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Investigation note

Obtaining bioplastic films from castor oil plant

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Abstract

The excessive use of petroleum-based plastics creates a serious problem of environmental pollution, for this reason, this work proposes the production of bioplastic films based on cellulose extracted from leaves and stems of Ricinus communis L. (castor oil plant). The project was carried out in 2022 in the state of Michoacán, Mexico. The bioplastic was obtained in two stages, first the extraction of cellulose is carried out by an alkaline treatment at 80 °C, then, the cellulose obtained is mixed with water, glycerin, and acetic acid for the formation of the bioplastic film by the casting method. With the above procedure, uniform films with a thickness of 0.12 mm were obtained. Regarding the tensile strength, a maximum value of 7.1 MPa was found, as the amount of glycerin increases, the tensile strength increases. Through scanning electron microscopy analysis, it was observed that bioplastic films with 5% glycerin exhibit more uniform and homogeneous textures. The castor oil plant can be used not only to obtain oil but also to obtain plastics from sources alternative to petroleum, which would favor its cultivation in Michoacán.

Keywords:

Ricinus communis L., casting, cellulose, tensile strength..

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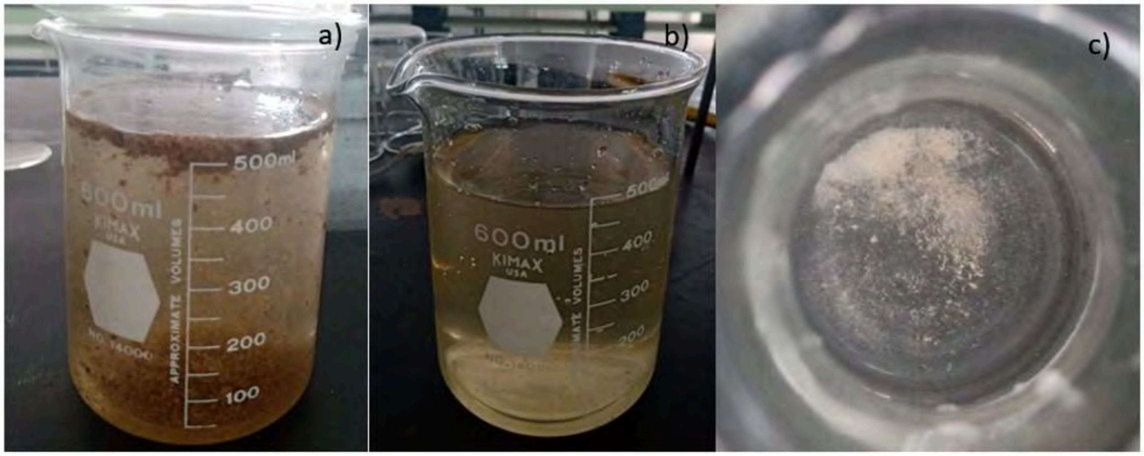
The castor oil plant (Ricinus communis L.) is a species from the family Euphorbiaceae and this plant is of economic importance due to its oil content, which is mainly used in the agricultural, industrial, and pharmaceutical sectors (Yeboah et al., 2021; Shekade et al., 2023). According to studies carried out by the International Union for Conservation of Nature, it is indicated that this plant is native to Africa (Landoni et al., 2023). There are currently 1.1 million hectares of castor oil plants worldwide, with India, China, Brazil, and Paraguay being the largest producers; Chile, Mexico, Peru, Colombia, and Ecuador have soils suitable for the cultivation of the plant (Valencia et al., 2019).

For Mexico, from 2018 to 2020, an average of 635 hectares of castor oil plant were harvested and a production of 4 361 t was obtained (INIFAP, 2022); nevertheless, there is a greater production potential for its cultivation in Mexico. An application other than extracting the oil from the seeds is an alternative to encourage its cultivation. Due to its composition (45% cellulose, 30% hemicellulose and 12% ash) (Vinayaka et al., 2017), the castor oil plant is a plant that can be used to obtain bioplastic films.

Through this project, a bioplastic was developed from the stem and leaves of the castor oil plant, which not only encourages the cultivation of the plant but can also represent a decrease in the use of plastics obtained from petroleum sources, the waste of which generates pollution to the environment. Castor oil plant grown in the region of Lázaro Cárdenas, Michoacán in Mexico was used as a raw material.

