AGRO PRODUCTIVIDAD

Colegio de Postgraduados

Use of agroindustrial waste to obtain cellulose from oil palm bagasse (*Elaeis guinnensis*)

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ABSTRACT

Objective: To obtain cellulose from oil palm agroindustrial waste that meets standard physicochemical characteristics to produce value-added products.

Design/methodology/approach: Bagasse fibers from the palm agroindustry were used to obtain cellulose, by means of the acid – alkaline hydrolysis methodology. The samples obtained in each stage and the cellulose obtained were characterized by the Fourier Transform Infrared Spectroscopy (FTIR) technique and thermogravimetric analysis (TGA).

Results: The final characterized product presented a band corresponding to 1370 cm^{-1} which is a characteristic value of cellulose. The peak at 1731 cm^{-1} is related to C=O bonds of unconjugated ketones present in hemicellulose. A major thermal event for treated fiber near 355 °C and the high residual mass indicate a good chemical treatment for hemicellulose and lignin elimination.

Study limitations/implications: A fiber yield of 39.3% cellulose was obtained during the process from oil palm bagasse.

Findings/conclusions: Obtaining cellulose from a highly polluting residue such as palm bagasse and with high production figures in our state, makes it a potential for use to generate biopolymers in combination with natural polysaccharides, providing sustainable benefits and economic impact and promoting sustainable development by replacing conventional fossil plastics, in addition to obtaining value-added products for the same agribusiness and in sectors such as the food industry.

Keywords: Agribusiness, Oil Palm Bagasse, Pulp, Cellulose.

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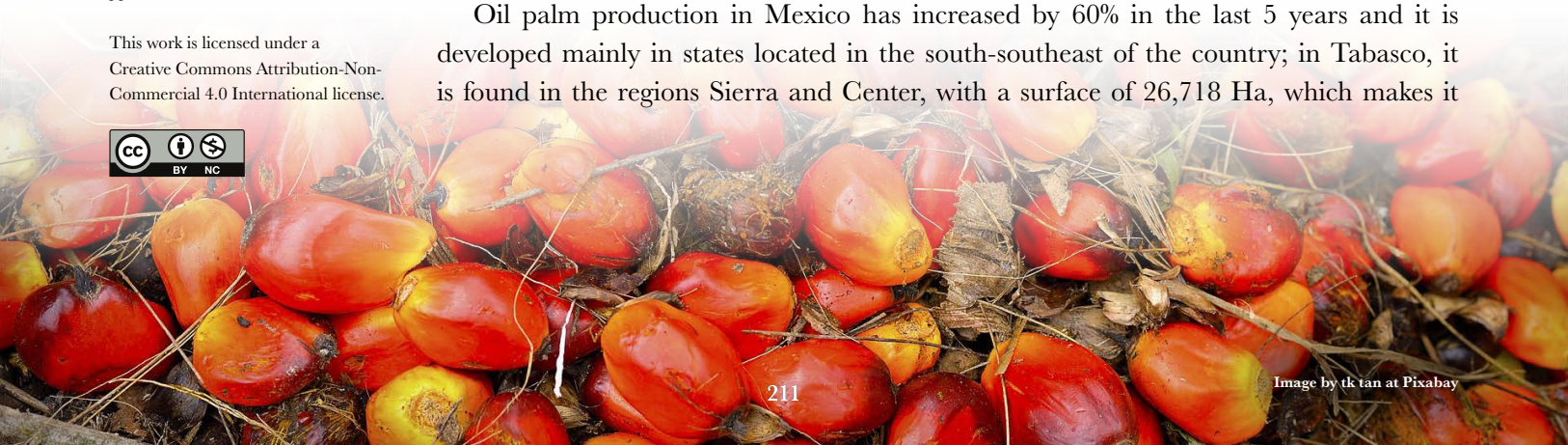
INTRODUCTION

Oil palm production in Mexico has increased by 60% in the last 5 years and it is developed mainly in states located in the south-southeast of the country; in Tabasco, it is found in the regions Sierra and Center, with a surface of 26,718 Ha, which makes it



