Obtaining bioplastic from *Opuntia ficus indica* reinforced with starch from *Ipomoea batatas*

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***Abstract*– Currently, several countries overuse conventional plastics, generating negative alterations in the environment. Opuntia ficus indica and Ipomoea batatas can generate biofilms competitive with commercial plastics. Therefore, the objective of this research was to obtain bioplastic from Opuntia ficus indica reinforced with starch from Ipomoea batatas. For the elaboration of the bioplastic, pectin was extracted from Opuntia ficus indica and mixed with glycerin, acetic acid, cinnamon powder and clove powder. On the other hand, starch from Ipomoea batatas was obtained by the process of grating, addition of water and filtration. Nine bioplastic samples were obtained with different doses of pectin and starch. The results indicated that the bioplastic sample with 180 g of pectin and 30 g of starch presented the best mechanical properties with tensile strength of 1.5 N, density of 0.45 g/cm^3 and elongation of 15.85%. In addition, the bioplastic presented good biodegradability in agricultural soil, with an approximate percentage of 89% in 30 days of contact. Finally, it is concluded that the bioplastic obtained complied with the elasticity and breaking properties, being suitable for the elaboration of bags for plants and compost for agricultural use, mainly due to its rapid biodegradability.**

***Keywords*-- Opuntia ficus indica, Ipomoea batatas, bioplastic, mechanical properties, biodegradation.**

I. INTRODUCTION

As the years have passed, population growth and the production of solid waste such as plastic is a great concern due to its excessive use, critically affecting various ecosystems as well as the health of human beings [1]. Plastics are synthetics derived from petroleum hydrocarbons, being of difficult degradation and high persistence over time [2]. Unlike bioplastics that are from natural sources such as starch, cellulose, etc., and can be degraded by microorganisms in a short time [3]. The bioplastic is obtained by extraction methods that consist of separating the soluble components from the solid using a liquid solvent such as water [4].

Among the natural sources that have been mostly used to obtain bioplastics are *Solanum tuberosum* [5], *M. indica* and *M. paradisiaca* [6], corn and quinoa starches [7], cassava [8], pectin [9], sweet potato and potato [10].

For the reduction of volume and contamination by conventional plastics, a bioplastic of *Opuntia ficus indica* reinforced with the starch of Ipomoea batatas that presents easy deterioration and is non-toxic is chosen [11]. *Opuntia ficus indica* is commonly known as tuna, penca or Indian fig belonging to the cactaceae dicotyledonous angiosperm family [12]. This polysaccharide presents thickening, plasticity and viscosity characteristics [13]–[15]. In addition, Ipomoea batatas known as sweet potato or sweet potato, corresponds to the convolvulaceae family. This starch contributes to properties such as gelatinization [16].

The use of these natural sources is a low-cost alternative that generates new by-products for agriculture. Therefore, the present research allows promoting and generating bioplastics that are friendly to the ecosystem, using *Opuntia ficus indica* reinforced with starch from *Ipomoea batatas*.

II. MATERIALS AND METHODS

A. Obtaining and characterization of Opuntia ficus indica and Ipomoea batatas

Ten kilograms of *Opuntia ficus indica* raw material was collected and classified to obtain the mucilage and determine its humidity and viscosity. On the other hand, 1 kg of Ipomoea batatas was used, which was grated and sieved until a particle size of 300 μm was obtained.

Figure 1 shows the mucilage and starch obtained from *Opuntia ficus indica* and *Ipomoea batatas*, respectively.

Fig. 1 Raw material: a) *Opuntia ficus indica*, b) Mucilague, c) *Ipomoea batatas* and d) Starch.

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B. Elaboration of the bioplastic

Previously, mixtures of 150 ml of distilled H2O, 0.75 g cinnamon and 0.75 g clove powder were prepared. To these mixtures different doses of mucilage (10, 15, 20, 25, 30 and 50 g) were added until homogenization. On the other hand, mixtures of 150 ml of distilled H_2O and 15 g of Ipomoea batatas were prepared. Subsequently, both mixtures were homogenized under low heat (53.67 °C), adding 12 ml glycerin and 10 ml acetic acid. The bioplastic samples were then dried in the open air (25°C) for 9 days.