To obtain cellulose, the leaves and stem are first washed and dried, and then both tissues are ground. An alkaline process was carried out to obtain the cellulose (Figure 1a), in which 100 g of the ground leaves is placed in a beaker and 500 ml of 8% m/v NaOH (J. T Baker) is added, keeping a constant temperature of 80 °C for 30 min (Escoto et al., 2015; Pinos and Braulio, 2019). Once the cellulose is obtained, it is filtered, allowing only the liquid to pass through, while the fiber (bagasse) is discarded (Figure 1b). The cellulose precipitates at the bottom of the container resembling a fine powder as shown in Figure 1c.

Figure 1. Process for obtaining cellulose by means of the alkaline process. a) cellulose extraction; b) filtration; and c) filtered and dried cellulose.



By means of the described procedure, a yield of 8.5% (basis in dry weight of the leaves and stems) of cellulose was obtained, this yield is low compared to other sources, such as bananas (Chopra et al., 2023) or sugarcane (Lopez-Martínez et al., 2016); however, it is possible to improve by varying the extraction conditions. Once the cellulose is extracted, glycerin (≥99.5%, Sigma-Aldrich) and acetic acid (≥99%, Sigma-Aldrich) are added to form the bioplastic.

A 3^2 design factorial was carried out, where the amount of glycerin (factor 1) and the amount of acetic acid (factor 2) were varied in three levels (5%, 10%, and 15%) to determine the effect that glycerin or acetic acid have on the morphology and tensile strength of the films produced. The

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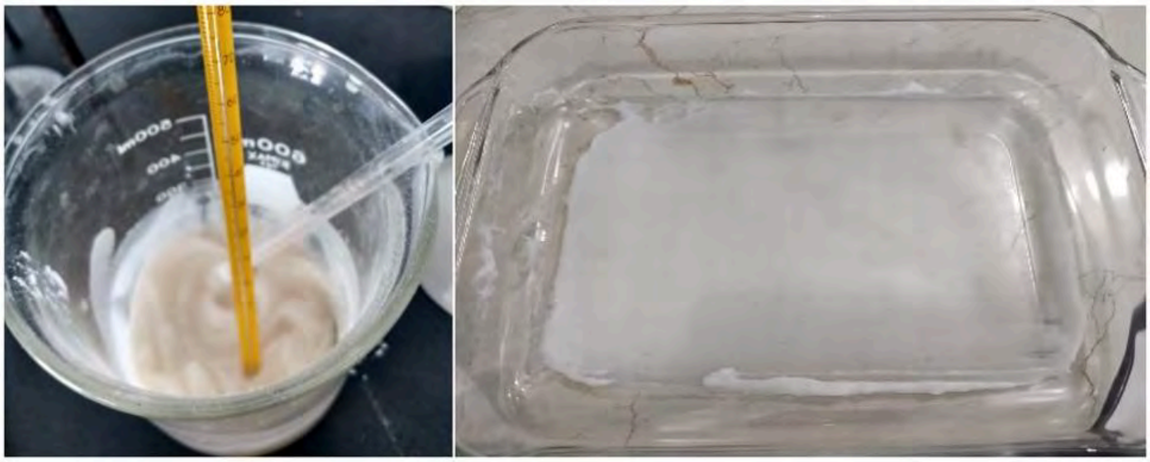
acetic acid stabilizes the structure of the bioplastic film and the glycerin acts as a plasticizer. For the preparation of the film, the casting method was used, it is left to rest for a time of 48 hours at room temperature until the film can be detached (Jerez et al., 2007; Saiful et al., 2019). Figure 2 a-b shows the bioplastic and the formed film.

Figure 2. Bioplastic formed by the casting method. a) bioplastic before being poured; and b) bioplastic film.



a) b)

Micrographs were obtained using a Jeol JSM 7600F field emission scanning electron microscope at 1000X. Figure 3 a-j shows graduated cylinders of the films formed from the bioplastic, nine samples (with their respective replications) were obtained.