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the fourth agribusiness in the state (SIAP, 2020). Oil production generates byproducts of technical and economic interest such as husks, fibers resulting from fruit pressing, pits, and ash. Around 1,1 t of fibers generated per ton of oil produced could be used as prime material for industrial and artisanal products, and to elaborate biocompounds, which reduces the use of synthetic polymers, thus obtaining higher degradability, lower toxicity, better mechanical properties, and thermal resistance (Shinoj *et al.*, 2011). Presently the abundant amount of empty oil palm bunches has caused environmental problems, such as combustion and generation of fungi in the accumulated residues. The disposal of residues generated during the oil extraction process represents a great challenge, since these ought to be used or have some treatment before being eliminated. Considering the above, this study presents an alternative for the use of these agroindustrial residues. The purpose consists in obtaining cellulose from oil palm bagasse (*Elaeis guineensis*), contributing to the decrease of agroindustrial waste, in addition to obtaining an added-value product.

MATERIALS AND METHODS

The biological material used (palm bagasse) was supplied by an oil palm agribusiness located in Tacotalpa, Tabasco, Mexico. This material was found with excess moisture and dirt, so it was washed with running water and sun-dried at environmental temperature for 24 h. The material was selected after drying (Figure 1A), since the bagasse is mixed with other fibers and residues generated during this agroindustrial process. The clean and dry bagasse was ground in an industrial blender brand Veca International model LI-17A, with the aim of reducing the fiber chains to an approximate size of 4 cm (Figure 1B).

Cellulose extraction

A pre-treatment on the fiber began once the bagasse was dried and ground, with the aim of eliminating pectins and resins present. The methodology used was proposed by Bolio *et al.* (2011) through the Cazaurang method, conducted in 5 stages: pre-treatment, hydrolysis, chlorination, alkaline extraction and blanching. The pre-treatment consisted in leaving the fiber to rest in a NaOH solution at 10% (p/v) at environmental temperature and

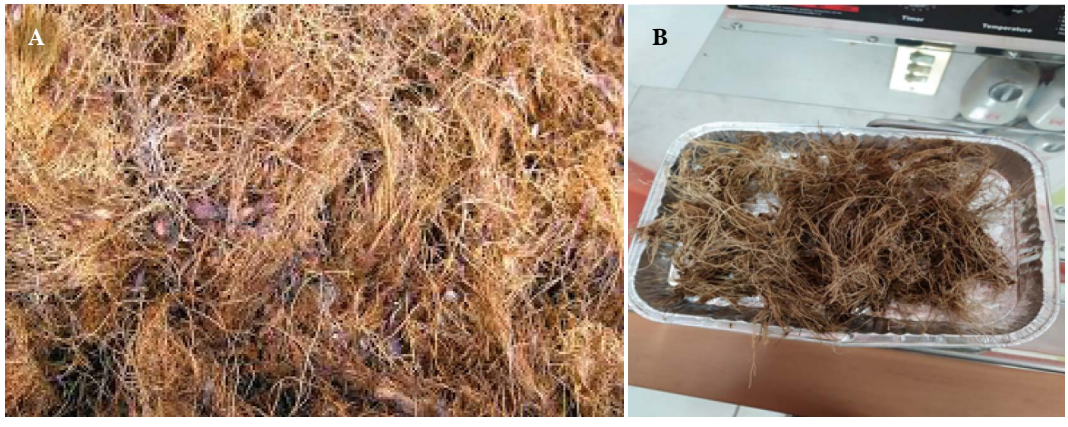

Figure 1. Prime material (oil palm bagasse).

in mechanical agitation for 120 min (Figure 2A), and the resulting fiber was washed with running water until reaching a neutral pH.

Acid hydrolysis. During this stage, access to reagents in the fiber to remove amorphous regions was eased, and the pre-treated fiber was placed in a H_2SO_4 solution at 0.4% maintaining a temperature of 90 °C for 60 min with constant agitation; after this time the fiber was washed until obtaining a neutral pH (Figure 2B).

