Development of a bioplastic from banana peel

Desarrollo de un bioplástico a partir de residuos del plátano

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ABSTRACT
The problems caused by synthetic plastics have motivated the use of other materials. This research consisted of taking advantage of the banana peel and cellulose from the pseudostem of this plant to obtain a bioplastic. Dry milling was applied to extract the flour and an acid-alkaline treatment for the cellulose. The elaboration of the thermoplastic material did with a mixture design where fixed amounts of shell flour (5 g), 15% NaOH (5 mL), and water (4 mL), varying the concentrations of the plasticizers, which were glycerol and sorbitol. In two of the formulations, was added as filler 0.5 g of cellulose. The bioplastic obtained was characterized according to its thickness, water vapor permeability (WVP), tension force (TF), break time (bt), and biodegradability. The type of plasticizer and the cellulose content did not affect the thickness of the bioplastic, but it did affect the WVP, TF, and bt. WVP decreases when glycerin is used and increases with the addition of cellulose. The best result for WVP was 1.83 x 10⁻⁹ g/Pa.s.m in the formulation where only was used glycerol, while the best values for TF, bt, and biodegradability were 2.4 MPa, 17 seconds, and 37.77%, respectively, with 75% sorbitol and 25% glycerol. Expanding the study of the best formulations would allow their use as a replacement for synthetic plastics.

Keywords: agro-industrial waste, biodegradable plastic, biofilm, thermoplastic starch

RESUMEN
Las problemáticas causadas por los plásticos sintéticos, ha motivado el uso de otros materiales. Esta investigación consistió en el aprovechamiento de la cáscara del plátano y celulosa del pseudostem de esta planta, para la obtención de un bioplástico. La harina se extrajo por molienda seca y la celulosa con un tratamiento ácido-alcalino. En la elaboración del material termoplástico, se trabajó con un diseño de mezclas donde se establecieron cantidades fijas de harina de cáscara (5 g), NaOH al 15% (5 mL) y agua (4 mL), variando las concentraciones de los plastificantes las cuales fueron glicerol y sorbitol. En dos de las formulaciones, se adicionó como material de relleno 0.5 g de celulosa. El bioplástico obtenido se caracterizó en función de su espesor, permeabilidad al vapor de agua (PVA), fuerza de tensión (FT), tiempo de rotura (tr) y biodegradabilidad. El tipo de plastificante y el contenido de celulosa no incidió en el espesor del bioplástico, pero sí en la PVA, FT y tr. La PVA disminuye cuando se utiliza glicerin y aumenta con la adición de celulosa. El mejor resultado para PVA fue de 1.83 x 10⁻⁹ g/Pa.s.m en la formulación donde sólo se utilizó glicerol, mientras que los mejores valores para FT, tr y biodegradabilidad fueron de 2.4 MPa, 17 segundos y 37.77% respectivamente cuando se trabajó con 75% de sorbitol y 25% de glicerol. Ampliar el estudio de las mejores formulaciones, posibilitarían su uso como reemplazo de los plásticos sintéticos.

Palabras clave: residuos agroindustriales, plástico biodegradable, biopelícula, almidón termoplástico

Received: January 14th, 2021
Accepted: November 30th, 2021

Introduction

Plastics are a family of materials that come from fossil resources and are present in most sectors of the economy. Its high consumption is causing environmental problems, such as prolonged permanence in landfills, greenhouse gas emissions during its burning, and irreversible damage to marine ecosystems. Approximately eight million tons (Mt) of plastic reaches the sea annually, with consequences of the surface to the seabed (Parker, 2018).

These materials enter the aquatic, atmospheric, and terrestrial systems, migrate among themselves, accumulate in the environment, and pass to man through the food chain (Li et al., 2020). Plastics are estimated to be responsible for emitting 400 Mt of greenhouse gases each year. If the current production rate continues, this industry alone will consume 20% of world oil production by 2050 (Mahapatra et al., 2020). Hence the need to obtain biomaterials from plant or animal biomass that, if possible, do not compete with the food needs of the human population. One
of them is bioplastics, which can be biologically based, biodegradable in nature, or with both characteristics.

