Extraction and Characterization of Natural Cellulosic Fiber From Jipijapa (Carludovica palmata)

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ABSTRACT

Nowadays, natural fibers with their environmentally friendly qualities represent an important alternative to substitute the use of synthetic fibers in polymer matrix reinforcement. This study aimed to characterize cellulosic palmate fibers (CFE) extracted from the bundles of Jipijapa straw (BJS). The extraction of CFE was carried out by means of an acid hydrolysis, chlorination, alkaline extraction, and bleaching of the BJS. The physicochemical, thermal and mechanical properties of CFE were determined using techniques of FTIR, TGA, X-ray diffraction, AFM and SEM. The holocellulose content (55.70±3.00 %), lignin (23.71±1.01 %), ash (8.30±0.10 %), moisture (8.50±0.50 %) and extractives (10.10±0.50 %) of BJS, were comparable to those reported in the literature for other natural fibers. The spectroscopy FTIR, TGA and X-ray diffraction confirmed that CFE are rich in cellulose content and possess thermal stability, with a crystallinity index of 57 %. Based on the results of SEM, AFM, aspect ratio, mechanical properties, contact angle and surface energy, it was possible to determine and explain the potential application of CFE as reinforcement in the elaboration of biocomposite materials.

Keywords: Carludovica palmata, cellulosic fiber, characterization, renewable sources, natural fiber

1. INTRODUCTION

In recent years, due to the worldwide energy crisis resulting from the indiscriminate use of petroleum derived products and the alarming increase in environmental contamination, greater interest has been shown in the development of new, green or ecological materials from renewable sources for their use in the industry. In this respect, due to the fact that conventional
synthetic fibers such as glass, carbon and kevlar are not ecological, researchers are constantly searching for new, natural, raw materials which are renewable and biodegradable, and overall environmentally friendly. Natural fibers therefore, are one of the most widely identified sources. The natural fibers of plants possess long, thin cells which usually have thick walls, perforated and highly lignified. The cell wall of natural fibers is composed of cellulose, hemicellulose, lignin, pectin and other components with low molecular weight. Cellulose is the main constituent of the cell wall in all plants. It is a linear polymer of poly-β (1→4)-D-glucose with a syndiotactic configuration. Cellulose is considered to be the main structural component of the natural fiber and its content varies from 50 % to 70 %, although percentages lower than 30 % have been reported. Moreover, it is a sustainable, biodegradable source, abundant in nature, economic and also exhibits a lower density in comparison to the majority of the fillers currently being used as reinforcements in biocomposite materials. In addition, within its structure, cellulose contains hydroxyl groups, conferring it a hydrophilic nature. Cellulose also contains approximately 80 % of crystalline regions.

The materials obtained from the biomass contain a complex ultrastructure of three main components. The delignification is usually a key stage for separation of such ultrastructure, allowing the extraction of cellulose from natural fibers with high yields. The natural conventional fibers deriving from flax, hemp, kenaf, jute and sisal, among others, have been widely used as reinforcement of thermoplastic polymers owing to their thermal and mechanical properties. A recent report described a comparison between the thermal and mechanical properties of an important, non-conventional fiber denominated Carludovica palmata, commonly known as Jipijapa (classified as foliar fiber) bleached with sulphur vapour and without bleaching. The characterization results were found to be similar to the conventional fibers. The importance of the Jipijapa resides in the fact that it is the most widespread species in the genus Carludovica, ranging from Guatemala to Central Bolivia. This species grows in moist tropical forest and in areas of high sunlight.

The Jipijapa palm is long, smooth and exhibits high tenacity with an elemental fiber diameter varying between 10 and 20 µm. It is widely cultivated in the northern region of Campeche State, Mexico, where it is used in the artisanal fabrication of woven hats; a traditional, economic activity involving the participation of the entire family and on which the economy of the villagers in this area is based.

It is well known that the properties of natural fibers such as the Jipijapa can be affected by a number of factors, including the climate, plant age and chemical treatments, among others. In spite of the importance of Jipijapa for the Southeast of Mexico, in particular for Campeche State, very little is known about its cellulose content or the mechanical, thermal and morphological properties of the cellulosic fiber. The obtainment of information regarding the cellulose yield of the Jipijapa and its properties, would allow the emission of recommendations for its different applications in modern industry, which could improve the economic conditions of the northern region of Campeche State, Mexico. Therefore, the aim of the present work was to isolate (by means of an alkali treatment) and characterize the cellulose fiber obtained from the Jipijapa palm (CFE), for a possible use as renewable and biodegradable raw reinforcement in the manufacture of biocomposite materials for industrial applications.