Chlorination. The resulting fiber of the prior step was incorporated to a NaClO solution at 3.5%, at a temperature of 40 °C and with constant agitation for 10 min. After this time, the fiber was washed with running water until obtaining a pH of 7.0.

Alkaline extraction. This stage has the objective of solubilizing the hemicellulose and reducing the size of the cellulose chains. A NaOH solution at 20% (p/v) was incorporated to the product from the chlorination stage during 10 min and kept with manual agitation, and then with agitation at 150 RPM for 50 min (Figure 2C). After this time, the fiber was washed with running water until obtaining a pH of 7.0.

Blanching. In this step the chromophore groups and residual lignin were eliminated, the previous fiber was taken to a solution of NaClO 0.5% with continuous agitation at 150 RPM in a Mixer Model BDC1850 during 60 min (Figure 2d). Finally, the fiber was washed until reaching a neutral pH and left to dry at room temperature for 24 h and then

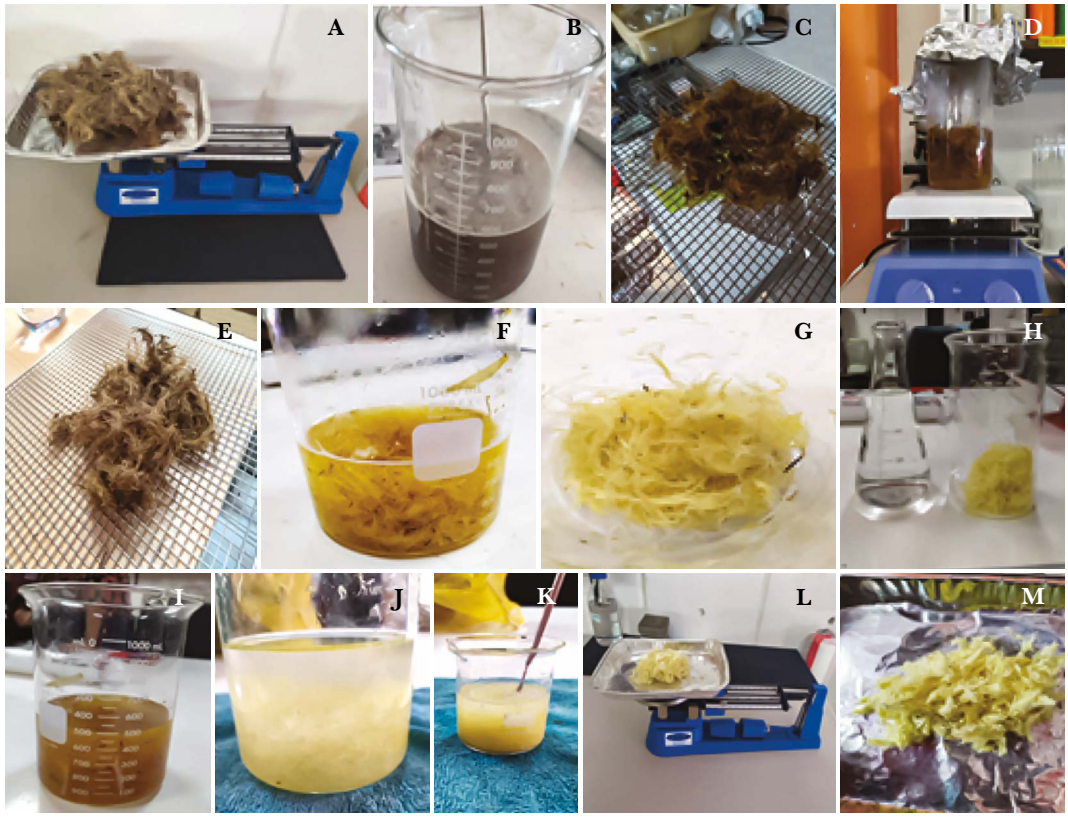

Figure 2. Cellulose extraction process from oil palm bagasse. A: Bagasse weighing; B: Pre-treatment; C: Drying in conventional furnace; D: Acid hydrolysis; E: Drying; F: Chlorination; G: Drying; H-I: Alkaline extraction; J: Blanching; K: Rest; L: Dry fiber/weighing; M: Cellulose.

in a drying furnace at 60 °C for 24 h (Figure 2E). Each of the samples was stored in airtight bags for their later characterization.