Agribusiness waste is a source of plant biomass, from which a variety of products through chemical or microbiological treatments are obtained (Gutiérrez-Macias et al., 2017). Among them are those generated in the production and processing of plantain, where leaves, pseudostems, rachis, peels, and fruits, are identified as residues (Granda et al., 2005; Mondragon-García et al., 2018). Of the banana harvest is between 20 and 30% of the available biomass used (Belalcazar, 1991). During its processing, the peel is discarded, which constitutes 30% of the weight of the fruit (Wadhwa and Bakshi, 2013).

Ecuador is a country with agricultural participation within its economy. Among its main products are bananas, with production for 2019 of almost 750 thousand metric tons (Ministerio de Agricultura y Ganadería, 2020). The destination of this fruit is exportation, local consumption, and processing for the production of snacks, banana flour and, vacuum-packed peeled bananas in small and medium industries. The waste generated in this activity contains compounds of interest such as cellulose, hemicellulose, and starch, useful in the production of bioplastics.

In the Central American and Latin American context has been evaluated, the possibility of applying biorefinery processes to use the banana residues as raw material for the production of biofuels, nanocellulose fibers, bioplastics, and other high-value products (Redondo-Gómez et al., 2020). Some research reports obtaining biopolymers from banana peel and corn starch, banana peel, and glycerol (Kader-Sultan and Wan-Johari, 2017; Rusdi et al., 2020). In this sense, was made a bioplastic from the banana peel, the pseudostem of the plant, and the plasticizers. The objective of this research was to evaluate the impact that it has the type of plasticizers on the physical and mechanical properties of this bioplastic produced.

Experimental

The banana peels and pseudostems used came from plantations and artisan factories located in the province of Manabí-Ecuador. They are, described below the procedures for extracting and characterizing the residue, preparing the thermoplastic mixture, and determining its properties.

Materials Extraction and Characterization

The flour was extracted from the banana peel by dry grinding. For this, twelve healthy immature bananas were selected, washed with drinking water, and disinfected by immersion in a 1% (w/v) NaClO solution for 10 minutes. The endocarp was removed and dehydrated in a hot air tray dryer at 40 °C for 12 hours. On the other hand, it was ground and sieved twice, on 40 and 20 μm sieves. It was packed the flour in polyethylene bags until use (Mazzeo and Alzate, 2008).

It was characterized the banana peel flour in terms of moisture, starch content, gelatinization temperature, water absorption index (WAI), water solubility index (WSI), swelling power (SP), amylose, and amylpectin content. It was determined moisture with a BMA 150 brand thermobalance (Tirado et al., 2015). The presence of starch was confirmed with a colorimetric analysis, applying an iodine solution stain on the sample (López et al., 2014).

The gelatinization temperature was determined by dissolving 10 g of flour on a dry basis (DB) in 100 mL of distilled water. 50 mL of the suspension were taken and immersed in a thermostatic bath at 85 °C with stirring. As the paste formed, the temperature was recorded with a thermometer until it stabilized (Grace, 1977).

It is described the procedure for determining WAI, WSI, and SP. 1.25 g of flour were taken, placed in a centrifuge tube with 30 mL of distilled water at 60 °C and stirred. The mixture was placed in a thermostatic bath at 60 °C for 30 min, stirring after the first 10 minutes of heating. It was centrifuged at room temperature at 4900 RPM for 30 minutes. The volume (V) was measured, 10 mL of the supernatant were taken and dried in an oven at 70 °C for 14 hours. Centrifuges tubes weighed with the sediment and dry residue (Anderson, 1982). The calculations were made by Equations 1, 2, and 3.

\[
\text{WAI} = \frac{\text{Gel weight (g)}}{\text{Sample weight (g)}} \tag{1}
\]

\[
\text{WSI} = \frac{\text{Soluble weight (g) \times V \times 10}}{\text{Sample weight (g)}} \tag{2}
\]

\[
\text{SP} = \frac{\text{Gel weight (g) \times V \times 10}}{\text{Sample weight (g) \times V \times 10}} \tag{3}
\]

Amylose was quantified by spectrophotometry with a wavelength of 620 nm, using the calibration curve for the standard solution (Galicia et al., 2012). Amylopectin content was obtained by difference using Equation 4.

\[
\%\text{Amylopectin} = 100\% - \%\text{Amylose} \tag{4}
\]