2. MATERIALS AND METHODS
2.1 Materials

The bundles of Jipijapa straw (BJS)
were acquired in January 2017 in the locality of Calkini, Campeche, México. The BJS were dried by the action of sunlight and cut into small segments (1─3 cm long) (Figure 1). The analysis of the chemical composition of the BJS was performed with the standard procedures reported in previous works [9]. The means and standard deviations of moisture, holocellulose, lignin, ashes and extractables were calculated and reported.

Figure 1. Plant material used in this work.

In order to extract the cellulosic fibers, sulphuric acid and sodium hydroxide, both reactive grade acquired from Sigma Aldrich, were used. Commercial sodium hypochlorite (CLORALEX ®) was also used.

### 2.2 Extraction of Cellulose Fibers

The extraction of CFE from the BJS of *Carludovica palmata* was carried out according to the procedure described by Casaurang-Martínez et al. [10] and others [2, 5].

About 100 g (small segments of BJS) were exposed in a solution of sulphuric acid (1%, v/v, in distilled water), at 100 °C for 1 h. Once the treatment was finished, the BJS were removed and washed with distilled water (2 times). The BJS were then treated with an aqueous solution of sodium hypochlorite (3.5%, w/v, in distilled water) at room temperature until a pH of 9.2 was reached. After this, the BJS were removed and washed again with distilled water (2 times). Afterwards, the BJS were subjected to an alkaline extraction with a solution of sodium hydroxide (20%, w/v, in distilled water) for 3 h, maintaining mechanical agitation constant at 1, 200 rpm. The BJS were then removed and washed with distilled water. Subsequently, the BJS were bleached with a solution of sodium hypochlorite (0.5 %, w/v, in distilled water) for 1 h having constant mechanical agitation at 1,200 rpm. After this time, they were removed and washed again with distilled water. For the final step in the extraction process, the CFE were dried at room temperature for 24 h. The yield of CFE obtained from the BJS, was determined through equation 1.

$$ Y = \frac{W_0 - W_f}{W_0} \times 100 \quad (1) $$

Where $Y$ is the percentage (yield) of CFE, $W_f$ is the final weight of sample, and $W_0$ is the sample initial weight.
2.3 Chemical Composition of Bundles of Jipijapa straw (BJS)

In order to carry out the determination of the chemical composition of the fiber, the samples were previously ground in a mill of blades and sieved according to the procedure established in the standard TAPPI T 264-cm 07. Subsequently, the determination of the contents of lignin, ashes and extractables were completed according to the standards TAPPI T 222-om-98, T 413-om-11 and T 264-om-88 respectively. All characterizations were determined as a percentage of dry base. All samples were also analyzed in quadruplicate.

2.4 Length to Diameter Ratio (l/d)

The aspect ratio of the CFE was determined with a Leica model DMLM microscope, equipped with a Sony® model CD/RGB camera and the measurements were performed on 500 samples using ImageJ® software with a magnification of 100x.

2.5 Surface Morphological Analysis by SEM

The surface morphology of the CFE was observed on three specimens employing a JEOL, JSM-5900 LV model, Scanning Electronic Microscope. The micrographs were obtained using a voltage value between 20 and 25 KV.

2.6 Fourier Transform-Infrared (FT-IR) Analysis

The FT-IR spectra was used to determine the presence of functional organic groups in CFE structure. Three specimens were analysed in a Nicolet 8700 equipment under Attenuated Total Reflectance mode [5], in a wave number interval between 4000-650 cm\(^{-1}\) and 100 sweeps at a resolution of 4 cm\(^{-1}\) [5].

2.7 X-ray Diffraction (XRD) Analysis

A Siemens diffractometer, model D-5000, operating at Cu-K\(\alpha\) radiation wavelength (\(\lambda = 1.54\) Å), 40 kV, 30 mA and sampling interval of 0.02° was used to measure five specimens. Scattered radiation was detected in the angular range of 5–35° (2θ). The CFE crystallinity index, CI (%), was calculated using Segal’s empirical expression [11] (Equation 2):

\[
CI(\%) = \frac{I_{002} - I_{110}}{I_{002}} \times 100
\]  

Where:

- \(I_{002}\) is the maximum intensity of the peak of the crystalline phase and;
- \(I_{110}\) is the intensity of the peak of the amorphous phase.