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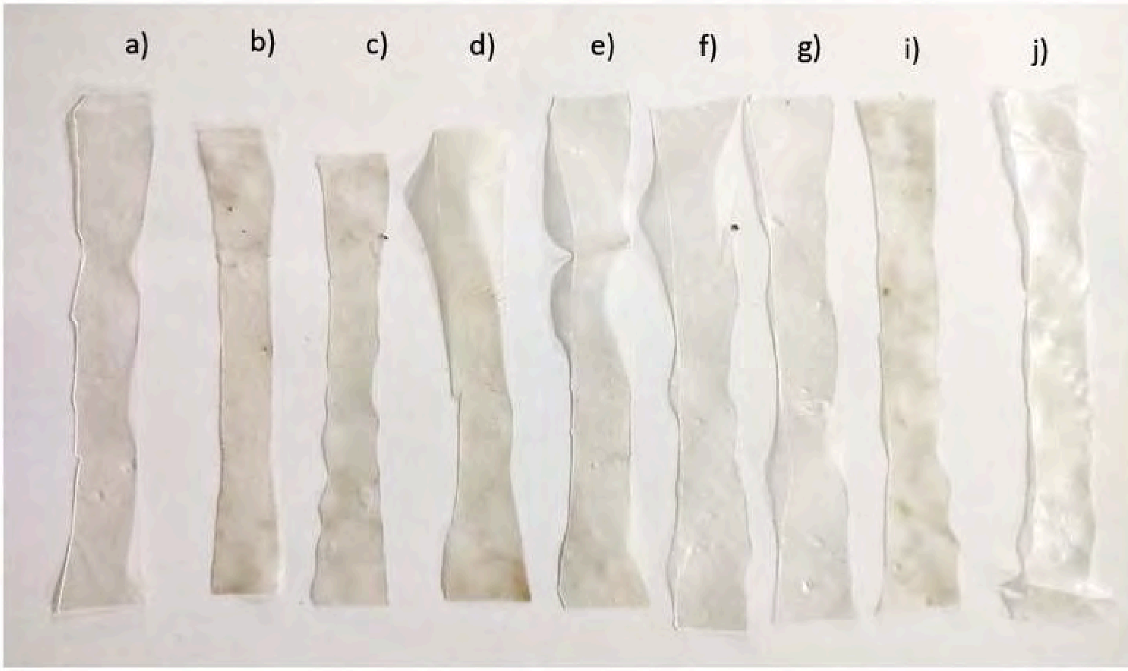
Figure 3. ***Image of the graduated cylinders of bioplastic films obtained from the cellulose of the plant Ricinus communis L. varying the concentration of acetic acid and glycerin.***



Figures 4 a-b-c show micrographs of the film surfaces where glycerin was varied by 5%v, 10%v, and 15%v, respectively, with a fixed amount of acetic acid of 5%v. It was observed that Figure 4-a (5% glycerin) has a smoother surface compared to Figures 4-b (10% glycerin) and 4-c (15% glycerin), which show surface defects. Micrographs with the same glycerin variation (5%, 10%, and 15%) but with a concentration of 10%v of acetic acid are observed in Figures 4 d-e-f. No overly rough surfaces were observed in the images, with the smoothest surface being observed in Figure 4-d.

In the same way, in Figures 4 g-h-i show the micrographs of the films with the same variation of glycerin, but with a concentration of 15%v of acetic acid. Surfaces with greater roughness are observed in all cases (Figures 4 g-h-i), which is due to a higher amount of acetic acid. In Figure 4-i, air bubbles are observed in the film, while in Figures 4-g and 4-h, granules form on the surface. A low glycerin content results in films with fewer surface defects.

