



Potato starch-based films: Effects of glycerol and montmorillonite nanoclay concentration

Películas de almidón de papa: Efecto de la concentración de glicerol y nanoarcilla montmorillonita

E. Medrano de Jara¹, E. García-Hernández^{2*}, M. J. Quequezana-Bedregal¹, C. D. Arrieta-González², R. Salgado-Delgado², H. Lastarria-Tapia¹, J. A. Castañón-Vilca¹

¹Escuela Profesional de Ingeniería Química, Facultad de Ingeniería de Procesos, Universidad Nacional de San Agustín de Arequipa, C.P. 04001, Arequipa, Perú.

²Tecnológico Nacional de México/I.T. Zacatepec/División de Estudios de Posgrado e Investigación, Calzada Tecnológico No.27, Colonia Centro, C.P. 62780, Zacatepec; Morelos, México.

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Abstract

Biodegradable films were obtained from potato starch mixed with montmorillonite nanoclay (MMT), glycerol and the addition of acetic acid, by the casting method; and then characterize them. It was observed that according to the increase in the presence of MMT nanoclay in the film, this improved the elastic modulus and water vapor permeability; while the increase in glycerol had the opposite effect on the properties evaluated. On the other hand, with scanning electron microscopy it was observed that the surfaces of the films were homogeneous. Being the film, of composition 1 ml of glycerol and 0.05g of MMT nanoclay an alternative to being used as food packaging since it has better properties compared to those that only presented glycerol in its formulation.

Keywords: potato starch, nanoclay, glycerol, biofilm, mechanical properties.

Resumen

Se obtuvieron películas biodegradables a partir del almidón de papa mezclado con nanoarcilla montmorillonita (MMT), glicerol y la adición de ácido acético, mediante el método de casting; para luego caracterizarlas. Se observó que de acuerdo al aumento de la presencia de nanoarcilla MMT en la película, este mejoró el modulo elástico y la permeabilidad al vapor de agua; mientras que el incremento del glicerol presentó el efecto contrario en las propiedades evaluadas. Por otro lado con la microscopía electrónica de barrido se observó que las superficies de las películas fueron homogéneas. Siendo la película, de composición 1 ml de glicerol y 0.05g de nanoarcilla MMT una alternativa para ser utilizada como empaque en alimentos ya que presenta mejores propiedades en comparación con aquellas que solo presentaron glicerol en su formulación.

Palabras clave: almidón de papa, nanoarcilla, glicerol, biopelícula, propiedades mecánicas.

1 Introduction

In recent years, there has been a growing interest in biopolymer films, mainly due to concerns about the elimination of conventional petroleum plastic materials (Oropeza *et al.*, 2016).

Polyethylene is the synthetic material commonly used for making agricultural coverings and food packaging films. The process of removal and disposal of this material involves not only costs but also an adverse effect on the environment. Accumulations of waste and pollution caused by plastic packaging films

can be reduced if such materials were biodegradable (Otey & Westhoff, 1979).

Biodegradable plastics emerged as a viable alternative to the problems caused by the accumulation of plastic waste. Nowadays, today is reconsidering agricultural waste perfecting this technology in the production of biopolymers and food packaging to meet consumer demand for food quality, healthy and safe (Valdes *et al.*, 2014).

Edible films and coatings can be made from a variety of biopolymers, including polysaccharides, such as, starch, chitosan, alginates, cellulose derivatives, among others; proteins, for example,

* Corresponding author. E-mail: edgar.gh@itzacatepec.edu.mx
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gelatin, soy protein, wheat gluten, among others; and lipids, such as waxes, triglycerides, fatty acids and mixtures thereof (Rodríguez-Marín, Alvarez-Ramírez, and Bello-Pérez, 2016). Potato starch is a polysaccharide found in abundance, low cost, biodegradable, edible, and can be obtained from agro-industrial waste. In this way, the real situation in various industries in the world, those that produce French fries, flakes and snacks; emit solid waste containing traces of starch included in its composition. This creates the need to find solutions that reduce the environmental impact produced by these types of industries. On the other hand, potatoes are the fourth food crop of importance in the world (Prada, 2012). Potato starch, like all starches, has amylose and amylopectin in its composition, being linear polymers (amylose) which crystallize more easily than branched polymers (amylopectin), it has been observed in films that the process of crystallization of amylose can occur in short period of time (in an interval of up to 24 h), during drying in the film making process (Rindlav-Westling *et al.*, 1998). This polymer despite being biodegradable under suitable conditions, in the native state has some shortcomings regarding its mechanical and moisture sensitivity properties (Shin *et al.*, 2011). However, these films have low mechanical resistance and are sensitive to moisture due to the highly hydrophilic nature of their components. These properties can be improved by the addition of biodegradable polymers, such as cellulose fiber, nano-clays or others (Flores-Martínez *et al.*, 2017).