The crystal size (D) of the CFE was calculated using Scherrer’s equation [12] (Equation 3).

\[
D = \frac{K\lambda}{\beta \cos \theta}
\]

where D is the crystal size, K is Scherrer’s constant (K = 0.94), \(\lambda\) the wavelength of the K\(\alpha\) radiation (1.54 Å), \(\beta\) the full peak width at half of the maximum, and \(\theta\) Bragg’s diffraction angle.

Lorentziana-Gaussiana mixed functions were employed to deconvolve the peaks, using the software PeakFit ver.4.12.

2.8 Thermogravimetric Analysis (TGA)

The thermal stability of five CFE specimens was analysed using a TGA-7 Perkin-Elmer Instrument setting an interval of temperatures from 30 to 700 °C in a nitrogen atmosphere of 50 mL/min and a heating speed of 10 °C/min.

2.3.7 Contact Angle and Free Surface Energy

Contact angle analysis required the use of two solvents: distilled water and diiodomethane (Sigma-Aldrich).

The test was performed by placing three drops (6 µL) of the liquid, with the aid of a pipette (Transferpette®), over five CFE tablets, previously prepared by using a Carver hydraulic press applying a pressure of 2 x 108 Pa for 10 s. Measurement of the contact angles was carried...
out using Tantec equipment, model LR92249. With the measurement of the contact angle, it was possible to determine the surface energy of the tablets using the method of Owens-Wendt with the extended equation of Fowkes [13].

### 2.9 Atomic Force Microscopy Analysis (AFM)

AFM was used to obtain topographic images of surface samples. AFM images of five specimens were obtained with an atomic force microscope (SPM, Ambios Universal, USA) using a Si-N cantilever in noncontact mode. The images were taken from eight different zones on a sample with a resolution of 512 x 512 px. The surface root mean square roughness (Rrms) was determined using the WSxM v5.0 develop 8.1 software of Nanotec.

### 2.10 Mechanical Testing

The tensile tests on CFE were performed using a machine for micro-mechanical tests, Minimat, equipped with a load cell of 1000 N. The test was conducted in accordance with the standard NMX-A-069 1990. The resistance (MPa), elongation (%) and elastic modulus (MPa) were measured in 100 samples with an average longitude of 7 mm and average diameter of 9 µm. Before the test, the samples were conditioned over a period of 24 h at 25 °C and relative humidity of 60 %. The samples were tested using a cross-head speed of 1.2 mm/min. The means and standard deviations of Tensile Strength (MPa), Elastic Modulus (MPa) and elongation at break (%) were calculated and reported.

### 3. RESULTS AND DISCUSSION

#### 3.1 Chemical Composition of Bundles of Jipijapa Straw (BJS)

Table 1 shows the results of the chemical composition of the BJS. It has been reported in the literature that, under similar conditions of relative humidity and temperature, the water content for different natural fibers ranges in the interval of 7-13 % [14]. In this work, BJS obtained a moisture value of 8.50±0.50 %, which is found inside the interval previously mentioned. Holocellulose content corresponding to the polymeric carbohydrates, cellulose and hemicellulose, a mean value of 55.70±3.00 % was obtained [15]. Literature reports similar values in the holocellulose content for different natural fibers deriving from other natural sources such as banana (51 %), bamboo (56-73 %) and wheat straw (53-86 %) [14]. Determining the content of these polysaccharides is important due to their influence on the mechanical properties, water absorption and natural fiber biodegradation. The BJS contains a smaller amount of lignin (23.71±1.01 %) in comparison to holocellulose value and it has been reported that lignin serves as a chemical adhesive between cellulose and hemicellulose [16]. In the case of lignin, similar values have also been reported in the literature on natural fibers such as kenaf, which is found in an interval of 15-20 % [17]; other authors have reported different materials, such as bamboo exhibiting values of 21-31 % and wheat straw having 12-20 % [14]. In addition, the ash content (mineral elements) for BJS presented an average value of 8.30±0.10 %. Authors report that the ash content for materials such