Cellulose was extracted from the pseudostem of the banana. For this, it was cut into sections, washed with distilled water, separated by layers, and washed again. It was dried to constant weight and degreased using Soxhlet extraction. It was submitted to an acid treatment with a solution of CH3(COOH) at 80% (w/v) and HNO3 at 65% (w/v) with stirring. Then it was shaken with a 10% (w/v) NaOH solution, washed, and dried at 55 °C. The pulp finally obtained was ground and sieved to reduce its size (Romero-Viloria et al., 2014). The cellulose content with the Kurschner and Hoffer method, holocellulose applying the TAPPI T-21 method, lignin with the Klason method was determined, and hemicellulose through Equation 5 (Romero-Uscanga et al., 2014).

\[
\%\text{Hemicellulose} = \%\text{Holocellulose} - \%\text{Cellulose} \tag{5}
\]

Preparation of the thermoplastic mixture

Before establishing the design of experiments, a preliminary test of 16 formulations was carried out with different compositions of banana peel flour, cellulose, water, glycerin, sorbitol, 5 and 15% NaOH solution (w/v) to identify those mixtures that form the film. In each elaborated plastic mixture, the pH with a potentiometer did measure. Based on the results obtained, were established a mixture design with fixed amounts of banana peel flour (5 g), 15% NaOH (5 mL), and water (4 mL), varying the concentrations of the plasticizers used, which were glycerol and sorbitol (0 to 2 g) (Table 1).
The procedure consisted of mixing the banana peel flour with the water and the NaOH solution at 20 °C. It was stirred at 400 RPM for 10 minutes and placed in a thermostatic bath. Then the selected plasticizer was added, and the temperature was increased to 65 °C, maintaining stirring. The gel obtained was cooled to 20 °C to eliminate bubbles, and it did deposit on Petri dishes to form the plastic films by the casting method. It was dried at room temperature for 24 hours and then demolded. After determining the characteristics of the bioplastic obtained, the formulations with the best physical appearance and resistance were selected concerning the rest. 0.50 g of cellulose was added to the selected formulations, and then the effect caused by this filler material on the physical, chemical, and mechanical properties of the material did determine.

Bioplastic properties

The characteristics determined in the film obtained were: thickness, water vapor permeability (WVP), biodegradability, and tension force at the break. The thicknesses were measured directly on the film in three different sections, with a precision micrometer of 25 × 1 mm linear vernier C4.svg (Anchundia et al., 2016). The WVP was made according to the modified E96–80ASTM standard, described by Joaqui and Villada (2013), for which samples of the material were sectioned into 2 × 2 cm sizes and used to seal a hole in the top of a plastic cuvette of 1 x 1 cm that contained distilled water. The cuvette was placed in a desiccator for 24 h. The initial and final weight of the film was taken, as well as the moisture percentage. To calculate WVP were used Equations 6 and 7.

\[
WVP = \frac{WVT \times T}{Pw \times \Delta RH} \quad (6)
\]

\[
WVT = \frac{m}{t \times A} \quad (7)
\]

Where WVP is the water vapor permeability (g/Pa.sm), WVT is the water vapor transmission rate (g/s.m²) calculated from the mass m (g), time t (s) that lasted the experimentation that was 24 hours, and the area A of the film exposed to the transfer of humidity (m²). T is the average thickness of the film (m), Pw is the partial pressure of pure water vapor (3160 Pa at 25 °C), and ΔRH is the relative humidity gradient between the container (0%) and the medium (41%). Biodegradability was carried out through the weight loss of the thermoplastic material, based on a soil burial test (Saffian et al., 2016). The natural soil was collected free of composting material. The samples were weighed, placed with soil in polyethylene bags, and kept at room temperature, with a relative humidity of approximately 43% for 40 days. Every ten days, the samples were removed, rinsed with water to remove soil residues, dried for one hour at room temperature to remove moisture, and finally weighed. The percentage of biodegradability of the bioplastic for the evaluated environment was determined by weight difference with Equation 8.

\[
\text{Weight loss} = \frac{\text{Starting weight} - \text{Final weight}}{\text{Starting weight}} \times 100\% \quad (8)
\]

Tensile tests were done to measure the tensile strength and break time of the film. For this, the Nestor brand universal machine was used according to the method described in the modified ASTM D-882 standard (ASTM D882-18, 2014). The diameter, area, and thickness of three samples of the films were measured. They were then placed between the clamping presses of the equipment and subjected to tension until they broke.

