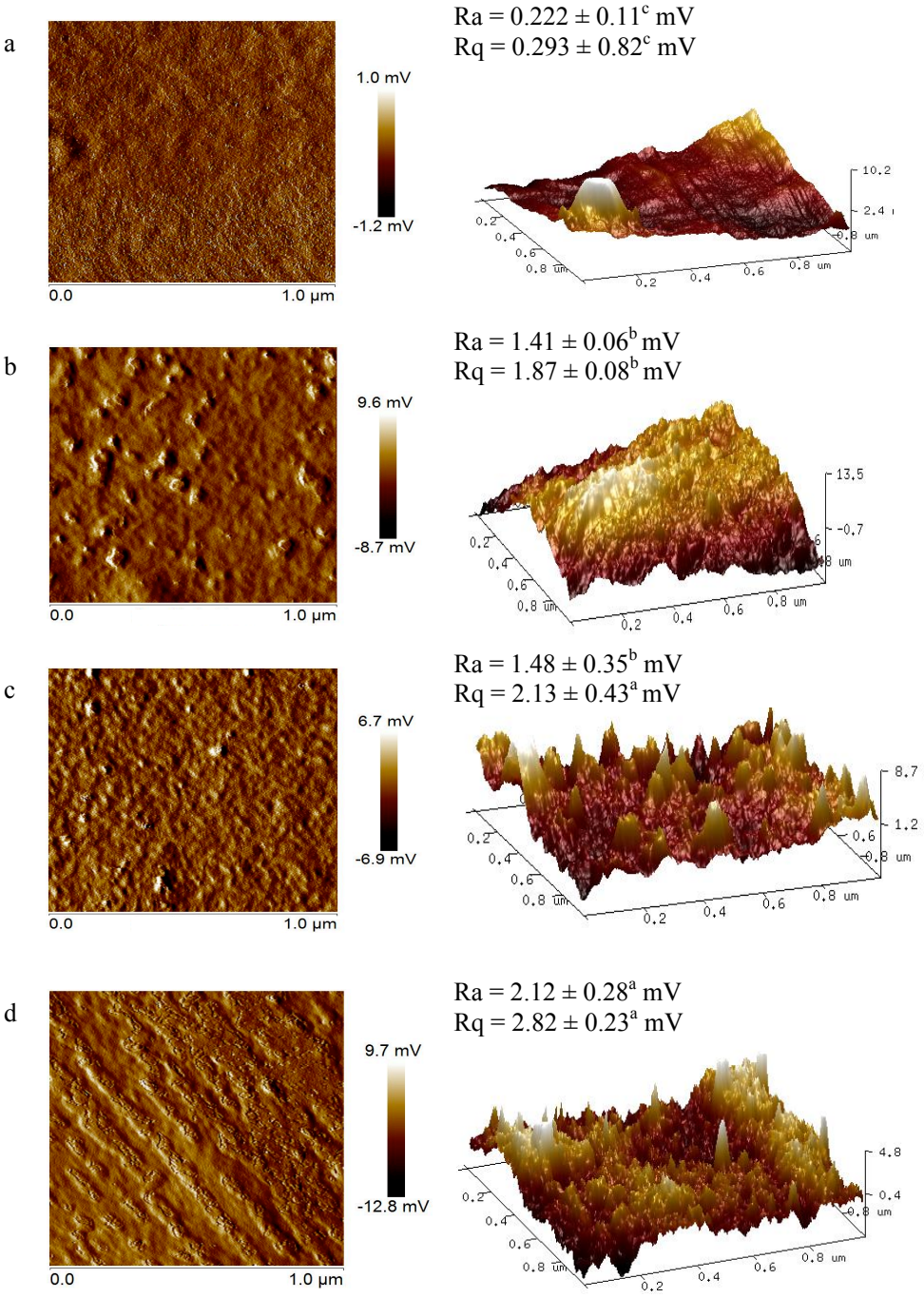

Fig. 4. AFM topography images of *Aloe vera*-Gelatin-Glycerol-EO pepper films. Letters a, b, c, and d in the AFM images represent 0, 0.5, 1.0, and 1.5% pepper oil, respectively. Ra: average roughness, Rq: root-mean square roughness. Values of the same parameter with same letters are not significantly different ($p < 0.05$).

Conclusions

The *Aloe vera* films with the essential oil of pepper (*Pimenta dioica* L. Merrill) did not have a significant effect on the total color difference but resulted in an increase in water vapor permeability. An increase in the essential oil concentration resulted in significantly lower tensile strength with a concurrent increase in the

elongation at break, making the material more pliable. Microstructural studies allowed for the evaluation of the complexity, homogeneity and roughness of the films and changes were observed, as the concentration of oil increased the roughness of the film. The results obtained in this work suggest that *Aloe vera* films infused with pepper essential oil showed potential for use as active edible films, although further studies are necessary before using such films as an active packaging for food commodities.

Acknowledgements

The authors gratefully acknowledge financial support from CONACyT and Tecnológico Nacional de México (TecNM). The authors also thank the Department of Food Industries of Instituto Tecnológico de Roque, the Department of Chemical Engineering of Instituto Tecnológico de Celaya, and Centro de Nanociencias y Micro y Nanotecnologías (CNMN) IPN for supporting the facilities for this research work and acknowledge the technical assistance from Department of Agroindustrial of Universidad Politécnica de Guanajuato.

Nomenclature

L*	lightness variable
a*	green to blue
b*	yellow to red
C*	chroma
x	thickness, mm
t	time, s
A	film area, m^2
TS	tensile strength, MPa
%E	elongation at break
EM	elastic modulus, MPa
Rq	roughness, root square deviation of the heights, mV
Ra	roughness, arithmetic average of the absolute values of the height deviations, mV
Zi	height deviation
N	number of points in the image
WVP	water vapor permeability
RH	relative humidity
Greek symbols	
ΔE	total color difference
Δm	mass change over time, g

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