The bioplastic samples prepared were 6, and these differed in the dose of mucilage added (M1 (10 g), M2 (15 g), M3 (20 g), M4 (25 g), M5 (30 g) and M6 (50 g)), as shown in Figure 2. Figure 3 shows the process of homogenization of the mixtures and drying of the bioplastic samples.

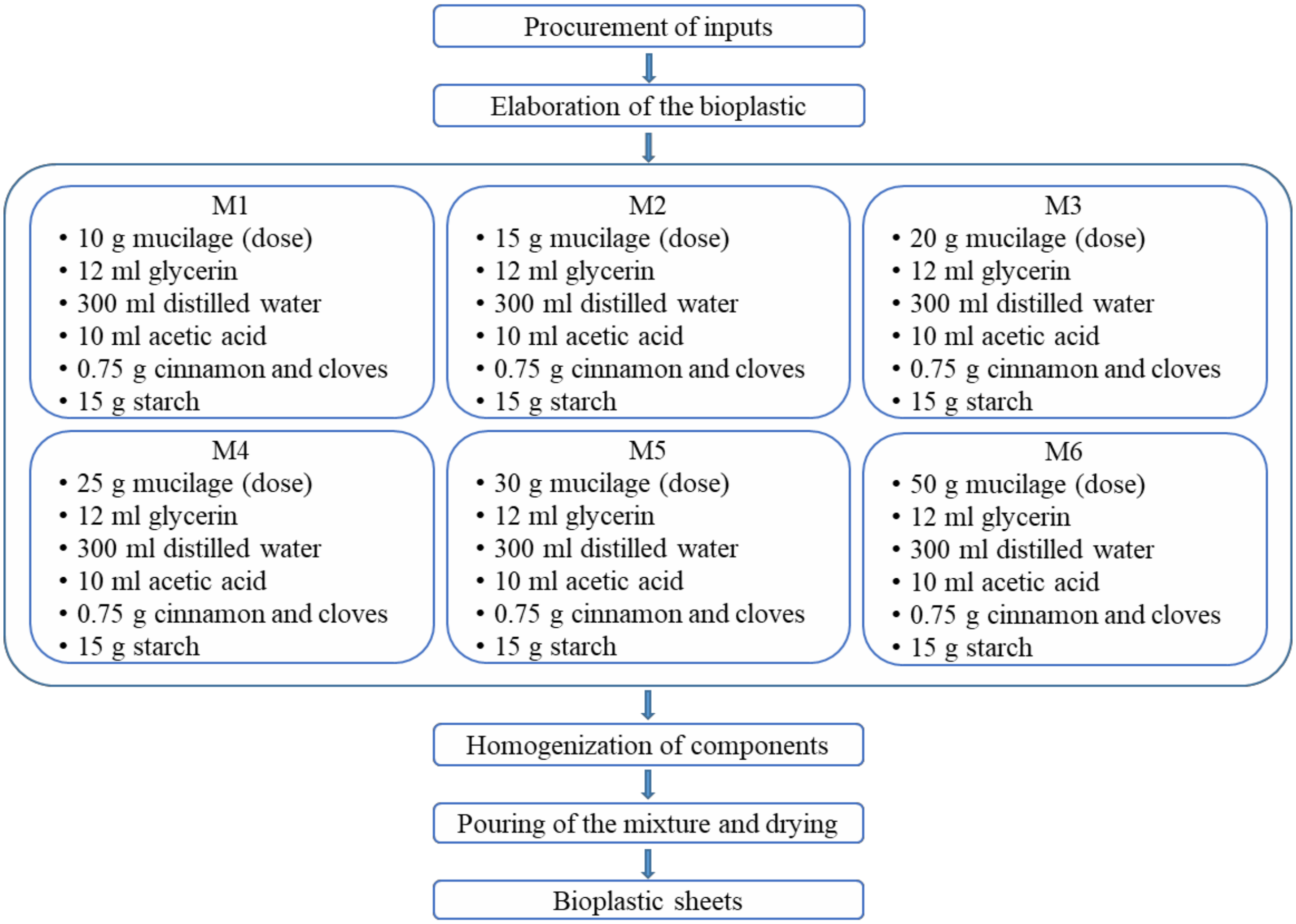

Fig. 2 Process for obtaining bioplastic sheets.