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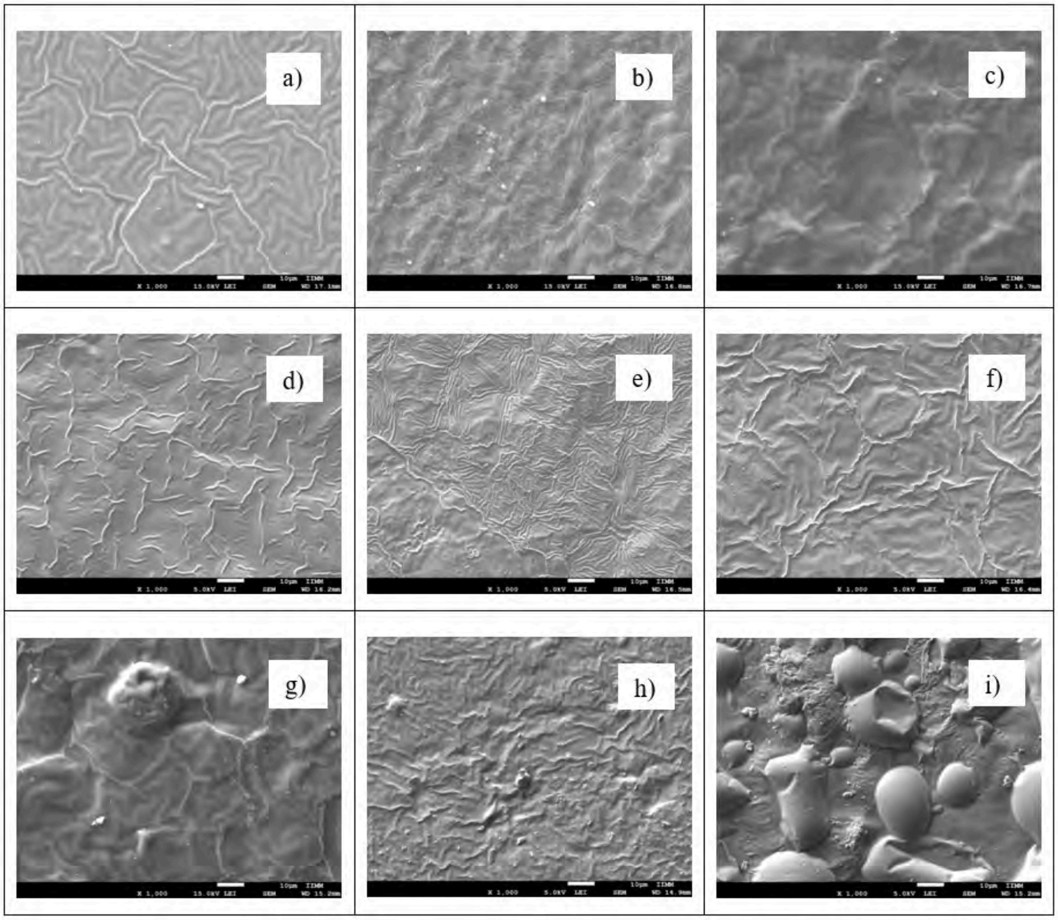
Figure 4. Micrographs of bioplas c films varying the concentra on of glycerin and ace c acid. With 5 %v ace c acid. a) 5 %v glycerin; b) 10 %v glycerin; and c) 15 %v glycerin, with 10 %v acetic acid; d) 5 %v glycerin; e) 10 %v glycerin; and f) 15 %v glycerin, with 15 %v acetic acid; g) 5 %v glycerin; h) 10 %v glycerin; and i) 15 %V glycerin.



The tensile strength was determined by a universal testing machine (AFG 500 N, Mecmesin) with an accuracy of ±0.1%. For the strength measurement, nine graduated cylinders, 100 mm long and 25 mm wide, were made in triplicate according to the ASTM D638 standard (ASTM D638, 2014).

Figure 5 shows the tensile strength values in MPa of the bioplastic graduated cylinders produced, the acetic acid content was varied and in each case, the glycerin concentration was varied by 5, 10 and 15%. For the 5% variation of acetic acid, the following tensile strength values were obtained: 7.1 ±0.4 MPa, 3.1 ±0.2 MPa and 1.3 ±0.1 MPa for glycerin concentrations of 5, 10, and 15% respectively; similarly, for the 10% acetic acid, the following values were obtained: 6.5 ±0.4 MPa, 2.9 ±0.2 MPa and 1.2 ±0.1 MPa for glycerin values of 5, 10 and 15%, respectively; finally for the acetic acid concentration of 15%, the respective tensile strength values of 5.1 ±0.2 MPa, 2.2 ±0.2 and 0.6 ±0.1 MPa were obtained.