Fourier Transform Infrared Spectroscopy (FTIR)

To determine the functional groups present in the samples obtained in each of the stages, a Fournier Transform Infrared Spectrophotometer (FTIR) was used, brand Thermo Scientific, model Nicolet™ Is™ 50 with ATR module and diamond crystal, using measurement intervals of 100 and 32 scans.

Thermogravimetric Analysis (TGA)

This test was conducted in a Setaram Labsys EVO 1110 equipment. The sample between 6.0-8.5 mg was placed in a platinum crucible and warmed from environmental temperature to 650 °C with a slope of 10 °C/min. The dragging gas used was argon at 20 psi.

RESULTS AND DISCUSSION

Cellulose extraction

During the process, a fiber yield of 39.3% of cellulose was obtained from the oil palm bagasse. Table 1 shows the cellulose fiber yield (%), which is lower compared to: banana pseudo-stem residues with yield of 66% (Bolio *et al.*, 2011), sugarcane bagasse with 48% (López-Martínez *et al.*, 2016), and the one found in platanillo (*Heliconia latispatha*) with 46% of cellulose obtained (García Fajardo, 2015). On the other hand, the yield obtained from the palm bagasse is higher than 29.3% obtained in residues of pineapple crown (Presenda *et al.*, 2020) and the 34% of final cellulose yield from sugarcane hay by Bolio *et al.* (2017).

FTIR Analysis

Figure 3 shows the infrared spectrum of oil palm bagasse and cellulose obtained. The bagasse sample presented characteristic lignin bands such as the peak and 1720 cm^{-1} related with carboxyl group bonds, which was eliminated during the process of cellulose extraction (Figure 3). Meanwhile, the peak of 1054 cm^{-1} is characteristic of the C-O bond (Contreras *et al.*, 2010). Moran *et al.* (2008) mentions that the peak of 900 cm^{-1} corresponds to C-H groups of aromatic hydrogens from lignin, which decrease their intensity corroborating that the process applied in this study allows removing most of the lignin in the cellulose extracted and at 1630 cm^{-1} the band corresponding to adsorbed water.

Table 1. Cellulose yield obtained.

Residue	Cellulose yield (%)	Reference
Palm bagasse	39.3	Present study
Cane Straw (*Saccharum* spp.)	34	Bolio *et al.* (2017)
Sugarcane bagasse (*Saccharum* spp.)	48	López-Martínez *et al.* (2016)
Platain (*Musa* sp.)	66	Bolio *et al.* (2011)
Platanillo (*Musa* sp.)	46	García Fajardo (2015)