The plasticizer is normally liquid and higher viscosity than water that is added to the mixture to improve the flexibility of the material by reducing the intermolecular forces (Halley *et al.*, 2006; Veiga-Santos *et al.*, 2005). Andersen & Houdson (2001), said that the plasticizing effect can be given by substances such as water, alcohols, aldehydes, ketones, organic acids, amines, esters, amides, and mixtures of these, but it is preferred to use plasticizers having a vapor pressure is low to prevent it from volatilizing at the end of an extrusion process or heating. Plasticizers most commonly used are polyols, especially glycerol or sorbitol.

It has been suggested that by modifying the surface of montmorillonite (nanoclay), with the addition of chemicals (organic acids), interactions with the polymer is favorable, allowing a better dispersion of the nanoclay in the polymeric matrix and therefore also improve its mechanical properties and barrier (Huang *et al.*, 2006). The winding structure nanoclay

in the polymer matrix enhances the barrier properties of water nanocomposite films (Hassannia-Kolae *et al.*, 2016). However, to achieve a homogeneous dispersion of the MMT is not easy, due to its hydrophilic surface. Therefore, the organophilization (inclusion of organic compounds in the interlayer space) of the MMT is a key step for its complete exfoliation in the polymer matrix. Organophilization results in organo-clays, which are the result of interactions between clays with organic components, and an intercalated structure can be formed where the polymer penetrates the interlayer region of MMT, obtaining a polymer / MMT structure with an increase in the interlaminar space of the MMT (Tang *et al.*, 2008).

The tests evaluated the films were: mechanical properties (tensile strength, percent elongation, Young's modulus), physical properties (solubility, thickness), and barrier properties (water vapor permeability (WVP)); are this the most important properties of biopolymer films, indicating the ability of the films to control water vapor transport from a food system and its surroundings; Functional groups (Infrared Spectroscopy Fourier Transform), through this technique can be interpreted and compared with the spectrum specialized databases for the presence of functional groups in the molecular structure defined (Pretsch *et al.*, 2000) and morphological analysis by Scanning Electron Microscopy (SEM). The objective of this study was to characterize edible films potato starch and evaluate the effect of glycerol and MMT.

2 Materials and methods

2.1 Materials

Montmorillonite nanoclay (MMT), acetic acid, and glycerol were purchased from Sigma-Aldrich and were used without further purification, commercial low salts water was used. Potato starch was obtained from one variety of potatoes cultivated in the estate of Mexico, Mexico.

2.2 Starch extraction

Potatoes were ground in a blender in water (1:2, w/v) until the powder was very fine. The crushed mass was filtered through the cotton fabric. The starch suspension was decanted for 5 h at room temperature.

Table 1. Formulation of mixtures for biodegradable films.

Film	Glycerol (G) [ml]	MMT nanoclay [g]
G1N0	1	0
G1N0.03	1	0.03
G1N0.05	1	0.05
G1.5N0	1.5	0
G1.5N0.03	1.5	0.03
G1.5N0.05	1.5	0.05
G2N0	2	0
G2N0.03	2	0.03
G2N0.05	2	0.05

After decantation, the liquid was removed and the precipitate (wet starch) was collected. The wet starch was dried in an oven at 50°C for 24 h (Melian, 2010).

2.3 Experimental design

For the formulation of the films, they were prepared according to the experimental matrix, as shown in Table 1, the two independent variables were G (volume of glycerol) and MMT (amount of montmorillonite), besides, all samples were evaluated by triplicate.

2.4 Film preparation

The casting method proposed by Mali, Grossmann, García, Martino, and Zaritzky (2002) was used to obtain the films, using 70 ml of each mixture defined in Table 1. The mixtures were prepared using 70 ml of a 0.5 N acetic acid solution and 2.8 g of potato starch (4% w/v). This mixture was kept under stirring for 20 minutes at 80 °C, then the glycerol and MMT were added maintaining the agitation for 10 minutes. Subsequently, each mixture was subjected to an ultrasound treatment for 30 minutes and finally poured into the previously silanized glass molds. The mixtures were thermally treated at 40 °C for 48 hours. Once the films were formed, they were removed from the silanized glass mold and stored in hermetic polyethylene bags at 28 °C for further characterization. Our experience in the management of biodegradable films leads us to choose optimal glycerol concentration, since it is a function of the manipulation of the film, since at higher glycerol concentration the films become unmanageable (gummy) in this type of filmogenic mixture, or result in an antiplastifying effect for it.