<table>
<thead>
<tr>
<th>Caricuata palmata</th>
<th>Moisture (%)</th>
<th>Holocellulose (% DW)</th>
<th>Lignin (% DW)</th>
<th>Ash (% DW)</th>
<th>Extractives (Cyclohexane-Ethanol): (% DW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.50±0.50</td>
<td>55.70±3.00</td>
<td>23.71±1.01</td>
<td>8.30±0.10</td>
<td>10.10±0.50</td>
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DW: dry weight.
as bamboo ranges between 1.5-4.7 %, for sisal, it can be found in the interval of 0.6-1 % and for kenaf, between 2-5 % [18]. In the case of extractives, it was estimated that BJS had a mean value of 10.10±0.50 %; which is higher than that reported in the literature for natural fibers, deriving from other sources, such as pineapple leaf (5.5 %) or from coconut (6.4 %) [18], and for fibers of Luffa Cylindrica (3.1 %) [19]. All the values found in the chemical composition of BJS are comparable to those registered in the literature mentioned in each case. However, the differences found may be due to the chemical composition of the lignocellulosic materials, since it is well known that this depends strongly on the geographic location, plant source, age of the plant, soil characteristics and the methods used to determine the composition [18].

In another result, the yield of CFE calculated through equation 1 was 46 %. This yield value is lower in comparison to those reported for cellulosic fibers deriving from plants of henequen, sisal and pineapple, whose yield is found between 50 % and 70 %; however, the yield reported in this work was higher to those obtained for cellulose fibers from banana plants (30 %) [3, 5].

3.2 Aspect Ratio

The CFE aspect ratio revealed a mean value of 84±42, considered to be characteristic of a long fiber, with a distribution of sizes “skewed” to the left (Figure 2) and the highest frequency found in the interval of 40 to 120 [20]. The distribution of fiber sizes is an indication of their quality; indirectly the method provides information about the degree of fibrillar shortening (degradation) due to the various experienced processes such as pulping and recycling [21].

The aspect ratio is very important to determine the fracture properties of a material. In the case of fiber reinforced composite materials, the concept of fiber critical length is required to develop its maximum stress condition in the polymer matrix. Fiber lengths shorter than their critical length allow failure due to the detachment of the interface at low loads. On the other hand, for fiber lengths larger than the critical length, the fiber is tensioned under applied stresses and consequently results in a higher resistance for the composite [22, 23]. Therefore, it indicates that the CFE is a material that possesses potential to be used as reinforcement for biocomposite material; since there have been reports of compound materials

![Figure 2. Distribution of CFE obtained from Bundles of Jipijapa straw.](image-url)
elaborated with cellulosic fiber having aspect ratios that fluctuate between 80 and 100 [20].

3.3 Surface Morphology

The SEM micrographs of the CFE are shown in Figure 3. It is reported that at different magnifications (Figure 3a and 3b) the fiber exposes a rough cylindrical surface with some superficial impurities that may not have been removed in previous processes. Fibrillation of the fiber can also be observed. Figure 3a shows separated bundles exhibiting similar diameters. In Figure 3b, a micrograph presents one individual fibril displaying a convoluted ribbon like arrangement resembling the structure of cellulose. On the other hand, JMCC presented a flat, small rigid rod like morphology indicating the presence of some non-cellulosic constituents within the cellulose fibrils when embedded, as is reported in other analysis [24]. Similar results have been reported by other authors who have obtained cellulosic fibers from different sources such as straw or cotton [25]. The small cracks and pores on the surface may facilitate the physical union between the fiber and matrix for the fabrication of biocomposite material.

![Figure 3. Images from Scanning Electron Microscopy (SEM) of the CFE. a) 50x and b) 100x.](image)

3.4 Fourier-Transform Infrared Spectroscopy in Attenuated Total Reflectance Mode (FTIR-ATR)

The main functional organic groups present in CFE were identified by FTIR spectrum, as shown in Figure 4. The peaks observed at 3325 cm⁻¹ and 1024 cm⁻¹ correspond to O─H stretching and O─H bending frequencies due to the cellulose [16]. The peak observed at 2921 cm⁻¹ corresponds to the C─H stretching vibration of the cellulose. The results indicate that the intensity of the peak around 1633 cm⁻¹ refers to the humidity absorbed on the surface of the fiber after the treatment with alkali [9]. In the literature, a peak intensity at 1730 cm⁻¹ [9, 16] has been registered relating to the stretching vibration of the C=O carbonyl group of the alpha keto carboxylic acid in lignin or the ester group in hemicelluloses and lignin. Another band (low intensity) observed at 1260 cm⁻¹ is associated with the stretching vibration of the carbonyl bond existing in lignin structure [16]. The sharp peak at 895 cm⁻¹, was attributed to the O─C─O stretching during the C─H deformation of the cellulose.