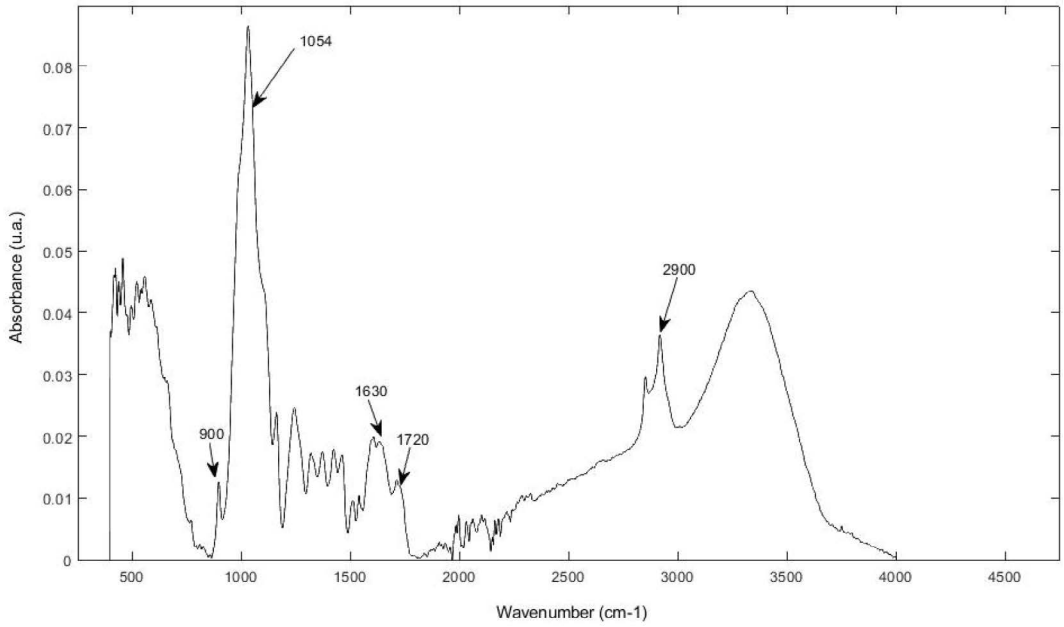

Figure 3. FTIR of oil palm bagasse.

The spectrum corresponding to cellulose (Figure 4) shows a band that corresponds to 1370 cm^{-1} which is characteristic of cellulose. The peak at 1731 cm^{-1} is related with C=O bonds of unconjugated ketones present in hemicellulose (Asfanas'ev *et al.*, 2007). Bands close to 3270 cm^{-1} and 710 cm^{-1} are observed, corresponding to contributions from cellulose Iβ(Boisset *et al.*, 1999). Likewise, the sample is constituted by a compound of bonds that belong to ethers present in the band 1020 cm^{-1} (Contreras, 2010).

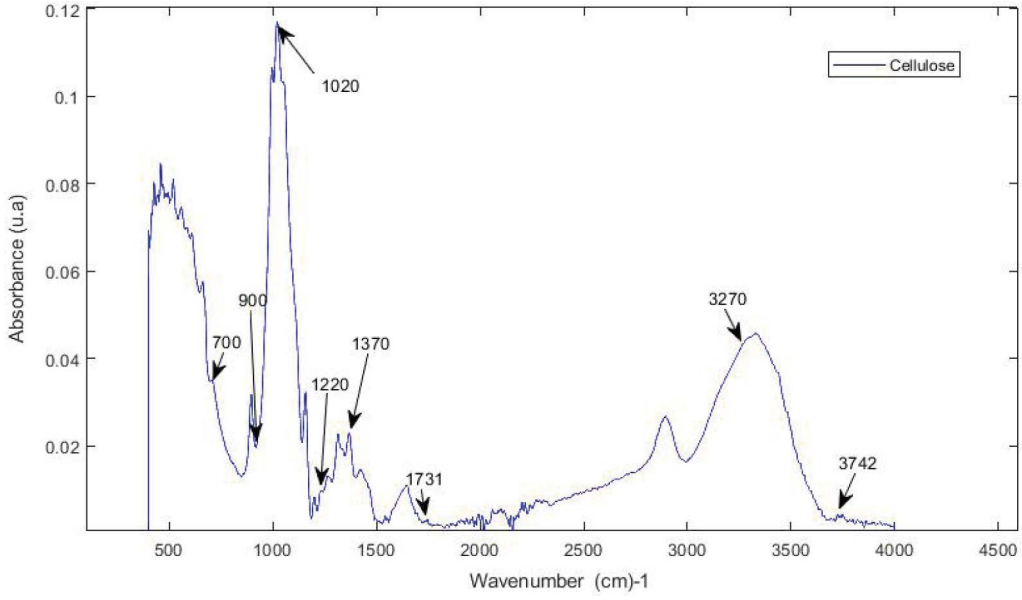

Figure 4. FTIR of cellulose obtained from oil palm.