2.5 Film characterization

2.5.1 Measurement of film thickness

The thickness of the films was made according to what is established in standard ASTM D 882-02. A Digimatic micrometer IP65 MITUTOYO, model MDC-1" MJ ($\pm 0.00005''$) was used for the thickness measurement. Ten random measurements were recorded for each film, verifying that the average thickness did not exceed the value of 1 mm.

2.5.2 Water solubility

The water solubility of the films was determined according to the ASTM D 570-98 standard. For this, two samples of each film with dimensions of 2x2 cm were cut. The samples were placed into 50 ml vials, adding 30 ml of distilled water. In that condition, the samples were left to stand for 24 hours at 21.4 °C. After the time, the water was decanted and the residues of the films were removed and dried for 24 hours at 100 °C. The percentage of solubility was calculated according to the equation:

$$\%Solubility = \frac{W_I - W_F}{W_I} \times 100 \quad (1)$$

where: W_F and W_I are the final and initial weights of the films, respectively.

2.5.3 FTIR analysis

FT-IR analyses were performed on a Perkin Elmer Spectrum Two spectrophotometer with Spectrum® software. The samples were analyzed in the transmittance mode in the range of 650 to 4000 cm^{-1} , with a resolution of 4 cm^{-1} and 16 scans, using the attenuated total reflectance accessory (ATR).

2.5.4 Morphological analysis

The analysis of the morphology of the films was carried out employing a scanning electron microscope JEOL model JSM-6010, at 2 kV and magnifications of 500X and 1000 X.

2.5.5 Mechanical properties

The measurements were made according to ASTM D882-02 standard. The equipment used was a BlueHill Lite from INSTRON Model 2519-107. The stress, percentage of elongation and Young's modulus were evaluated. Five rectangular samples of each film with dimensions of 1 x 10 cm were used. The samples were

kept for 48 hours in desiccators with a saturated saline solution of NaCl with a relative humidity of $50\% \pm 5\%$ and room temperature. The deformation rate used was 0.5 mm/s with a gap between heads of 50 mm. Young's modulus was calculated by equation (2):

$$\text{Young's modulus} = \frac{\sigma}{\epsilon} \quad (2)$$

where: σ represents the stress value obtained, and ϵ represents the value of elongation of the sample.

2.5.6 Water vapor permeability (WVP)

For this, a circular section of 8 mm diameter of each film was used and its thickness was measured. The samples were placed on the top of a 2 ml vial which contained 1 ml of supersaturated potassium nitrate solution (to obtain a constant relative humidity). The vials were placed inside a desiccator with a humidity indicator. As a drying agent, silica gel was used to generate a constant relative humidity. The variation in weight of the vials was recorded every hour on an analytical balance for 8 hours. The water vapor permeability of the films was determined from the slope of the time versus weight ratio, according to the following equation:

$$WVP = \frac{(G/t)}{P_{sat}(RH_1 - RH_2)A} \times z \quad (3)$$

where; G/t is the slope of the time versus weight ratio, z is the thickness of the film, A is the exposed area of the film, P_{sat} is the saturation pressure at the working temperature, and RH_1 and RH_2 are the relative humidity of the supersaturated KNO_3 solution and the relative humidity of the environment inside the desiccator, respectively (ASTM 96-00).

2.5.7 Statistic analysis

The results obtained were statistically treated using the MiniTab 18 Statistical Software (Minitab Inc, State College, PA, USA). The data of solubility, water vapor permeability and mechanical properties of the films were subjected to an analysis of variance (ANOVA) with a level of significance of 0.05 ($\alpha = 0.05$). A general linear model was performed to evaluate the significance of the components of the films with respect to properties studied. The Tukey method was used to determine the significant differences in the composition of the films in relation to the parameters evaluated, except for the thickness, where the non-parametric Kruskal-Wallis test was applied.

Table 2. Thickness (mm) films made of different amounts of MMT nanoclay and glycerol.