3.5 X-ray Diffraction Analysis

The diffractogram of the CFE is shown in Figure 5. Three peaks can be observed at 2θ = 22.4° (at crystallographic plane 002), 2θ = 15.7° (at crystallographic plane 101), and 2θ = 35.2°

Figure 3. Images from Scanning Electron Microscopy (SEM) of the CFE. a) 50x and b) 100x.
Figure 4. FTIR spectra of CFE obtained from Bundles of Jipijapa straw.

Figure 5. X-ray diffraction patterns of CFE obtained from Bundles of Jipijapa straw.

(at crystallographic plane 040), which represent the crystalline peaks of the cellulose I usually reported for natural fibers [16]. These results are similar to those reported by Browning [27], where the main crystalline planes for cellulose I are identified as the diffractions close to 2θ: 23° (plane 002), 15° (plane 101), 35° (plane 040). Moreover, it was reported that the peak at 15° could present difficulties due to the diffuse diffraction caused by the amorphous part. Crystallinity index (CI) refers to the measure of the amount of crystalline cellulose with respect to the global amount of amorphous materials. In the present work, the CI value obtained for CFE was 57%, which is comparable to cellulose fibers from cotton shell (48.9%) and Bark of Acacia Arabica (51.7%) [28]. The average crystallite size (D) in the direction perpendicular to the 002 lattice plane of CFE was computed by using Scherrer’s formula, as given in Equation (3) and was found to be 2.12 nm. D in CFE offers chemical reactivity and water absorption capacity properties quite close to flax fiber (2.8 nm) [29].
3.6 Thermogravimetric Analysis

The thermal analysis of natural fibers generates information regarding their thermal stability, which is a crucial characteristic in the elaboration of biocomposite materials with natural fibers as reinforcement, because they could degrade during the curing cycle, in the case of a thermo-fixed matrix, or during the extrusion process, in the case of thermoplastic matrices. Figure 6 shows the TGA thermograph and its derivative curve (DTG) performed on the CFE. It was possible to observe three regions of mass loss during the thermal stability study. The initial mass loss was between room temperature and 100°C, associated with the evaporation of the water (7.0 %) present in the CFE. Then, it remains thermally stable up to 250 °C with a minimal loss of mass (3 %) at which the thermal depolymerization of hemicellulose was initiated. The second mass loss was observed between 260-400 °C, within this temperature interval, a prominent peak at 350 °C was registered, relating to the possible decomposition of cellulose with a mass loss of 58 %. The pyrolysis between 400-600 °C (final degradation) corresponds to the lignin and wax with a mass loss of 11.0 %. The rest of residual mass 16.97 % at 700 °C remained in the sample. Based on the TGA and DTG analyses, it is possible to identify that CFE thermal stability is superior to those of sisal [22], banana [3], henequen [30], commercial cellulose [4], bamboo, hemp, jute and kenaf [31].

![TGA results of the thermal decomposition and its derivative (DTG) of CFE obtained from Bundles of Jipijapa straw.](image)

3.7 Contact Angle

The characterization of CFE also included the determination of surface energy (γs) and its respective polar component (γs,p) and dispersive (γs,d) using the method of Owens-Wendt [13] with the extended Fowkes’ equation, taking into consideration the values of the contact angles of the drops of liquid lying on the surface of the fiber and the surface tension value of the liquid used. The polar component presented a value of 42 mJ/m², while the dispersive component only contributed with 2.7 mJ/m². This result can be attributed to the different chemical treatments (acid hydrolysis, chlorination, alkaline extraction, or mercerization and bleaching) to which the natural fiber was subjected in order to obtain CFE, given that they produce changes in the structure of the fibers, as reported by Peršin et al. [32]. In addition, it has been reported that during mercerization, pores are formed in the fibers which allow greater access of an aqueous medium, while the washes remove
Moreover, after the treatment to obtain CFE, it is quite probable that there was an increase in the quantity of hydroxyl groups of the cellulose, which are left exposed once certain components of the fiber are removed, such as hemicellulose, waxes, pectins and a part of lignin, giving rise to an increment in the polarity of the fiber due to its interaction with water molecules through the formation of hydrogen links [33]. From the above, it is possible to appreciate that the surface energy ($\gamma$), registered in this work coincide with other authors who reported surface energy values of cellulose obtained from other sources such as eucalyptus with a value of approximately 49 mJ/m$^2$; kraft with a value of 51.9 mJ/m$^2$ and commercial cellulose with a value of 50 mJ/m$^2$ [34]. Based on the results, the use of CFE with polar thermoplastic matrices can be suggested; however, in order for them to be used with apolar matrices, an appropriate coupling agent will be required, which can reduce the polarity of CFE.