For each variable described, the experiment they were done in triplicate.

Statistical processing

For the statistical analysis, RStudio version 4.0.3 softwares was used.

Results and discussion

The colorimetric determination of the banana peel flour confirmed the presence of starch because it took a blue color when in contact with iodine. The rest of the analysis carried out for the characterization in terms of humidity, gelatinization temperature, WAI, WSI, SP, amylose, and amylopectin, are presented in Table 2.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value ± σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%)</td>
<td>14.80 ± 0.40</td>
</tr>
<tr>
<td>Gelatinization temperature (°C)</td>
<td>62.70 ± 1.50</td>
</tr>
<tr>
<td>Water Absorption Index (g gel / g sample)</td>
<td>4.73 ± 0.19</td>
</tr>
<tr>
<td>Water Solubility Index (%)</td>
<td>3.12 ± 0.56</td>
</tr>
<tr>
<td>Swelling Power (%)</td>
<td>4.81 ± 0.18</td>
</tr>
<tr>
<td>Amylose (%)</td>
<td>8.59 ± 0.82</td>
</tr>
<tr>
<td>Amylopectin (%)</td>
<td>91.41 ± 0.82</td>
</tr>
</tbody>
</table>

Source: Authors

The moisture in the banana peel flour was 14.80 ± 0.40, higher than that reported in similar investigations for banana flour and starch respectively, where it took values of 9.26 % and 9.45 % (Montoya et al., 2014) and 8 % and 9.27 % (Pelissari et al., 2012). This variation in the moisture content of the flour could be affected by the environmental conditions of the laboratory where the analysis was carried out (Lucas et al., 2013).

Banana starch gelatinizes in a temperature range similar to cereal starch (Montoya et al., 2014). In this research, the gelatinization temperature was lower than the value reported for flour (68 °C) and banana starch (66.41 °C) (Lucas et al., 2013). Pozo (2019) registered a temperature of 65 °C for green banana starch. The differences in the values obtained for the gelatinization temperature can be attributed to the genetic conditions of the fruit, the climatic conditions of the crop, and the weeks of harvest (Montoya et al., 2014).
The quality of the starch subsequently affects the properties of the bioplastic formed. Water resistance is an important property for biodegradable films, especially when used as a protective food barrier, where water activity and the possibility of film breakage are high (Moro et al., 2017).

The water absorption, solubility, and swelling power indices serve as indicators of the functional properties of starches (Rodríguez-Sandoval et al., 2012). The WAI, WSI and SP values were 4.73 ± 0.19 g gel/g sample, 3.12 ± 0.56% and 4.81 ± 0.18% respectively. The solubility and the swelling power depend on the state of ripeness in which the fruit is. Starches with high starch content and high viscosity will have low solubility, high water absorption, and high swelling power (Aristizábal and Sánchez, 2007). The quality of the starch subsequently affects the properties of the bioplastic formed. The resistance to the passage of water is an important property for biodegradable films, especially when used as a protective food barrier, where water activity and the possibility of film breakage are high (Moro et al., 2017).

The amylose and amylpectin content for the banana peel flour was 8.59 ± 0.82% and 91.41 ± 0.82% respectively. Pelissari et al., (2012) registered 23.10% and 35% for the amount of amylose in banana flour and starch. In the same way, Contreras-Pérez et al., (2018) obtained values between 23.5 and 31.3% for banana starch from 4 different varieties. The content of amylose and amylpectin in starch is a determining factor for the quality of finished foods. High values in amylose content favor greater solubility and a greater tendency to retrograde gels (Aristizábal and Sánchez, 2007). Amylose retrogrades faster than amylpectin, since due to its linear and highly polar nature, it tends to form hydrogen bonds between hydroxyl groups of adjacent molecules, causing a partial shrinkage of the starch known as retrogradation (Salinas-Moreno et al., 2003). Therefore, the higher the content of amylpectin, the lower the retrogradation and, therefore, the properties of the bioplastic material formed will be better.

On the other hand, the characterization for the extracted cellulose pulp is in Table 3.