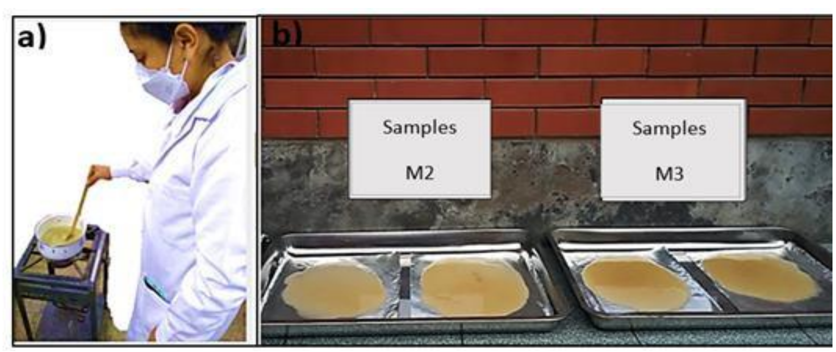

Fig. 3 Bioplastic elaboration: a) Homogenization of the mixtures and b) Drying of the samples.

C. Mechanical parameters of the bioplastic

The ASTM-D882 method was used as a reference for the elongation and tensile tests. For the evaluation, 27 bioplastic samples of 13x4 cm were used and analyzed in the QL-WH-A08L dynamometer.

D. Biodegradability of the bioplastic

For the evaluation of biodegradability (Figure 4), the method of burial in agricultural soil (CEC: 17.67; pH: 6.98; gravimetric humidity: 5.84% and organic matter: 0.98%) and the ASTM D6400 standard were used.

For this purpose, bioplastic bags (15x12cm) were made with different doses (15, 20 and 25 g) of *Opuntia ficus indica* that met the mechanical parameters. Then these bags containing agricultural soil and beet seeds were buried in 2 kg containers of agricultural soil. The biodegradation of the bioplastic was monitored every 5 days, in order to know the changes in the weights of the bioplastic bags.

Fig. 4 Biodegradation process of bioplastic samples: a) Bioplastic bags containing agricultural soil and b) Beet seed growth and degradation of bioplastic samples.

III. Results and Discussion

A. Characteristics of Opuntia ficus indica and Ipomoea batatas

It was observed that *Opuntia ficus indica* had a dark green tone, better physiological maturity condition and a hard and firm texture. Also, it presented values of 90% moisture and 0.218 CP of viscosity. Similarly, Ref. [17] showed that nopal pectin presented values of 92.45 % moisture and viscosity of 2.05%, indicating that nopal possesses a high methoxyl pectin. On the other hand, Ref. [18] showed that prickly pear cactus stalk mucilage has 99.93% humidity and the color visualized was whitish.

Ipomoea batatas presented an orange color (at mature conditions) and hard and firm texture. Characteristics that influence the elaboration of the bioplastic as mentioned by Ref. [16], indicating that starches acquire functional characteristics in amylose and firm properties conferring high gelatinization temperature, granule prominence and viscosity.

B. Optimum dose of mucilage for obtaining the bioplastic

Samples M1, M5 and M6 did not achieve a shorter drying time, exceeding 9 days. In addition, these samples did not meet the necessary mechanical characteristics, and consequently they broke. On the other hand, samples M2, M3 and M4 had a drying time of less than 9 days and met the basic characteristics for a bioplastic. Figure 5 shows the samples made from *Opuntia ficus indica* reinforced with Ipomoea batatas starch.