3.8 Atomic Force Microscopy Analysis

In order to characterize the surface of CFE, the roughness profile must be determined. The topography of CFE was observed through 3D images obtained from AFM. To achieve this, eight areas of the sample were examined; a representative image is shown in Figure 7a. The roughness profile of CFE (Figure 7b) allows to observe that it has a height and depth of maximum depthness (axis z) of approximately 650 nm and 32 nm, respectively, indicating that the topography is irregular. In Figure 7a, it is possible to observe that the images show a rough surface with hills and valleys which correspond to the cellulose fibers, without the presence of granules which could be associated with products such as lignin, as reported by Gustafsson et al. [35]. Therefore, the rough surface can be used to achieve an interaction of the fiber with the polymer matrix in the procurement of biocomposite materials. In the present study, the value of the root mean square of the roughness (Rrms) of CFE was determined as approximately 97.3 ± 21.1 nm. Inferior values were reported by Li et al. [36], who determined the value of the roughness of fibers modified with an enzyme (laccase) on kraft paper and found a value of 21.34 nm. These results can be explained, due to the fact that the fibers undergo morphological changes after the chemical treatments to which they have been subjected, in contrast with an oxidative treatment with enzymes which produce less damage to the fibers, as reported by Aracri et al. [37]. From these results, it can be observed that the roughness, moisturization and surface energy of CFE is strongly associated with the treatment to which they are subjected.

![Figure 7. 3D image of AFM (a) and the roughness profile (b) of the surface of CFE.](image-url)
3.9 Mechanical Testing

During the single fiber tensile test, a load vs. strain graph was plotted for the tested fiber samples, from which the mechanical properties of the CFE were determined. Table 2 shows the results of the mechanical tests performed on CFE. Mean values of 36.38±5.8 MPa, 957.3±50.6 MPa and 2.5±0.09 % were reported for tensile strength, elastic modulus and elongation at break, respectively. The values found in this work are similar to those reported for fibers extracted from fruits such as tamarind, palmyra palm and date palm, which have been proposed as reinforcement polymers in the preparation of compound materials. However, it is known that the mechanical properties of natural fibers depend to a great extent on their chemical composition [38].

Table 2. Mechanical properties (means ± standard deviations) of CFE obtained from bundles of Jipijapa straw.

<table>
<thead>
<tr>
<th>CFE</th>
<th>Tensile strength (MPa)</th>
<th>Elastic Modulus (MPa)</th>
<th>Elongation at break (%)</th>
</tr>
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<tbody>
<tr>
<td>Cariludovica palmata</td>
<td>36.38 ± 5.8</td>
<td>957.3 ± 50.6</td>
<td>2.5 ± 0.09</td>
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4. CONCLUSIONS

This report can be considered a pioneer containing information on the extraction and physicochemical, morphological, mechanical and thermal characterization of CFE. The contents of holocellulose, lignin, ashes, and extractives of bundles of Jipijapa straw (BJS) and the mechanical properties of CFE are comparable to those registered for other fibers that have been proposed as reinforcement in the manufacture of compound materials, therefore, these fibers can be used in the development of biocomposite materials.

The FTIR-ATR spectrum showed that the CFE extracted is rich in cellulose content due to the presence of its characteristic functional groups and the high crystallinity index (57 %). The thermal analysis indicates that CFE are stable up to 350°C, an advantage which allows these fibers to be processed with various polymeric resins. The aspect ratio of CFE corresponds to a long fiber which can be used for reinforcing compound materials. The morphology of CFE revealed by SEM micrographs and 3D topography obtained by AFM shows a rough surface with pores that can facilitate its interaction with polymeric matrixes. The results of the characterization clearly indicate that, due to the significant properties, the use of CFE as reinforcement, is a good alternative for the fabrication of biodegradable laminates since favours the evaluation of their thermal and mechanical properties.

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DISCLOSURE STATEMENT

The authors declare that they have no conflicts of interest.

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