Film	Thickness [mm]
G1N0	0.1737 ± 0.0355
G1N0.03	0.1677 ± 0.0342
G1N0.05	0.1697 ± 0.0148
G1.5N0	0.1873 ± 0.0188
G1.5N0.03	0.2257 ± 0.0270
G1.5N0.05	0.2127 ± 0.0100
G2N0	0.2307 ± 0.0273
G2N0.03	0.2273 ± 0.0438
G2N0.05	0.2070 ± 0.0546

3 Results and discussion

3.1 Film thickness

It was found that the average thickness of each film did not exceed the standardized value of 1 mm (Table 2). An increase in the thickness of the films was observed as the mass increased. The non-parametric Kruskal-Wallis test shows that there is no significant difference between film thicknesses, for a 95% confidence (p value = 0.111). According to Rangel-Brown, Montalvo-Paquini, Palou, and López-Malo (2013), the thickness is influenced by the method used, the concentration and composition of the first forming. Since no significant difference was found between the samples, that means that the method used, Casting's method, managed to obtain a homogenous film without disturbances, despite the varying concentrations of the components.

3.2 Water solubility

Figure 1 shows the solubility percentage of the films made with potato starch, glycerol, and MMT. Statistical analysis shows that there are differences between the films with 2 ml of glycerol (G2) and the rest of the samples. This analysis shows that the presence of glycerol has a significant effect on film solubility. The highest values were obtained with 2 ml of glycerol (58.67%, 60.54%, and 60.05%), while the lowest were those with a content of 1 ml of glycerol (39.47%, 38.58%, and 39.44%). Similar observations have been reported by other authors (López et al., 2008), noting that this is due to the hydrophilic nature of glycerol. Dos Reis, et al. (2014), also found that higher contents of both, yam starch and glycerol,

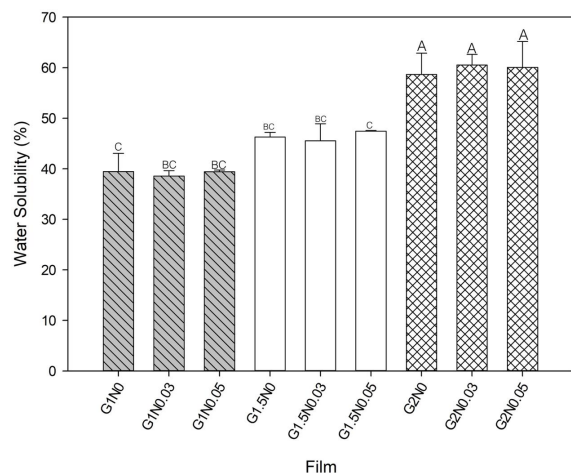


Figure 1. Bar graph comparing error with Tukey* Solubility (%) of films made with glycerol and MMT nanoclay.

increase the solubility of the films. The solubility is one of the important properties for the application of the films, such as for the coating of food, in some cases, they require that the film have insolubility in water to protect the integrity of the product and water resistance. However, high solubility is an indicator of biodegradability (Stuchell & Krochta, 1994).

3.3 FTIR analysis

Figure 2 shows the FT-IR spectrum of potato starch, and in Table 3 the main functional groups identified. From the figure, it is observed that the peak located between 2994 cm^{-1} and 3660 cm^{-1} represents the stretching of the OH groups, and the peak located between 2819 cm^{-1} and 2992 cm^{-1} represents the asymmetric and symmetric stretching of the methyl radicals, as reported by Rappoport (1967). Likewise, the band located between 1628 cm^{-1} and 1650 cm^{-1} represents the flexion of the OH group of water, which indicates that the polymer is hygroscopic (Conley, 1979). The peak located between 1320 cm^{-1} and 1498 cm^{-1} corresponds to the alkyl radicals. Between 1860 cm^{-1} and 1149 cm^{-1} four peaks are observed which are attributed to the C-O-C bonds and vibrations of the OH group, is this characteristic of the polysaccharides (Aburto, y otros, 1999) since the structure of the starch presents interactions CO with different chemical environments (COC, CH_2OH , and COH) (Ruiz, 2006).

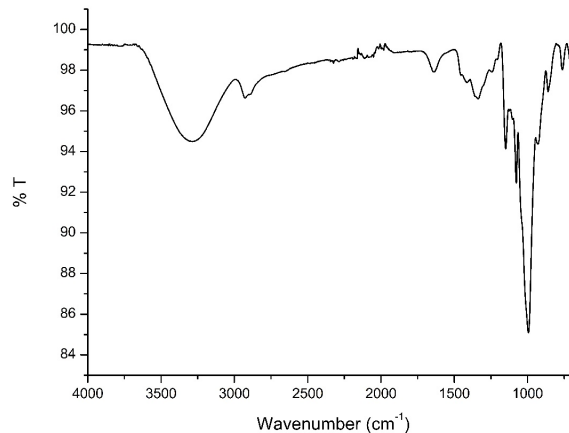


Figure 2. FTIR spectrum of pure potato starch (PPS).