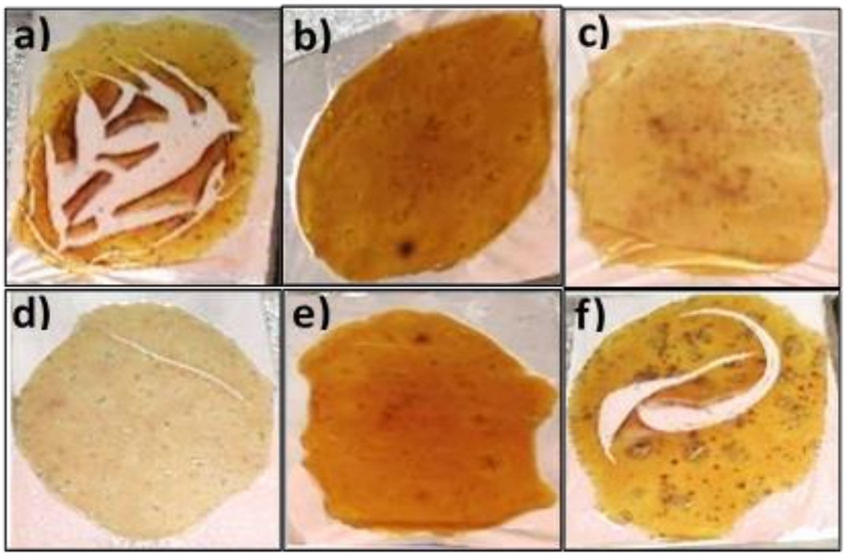

Fig. 5 *Bioplastic samples: a) M1 (10g), b) M2 (15g), c) M3 (20g), d) M4 (25g), e) M5 (30g) and f) M6 (50g).*

From Figure 5, it was observed that samples M2, M3 and M4 were adequate according to the characteristics demanded by a bioplastic, having plasticity, greater area, shorter drying time and favourable results in mechanical parameters. Similarly, Ref. [19] indicate that using concentrations higher than 20 g of *Opuntia ficus Indica* mucilage in the elaboration of bioplastic will show lower infiltration percentage and more percentage in the solubility test. On the other hand, Ref. [20] mention that concentrations higher than 30 g of mucilage produced a yellow coloration. On the contrary, Ref. [9] in the elaboration of pectin bioplastic with natural fiber coating mentioned that the most efficient dose was 6 g.

C. *Mechanical parameters*

Figure 6 shows that sample M3 (20 g) presented the highest elongation and tensile values of 6.379 Kg/mm^2 and 23.984 N/m^2, respectively; while M2 (15 g) presented the lowest values of 1.258 Kg/mm^2 and 7.031 N/m^2, respectively.

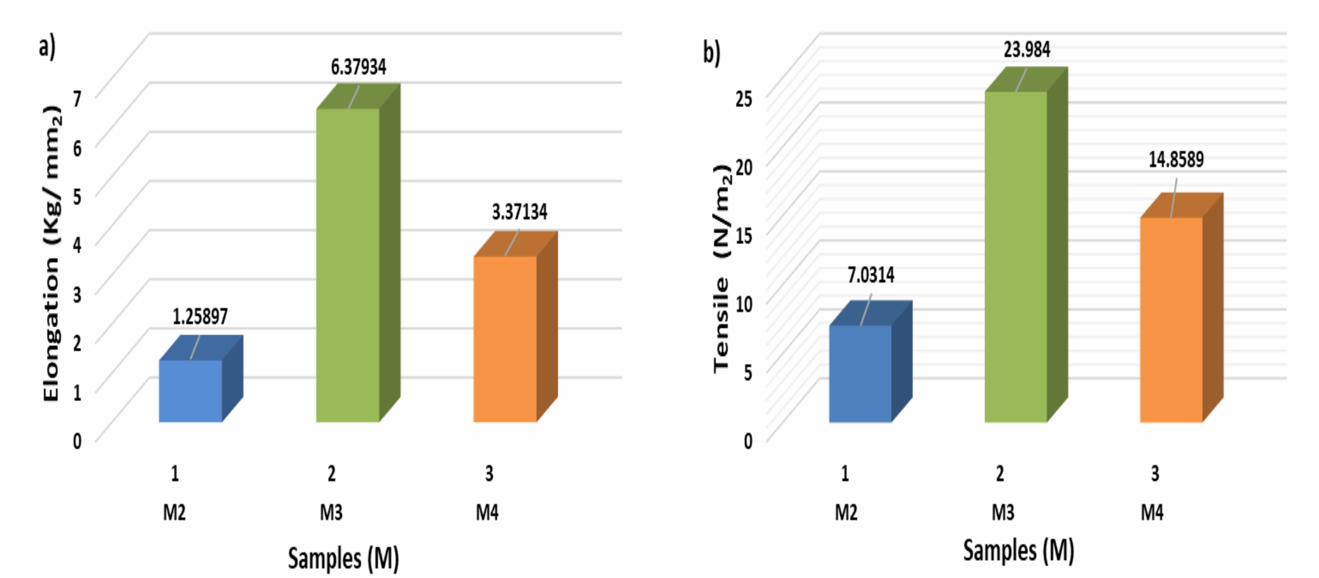

Fig. 6 *Comparison of elongation and tensile evaluations of the specimens. a) Elongation and b) Tensile.*