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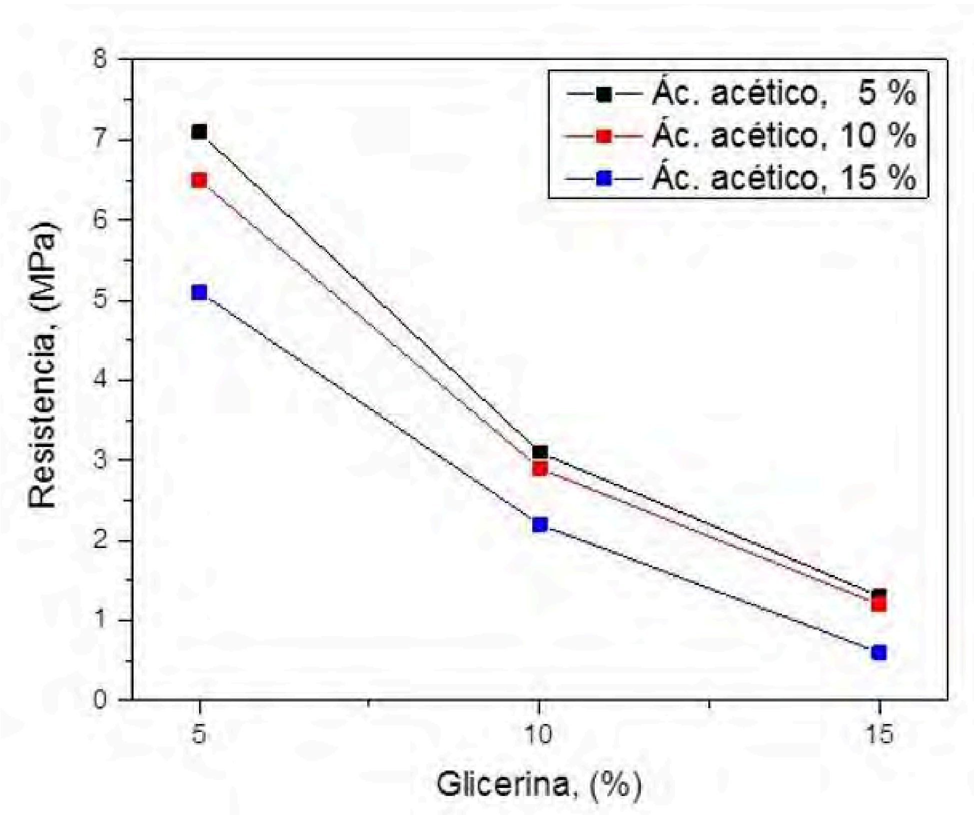
Figure 5. Effect in the variation of acetic acid content on tension.



It was observed that the lower the amount of acetic acid, the higher the tensile strength, which is due to the fact that the acetic acid, after the polymerization reaction is carried out (Nandiyanto et al., 2020), remains on the surface of the film, resulting in defects that decrease tensile strength. The results obtained were analyzed using descriptive statistics and Anova analysis in Minitab. According to the results obtained, it is observed that both factors studied have an effect on tensile strength.

Regarding the amount of glycerin, a similar effect occurs, as the amount of glycerin increases, the tensile strength decreases, which is due to the reduction of intermolecular forces, which causes the films to be more flexible, but less resistant (Santana et al., 2018). By comparison, we consider that our results are quantitatively superior to those obtained with other plant sources with respect to tensile strength (Table 1).

Table 1. Tensile strength values reported for bioplastics from different botanical sources.

Botanical source	Tensile strength (MPa)	Reference
Orange peel	5.5	(Mayhuire et al., 2018)
Banana with milk casein	4.4	(Palma-Rodríguez et al., 2017)
Cassava flour	1.8	(Navia et al., 2013)
Castor oil plant	7.1 ±0.4	The present work

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Conclusions

Currently, the castor oil plant is mainly used to obtain oil; through this study, it showed another use, which is the obtaining of bioplastic, if this application is carried out, it can favor a cultivation on a larger scale. It was possible to obtain bioplastic films from castor oil plants with high tensile strength values (7.1 ±0.4 MPa) compared to similar botanical sources. The cellulose of the castor oil plant was obtained through an alkaline process, obtaining an approximate yield of 8.5%.

The best parameters for obtaining the plastic films were 5% glycerin, 5% acetic acid and 20 g of cellulose through the casting process. It was observed that, as the percentage amount of glycerin increased, the tensile strength decreased between 0.6 ±0.1 and 7.1 ±0.4 MPa, while the percentage variation of acetic acid did not significantly influence the tensile strength.

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