Table 3. Wavenumber (cm^{-1}) and functional group of pure potato starch (PPS).

Wavenumber (cm^{-1})	Functional Group
3700-3020	Stretching OH group
2960	alkyl bond, methyl (CH)
2890	alkyl bond, methyl (CH)
1800-1680	ketone / aldehyde bond (C = O)
1650	OH flexure water
1480-1320	alkyl bond, methylene (CH)
1650	OH flexure water
1480-1320	alkyl bond, methylene (CH)
1390	alkyl bond, methyl ($-\text{CH}_3$)
1360	alkyl bond, methyl ($-\text{CH}_3$)
1310	alkyl bond, methyl ($-\text{CH}_3$)
1220-1160	ether, aromatic linkage (CO)
1060-990	alcohol, aromatic bond (CH_2OH)
930	Vibration OH group
880	ether, aromatic (COC) Link
720	alkane linkage (C- CH_2 -)

Figure 3 shows the FT-IR spectrum of the MMT nanoclay, and in Table 4 the main functional groups identified (Tabak *et al.*, 2007; Madejova, 2003; Tyagi *et al.*, 2000; Bazargani-Guilani & Rabbani, 2004). The band located between 3623 cm^{-1} and 3650 cm^{-1} corresponds to the stretching of the OH groups. This is due to the presence of silanols and coordination bonds between the aluminum cations (Al^{+3}) and the hydroxyl group. The intense band located between 950 cm^{-1} to 1035 cm^{-1} is attributed to the stretching vibrations of Si-O. The peak located at 917 cm^{-1} represents the flexion of Al-Al-OH. The peak located at 793 cm^{-1} is the signal characteristic of SiO_2 due to the vibration of the Si-O bond, and the signal located at 836 cm^{-1} is attributed to the flexion of Al-Mg-OH.

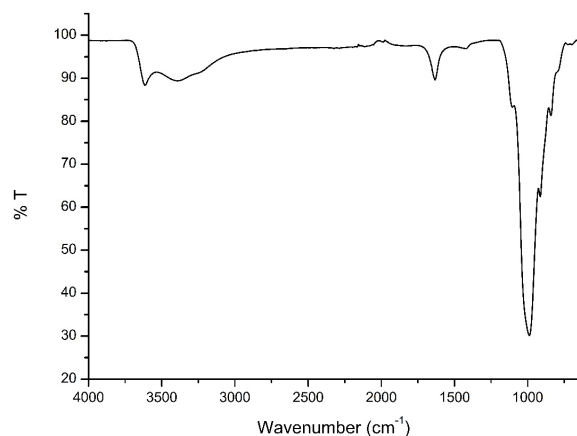


Figure 3. FTIR spectrum of MMT nanoclay.

Table 4. Wavenumber (cm^{-1}) and functional group of MMT nanoclay.

Wavenumber (cm^{-1})	Functional Group
3623	OH stretch
3422	Stretches, OH Hydration
3254	vibration OH
1639	Bending OH Hydration
1430 - 1382	Stretch of calcite and dolomite CO_3
1035	Stretch Si - O
917	Flexure Al-Al-OH
875	Flexure Al-Fe-OH
836	Flexure Al-Mg-OH
793	Platy form of thymidine
725	Free or amorphous silica
692	Quartz
654	flexure OH
524	Flexure Al-O-Si
466	Bending Si-O-Si

Figure 4 shows the FT-IR spectra of potato starch mixtures with the addition of 1 ml of glycerol and 0.00 g, 0.03 g and 0.05 g of MMT; where the same stretching signals of the OH group are observed in Figure 2 and 3 (2994 cm^{-1} to 3660 cm^{-1}), however, a decrease in the intensity of the peaks corresponding to these radicals is observed as the concentration of montmorillonite increases. This is due to the exfoliation of the nano-clay, reflected in a better compatibility with the polymer, producing a greater number of H bonds between the nano-clay and the polymer, since this develops with the OH radicals of the starch; consequently this leads to the decrease of this peak as the amount of montmorillonite