The results obtained for cellulose are compared with that indicated for a wheat straw with 57.09% (Romero-Uscanga et al., 2014), which was used as a reinforcement material in thermoplastic materials, providing mechanical properties similar to those of composites of wood flour (Mishra and Sain, 2009). Similar experiences show satisfactory results when using other agricultural residues, such as cocoa pod husk (Lubis et al., 2018) and rice straw (Bilo et al., 2018), as sustainable filler in bioplastics.

When making thermoplastic mixtures, the film was formed at basic pH (8.11 – 13.15) but not at neutral pH (7.3). The increase in the concentration of the NaOH solution favored the consistency and durability of the material. Díaz et al., (2019) characterized chickpea flour films and found that film-forming solutions at pH 10 had better results than solutions at neutral pH.

In the mechanical test, only formulations 1, 2, and 3 did not show breakage. In the rest of the formulations, the tensile strength and the breaking time could not be determined (ND). Then, to evaluate the incidence of the filler material on the characteristics of the bioplastic, 0.50 g of cellulose was added to F1 and F2 (F6 and F7, respectively) as they were the ones that exhibited the best appearance.

The results of the thickness, WVP, tensile strength and, break time for each formulation is in Table 4.

### Table 4. Properties of the bioplastic obtained

<table>
<thead>
<tr>
<th>Formulation</th>
<th>Thickness (mm)</th>
<th>WVP x 10^9 (g/Pa.sm)</th>
<th>Tensile force (MPa)</th>
<th>Break time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>1.61 ± 0.05</td>
<td>1.83 ± 0.21</td>
<td>1.90</td>
<td>11</td>
</tr>
<tr>
<td>F2</td>
<td>1.53 ± 0.21</td>
<td>1.86 ± 0.41</td>
<td>2.49</td>
<td>17</td>
</tr>
<tr>
<td>F3</td>
<td>1.64 ± 0.02</td>
<td>2.67 ± 0.18</td>
<td>2.00</td>
<td>13</td>
</tr>
<tr>
<td>F4</td>
<td>1.71 ± 0.19</td>
<td>2.32 ± 0.02</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>F5</td>
<td>1.55 ± 0.13</td>
<td>0.69 ± 0.03</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>F6</td>
<td>1.68 ± 0.09</td>
<td>2.68 ± 0.18</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>F7</td>
<td>1.67 ± 0.04</td>
<td>4.12 ± 0.82</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

Source: Authors

The thickness of the biodegradable films was between 1.55 and 1.71 mm, showing different results regardless of the type of plasticizer used. In an investigation where edible films were produced, a thickness of 0.11 mm was reported when using 0.5% banana peel and 0.17 mm thick with 1.5% banana peel (Anchundia et al., 2018). The permeability to water vapor took values between 0.69 and 4.12 x 10⁻⁹ g/Pa.sm, but in all cases, they were higher than 2.41 x 10⁻¹⁰ g/Pa.sm recorded for a film made with a banana skin and salicylic acid (Anchundia et al., 2016). The addition of cellulose favors the passage of water vapor and, according to Wang et al., (2018), this occurs because cellulosic materials absorb or desorb the humidity from the surrounding air until reaching an equilibrium moisture content.

According to what was obtained, both plasticizers reduce the passage of water vapor, but sorbitol does so to a lesser extent when it is not mixed with glycerol. The best mechanical properties were for F2, with a tensile strength of 2.40 MPa and a break time of 17 seconds. The mechanical behavior of the material obtained in this research was better than that of a bioplastic made with cassava starch, fique fiber, and glycerol, whose tensile stress was less than 2 MPa (Navia-Porras and Bejarano-Araña, 2014). On the other hand, it is lower than that reported for banana films, bark, and acetylsalicylic acid, whose tensile strength was between 4.43 and 10.80 MPa (Anchundia et al., 2016).

The influence of the plasticizer on the properties of the bioplastic was verified with an analysis of variance (ANOVA). The Shapiro-Wilk test was used to verify the normality of the data. For WVP and thickness, p-values of 0.105 and 0.9185, respectively, were obtained, complying with the normality assumption. The Bartlett test was also applied to verify the homoscedasticity of the variances. For thickness and WVP, p-values of 0.2787 and
0.4593, respectively, were obtained, satisfying the assumption of the equality of variances. In both tests, both the tensile strength and the breaking time had a p-value <0.05. For the tensile strength and the breaking time, given the characteristics of the data, the Kruskal-Wallis test was used.