The results obtained are supported by Ref. [21] who performed the chemical characterization of the juice of four variants of *Opuntia megacantha* cladodes obtaining strength values of 1.77 MPa and elongation 24.16%. Similarly, Ref. [5] evaluated *Solanum tuberosum* starch, obtaining maximum tensile values of 2.57 MPa and maximum elongation of 44.76 %. Ref. [10] mentions that bioplastics obtained from sweet potato and potato wastes, obtained tensile strength values of

0.148±0.92 (Mpa) and elongation of 10.85±2.50%, respectively. Ref. [9] also evaluated pectin films with mineral oil and glycerol, obtaining elongation values of 33.12±4.39 % and Young's modulus rupture stress of 105.04±13.94 MPa because glycerol provided elongation, while oil and pectin improve tensile strength.

Unlike Ref. [22], who elaborated biofilms formulated with *Solanum tuberosum* (potato) starch and the mucilage reached an elongation of 246.15%. Ref. [23], in the elaboration of bioplastics from potato starch, obtained tensile values 1.47 MPa and elongation of 19.99%. This difference in results is mainly due to the glycerol content and the plasticizer such as acetic acid, which produce the increase in elongation and cause maximum breakage.

D. *Biodegradation of bioplastic samples*

Table 1 shows the biodegradation of the bioplastic samples buried in agricultural soil. It was observed that the biodegradation was 99.99% in 35 days, due to the type of soil, humidity, microorganisms, carbon dioxide and organic matter. It was also found that the higher the percentage of glycerin, the shorter the biodegradation time.

TABLE I
BIODEGRADATION MONITORING OF THE BIOPLASTIC FOR EVERY 5 DAYS

Control in days	Initial date	Final date	Weight M2 (g)	Weight M3 (g)	Weight M4 (g)
D5	5/10/2021	10/10/2021	2009.43	2009.01	2008.89
D10	5/10/2021	15/10/2021	2008.30	2007.58	2007.42
D15	5/10/2021	20/10/2021	2006.87	2006.15	2005.95
D20	5/10/2021	25/10/2021	2004.87	2004.72	2004.48
D25	5/10/2021	30/10/2021	2002.87	2003.29	2003.01
D30	5/10/2021	4/11/2021	2001.74	2001.86	2001.54
D35	5/10/2021	9/11/2021	2000.61	2000.43	2000.07

Where: D5, 5 days; D10, 10 days; D15, 15 days; D20, 20 days; D25, 25 days; D30, 30 days and D35, 35 days

From Table 1, it was observed that samples M2, M3 and M4 obtained the value of 99.99% biodegradation in 35 days according to ASTM 5988. On the contrary, Ref. [3] point out that corn starch (*Zea mays L.*) bioplastic has a biodegradation percentage of 89.40% in 42 days. Ref. [23], in the elaboration of bioplastics from potato starch, reached biodegradation values 64.21% in sandy soil taking ISO 17556:2012 as a reference. Similarly, Ref. [24] analyzed the biodegradability of bioplastics made from Mangifera indica and Musa paradisiaca peels, indicating that mango peel had a reduction of 93.06% and banana peel 73.16% in 31 days.

The production of a bioplastic with good properties depends on the components and preparation conditions. The method used in this research was based on the cooking time of Ipomoea batatas starch and Opuntia ficus indica mucilage, achieving a better homogenisation and uniformity of the film. Subsequently, the biofilm is dried at room temperature (25°C) due to its gelatinisation and to obtain improvements in the mechanical parameters, achieving an adequate water retention in the film for its useful life in agricultural soil.

IV. CONCLUSIONS

The research showed that it is feasible to obtain bioplastic from *Opuntia ficus indica* reinforced with starch from *Ipomoea batatas*. The optimum dose to elaborate the bioplastic was 20 g of mucilage corresponding to sample M3, whose tensile and elongation values were 2.3984e-5 MPa and 638%, respectively. In addition, the biodegradation process showed that the bioplastic reached values of 99.99% in 35 days.

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