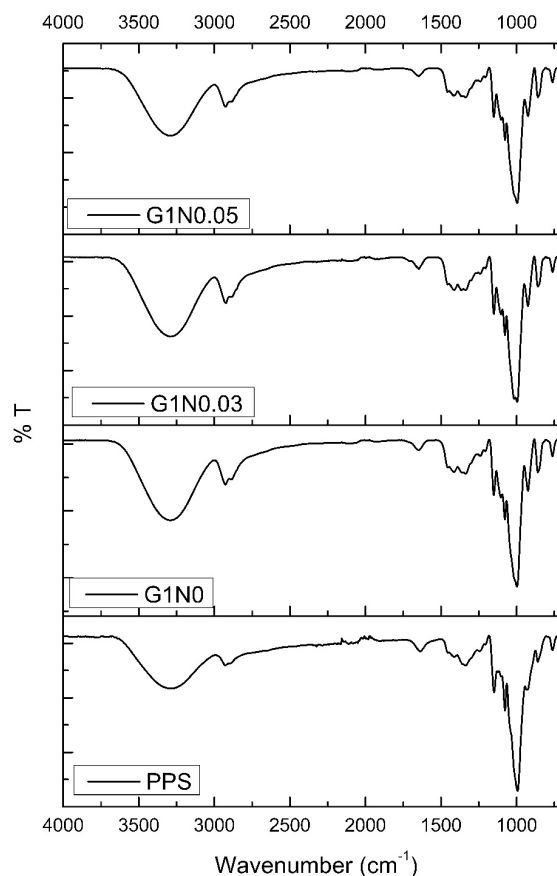


Figure 4. Comparative FTIR spectrum of pure potato starch (PPS) and films with different amounts of MMT nanoclay.

increases. This exfoliation process is due to the mixing with acetic acid, causing delamination of the MMT, completely losing its crystal structure, since these sheets are dispersed in the starch polymer matrix randomly (Azeredo, 2009; Tang *et al.*, 2008).

Figure 5 shows the spectra of potato starch mixtures with the addition of 0.05 g of MMT and 1 ml, 1.5 ml and 2.0 ml of glycerol. From the figure, an increase in the intensity of the peaks related to the OH groups is observed. The stretching of the OH group is better defined due to the amount of glycerol added. These results corroborate the aforementioned; increasing the amount of MMT reduces the permeability of the films due to a reduction in the movements of the OH group flexion of the water (Conley, 1979).

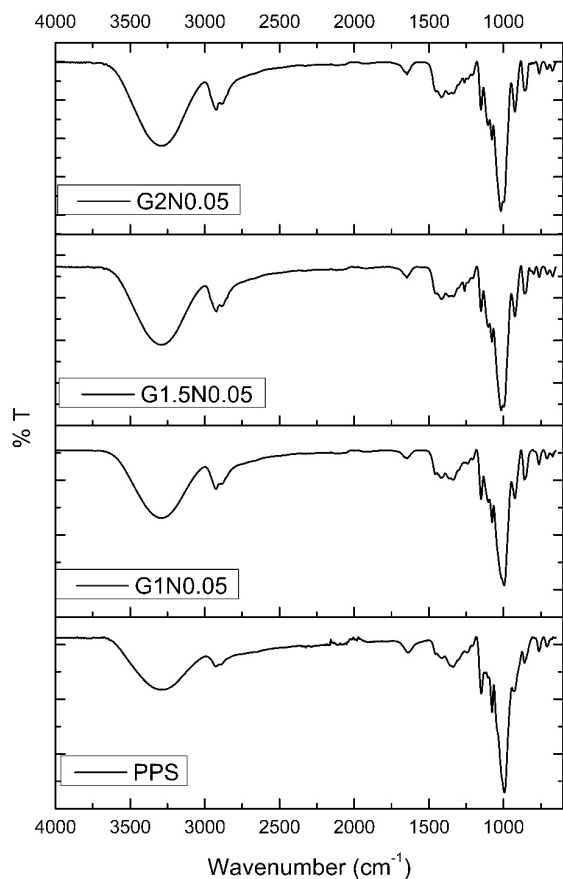


Figure 5. Comparative FTIR spectrum of pure potato starch (PPS) and films with different amounts of glycerol.