The procedure described was repeated to determine the influence exerted by cellulose on the characteristics of the material obtained. Fisher’s test was used for the thickness and WVP variables. The corresponding results for both factors (plasticizer used and addition of cellulose) are in Table 5.

Table 5. ANOVA for bioplastic properties

<table>
<thead>
<tr>
<th>Factor</th>
<th>Variable</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasticizer</td>
<td>Thickness</td>
<td>0.733</td>
</tr>
<tr>
<td></td>
<td>Water vapor permeability, WVP</td>
<td>4.78x10^-5</td>
</tr>
<tr>
<td></td>
<td>Tension force</td>
<td>0.01431</td>
</tr>
<tr>
<td></td>
<td>Break time</td>
<td>0.01431</td>
</tr>
<tr>
<td>Cellulose</td>
<td>Thickness</td>
<td>0.18700</td>
</tr>
<tr>
<td></td>
<td>Water vapor permeability, WVP</td>
<td>0.00389</td>
</tr>
</tbody>
</table>

Source: Authors

The ANOVA and the non-parametric test were carried out for the plasticizer factor indicate with a p-value <0.05 that there are significant differences in water vapor permeability, tensile strength, and break time, verifying the influence exerted by the type of plasticizer on the behavior of these variables. In similar studies, it was concluded that the concentration of the plasticizer affects the WVP, and it is correlated positively with the concentration of glycerol (Díaz et al., 2019; Faradilla et al., 2018). In other related research, it was determined that plasticizers influence the physical properties of soy-based bioplastics (Tummala et al., 2006) since they increased the tensile modulus and tensile strength when sorbitol was used instead of glycerol and when using a mixture of these intermediate values, were reached, about the results obtained when the plasticizers were used independently. For the cellulose addition factor, there was a p-value <0.05 in the WVP, indicating that the variable is affected when cellulose is added to the bioplastic film, as it was verified experimentally. On the contrary, the thickness did not have significant results; that is, it is not affected by the type of plasticizer used or by the addition of cellulose.

In the biodegradability test, information was only obtained for five of the formulations. At the end of the trial, the samples were fragmented, making them difficult to review. To compare the behavior of the bioplastic produced to other materials, a positive control (filter paper) was taken; and negative control (PET plastic bottle). The weight loss during the 40 days of the biodegradability test is presented in Figure 1. Likewise, the total percentage of weight loss of the bioplastic at the end of the test is shown in Table 6.

A decrease in the weight of the bioplastics was observed throughout the trial, being more evident during the first ten days of the evaluation. The best result was for F2 with a weight loss of 37.77% and, the lowest value corresponded to F6 with 8.28%. The negative value in both the positive and negative control infers a weight gain, probably, due to the presence of moisture or traces of dirt. In a similar investigation, a weight loss of 64.21% was reported after 90 days in compost for a bioplastic made with potato starch (Meza et al., 2016). On the other hand, in the evaluation of a bioplastic based on a banana peel for agricultural purposes, 65.10% of the initial weight was lost in a period of eight weeks, its degradation process is much faster compared to other plastics commercials intended for sowing (Huzaisham and Marsi, 2020).

Conclusions

Bioplastics made from plant or animal biomass represent an alternative to replace synthetic plastics. In this research, banana residues were used to obtain thermoplastic starch. For the extraction of starch and cellulose from the residual, physical and chemical methods were applied. According to the results ob-
tained in the experimentation, it was known that starch presents characteristics similar to those reported in previous works. The plasticizer used affected the PVA and the mechanical properties of the material. Although cellulose is used as a filler material to impart strength, in the case studied it, increased PVA, which is an unwanted characteristic in packaging materials. The biodegradability test showed that the material degrades for the evaluated conditions. The formulation with the lowest PVA; was found when using glycerol, working as a reference in food packaging applications. Regarding the mechanical properties, the best results did obtain when mixing glycerol and sorbitol. Although the formulations developed are not conclusive as a replacement for currently existing synthetic plastics, the results of this research serve as a reference for future work where other formulations are evaluated, aimed at obtaining bioplastics capable of competing with synthetic plastics.

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