3.4 Morphological analysis

Figure 6 shows the photomicrographs obtained by scanning electron microscopy, where it can be seen that the surface of the films are homogeneous

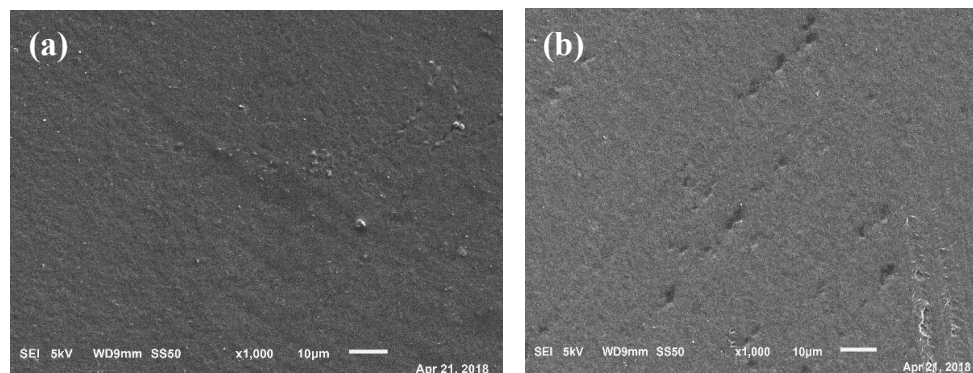


Figure 6. SEM micrographs (500 X, 20kV, 50 .mu.m). (a) G1N0.03 y (b) G1N0.05.

without insoluble particles and without the presence of pores, which can mean a good compatibility of the components with the polymer matrix, this is due to the fact that the MMT nanoclay was modified with a solution of acetic acid, which produced an organophilization, this process being necessary to obtain a good dispersion of the starch within the interlayer region of the MMT nanoclay, which leads to an improvement in the mechanical and barrier properties of the film.

3.5 Mechanical properties

Variance analysis performed on both stress and elongation measurements showed that there is a significant difference. Similarly, the analysis of variance made to the general linear model shows that an increase in the addition of glycerol ($p < \alpha$) significantly affects the value of the effort, and the presence of MMT nanoclay is significant for the elongation values (Figure 7). In general, the percentage of elongation of the films tends to decrease when the concentration of nanoclay is increased. This can be attributed to intercalation of the silicate layers, which causes a decrease in the flexibility of the films (Tang *et al.*, 2008). On the other hand, the effort tends to increase increasing the amount of added nanoclay. Similar results have been reported by Mondragón *et al.* (2008). Regarding glycerol, it is observed that by increasing the amount of glycerol the films formed are more flexible and less resistant. The above is due to a decrease in intermolecular forces such as hydrogen bridges (Ruiz, 2006). Regarding Young's modulus (Table 5 and Figure 8), it is observed that it decreases as the glycerol concentration increases, and on the contrary, an increase in the MMT nanoclay concentration increases Young's modulus; that is, the films become more rigid.

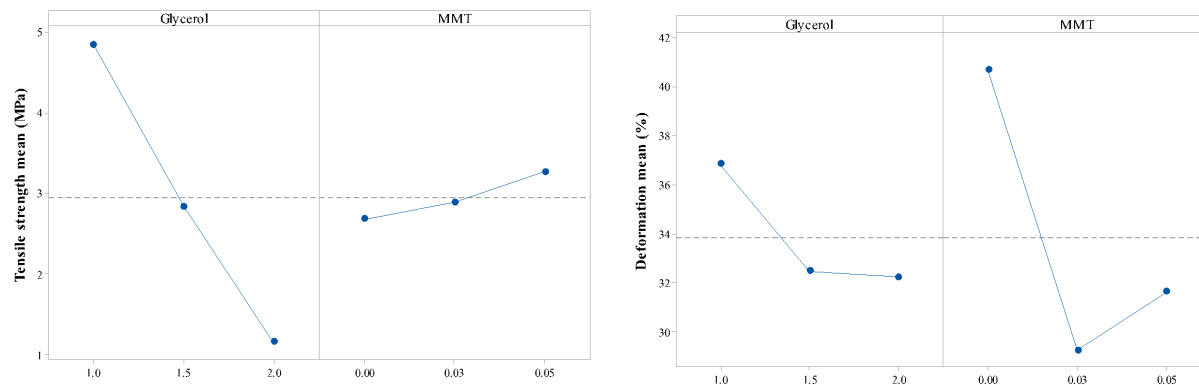


Figure 7. Main effects plot for a) Tensile strength (MPa) and b) Deformation (%).

Table 5. Tensile strength (MPa), Elongation at break (%) and Young Module of films.

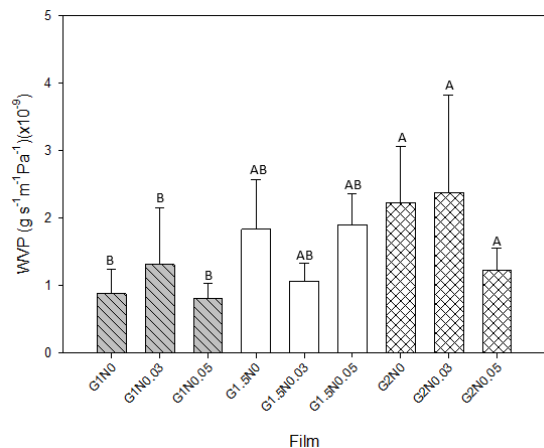
Film	Tensile strenght (MPa)	Elongation at break (%)	Young's Modulus (MPa)
G1N0	4.602 ± 0.918	40.110 ± 1.940	11.560 ± 2.770
G1N0.03	4.631 ± 0.356	33.850 ± 3.440	10.708 ± 0.5040
G1N0.05	5.286 ± 0.999	36.600 ± 4.420	14.830 ± 4.840
G1.5N0	2.384 ± 0.639	44.610 ± 3.000	5.297 ± 1.063
G1.5N0.03	2.990 ± 0.845	30.410 ± 7.300	10.680 ± 5.760
G1.5N0.05	3.126 ± 1.615	22.408 ± 1.499	13.680 ± 6.190
G2N0	1.042 ± 0.165	37.310 ± 3.820	2.782 ± 0.148
G2N0.03	1.041 ± 0.277	23.520 ± 3.750	4.488 ± 1.217
G2N0.05	1.370 ± 0.162	35.910 ± 4.240	3.831 ± 0.463

Majdzadeh-Ardakani *et al.*(2010) found that using an organic acid as a compatibilizing agent between MMT and a starch matrix, the strong interactions between starch and this, facilitated the penetration of starch into the clay gallery, which caused an increase in Young's module due to the nano-clay that was organophilized.

3.6 Water vapor permeability (WVP)

In Figure 8 the WVP values obtained for the different films evaluated are shown. It is observed that in the absence of the MMT nanoclay, the permeability of the films increases as the amount of added glycerol increases. The p-value obtained in the analysis of variance ($p = 0.105$) indicates that there is no significant difference between the samples. However, the analysis of variance performed on the general linear model indicates that the presence of glycerol is significant ($p = 0.046 < \alpha$). That is, the permeability values show a difference in those films with high plasticizer high concentration. This is due to the hydrophilic nature of glycerol which facilitates the

formation of hydrogen bonds with water molecules (Dias-Alves *et al.*, 2007). Likewise, it is also observed that when the MMT concentration increases, the water vapor permeability values decrease. According to Park (2003), this behavior is due to the tortuous passage available for the diffusion of water vapor molecules, due to the distribution of waterproof nanoclay layers. However, one of the main objectives to be able to use this filmogenic mixture as food packaging is to avoid or at least decrease the moisture transfer between the product and the surrounding atmosphere for this reason the WVP should be as low as possible (Gontard, Guilbert, and CUQ, 1992), therefore, films containing 0.05g of MMT can be chosen as candidates for application in food. According to Benderly *et al.* (2008) the dispersion of the layers of montmorillonite increases the length of the diffusion tray that follows a permeating molecule, so that by obtaining a good dispersion of the layers of the clay a decrease in permeability is expected. According to Benderly *et al.* (2008), the dispersion of these MMT layers increases the diffusion path of the permeant, so that the good



* Media that do not share a letter are significantly different.

Figure 8. Bar graph error WVP (g / SMPA) with Tukey* comparison in relation to the amount of glycerol present in films.

dispersion of the nano-clay produces a decrease in permeability.

Conclusions

Based on the results obtained in this study, it can be concluded that: According to the FT-IR analysis, the presence of glycerol increases the number of OH radicals present in the mixture, however, MMT nanoclay exhibits a glycerol antagonistic behavior. Likewise, the addition of acetic acid produces the exfoliation of the MMT nanoclay, improving its dispersion together with the polymer matrix. However, it is conclusive that the increase in glycerol concentration causes an increase in the elastic modulus, permeability and solubility of the films, this behavior being undesired for the use of the material as packaging, while the addition of montmorillonite improves the mechanical and barrier properties of the films, obtaining a possible mixture that could satisfy the requirements to be a packaging, either as a coating or food film.

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Nomenclature

MMT	montmorillonite nanoclay
ASTM	American Society for Testing and Materials
WVP	Water Vapor Permeability
SEM	Scanning Electron Microscopy
<i>Greeks symbols</i>	
ϵ	elongation
σ	stress

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