Thermogravimetric Analysis (TGA)

The thermogravimetric analysis was used to evaluate the thermal stability of the samples and to determine the quality of the cellulose obtained. The results are shown in Figure 5 and in Table 2. The TGA curve measures the loss of mass in function of temperature, while the DTGA curve corresponds to the one derived from the loss of mass, which indicates the decomposition speed of the sample.

It is observed that the bagasse and cellulose samples of oil palm present a mass loss of around 3.5% in 120 °C, corresponding to loss of moisture. The bagasse begins its decomposition at around 246.5 °C, while the cellulose starts at 286.81 °C. The delay in the cellulose decomposition is because the resin compounds, the hemicellulose and most of the lignin have been previously eliminated. This is proven when observing the first event of the DTGA curve from the bagasse, which begins at 239.3 °C and ends at 306.0 °C with a peak at 293.9 °C, corresponding to the thermal decomposition of hemicellulose and pectin compounds, in addition to the rupture of glycosidic bonds of cellulose; on the contrary, in the DTGA of the treated fiber it is not possible to observe this event, because of the elimination of these compounds during the alkaline treatment. The greatest event in thermal decomposition takes place at 349.6 °C and 355.5 °C for bagasse and cellulose, respectively, which corresponds to the thermal decomposition of βcellulose (Khalili, 2008; Kumneadklang, 2019). The delay in temperature of this peak shows that the fiber

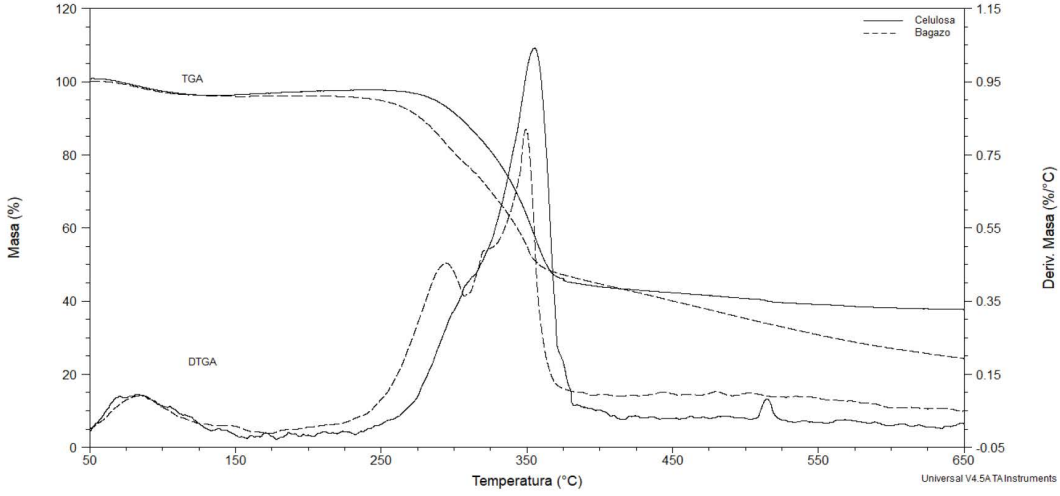

Figure 5. Thermogravimetric analysis of bagasse and oil palm cellulose.

Table 2. Thermal properties of the bagasse and cellulose.

Variable	Bagasse	Cellulose
T_{onset} (°C)	263.6	288.1
Residual mass (%) a 650 °C	24.3	37.7
T_{max} (°C)	349.5	355.5

T_{onset} (°C), Onset of thermal decomposition.
T_{max} (°C), Maximum thermal decomposition temperature.

treated has a higher thermal stability than bagasse, indicating that the hemicellulosic and lignocellulosic compounds have been mostly eliminated. A small decomposition event from the cellulose sample takes place at 515.1 °C, possibly due to the volatilization of short-chain lignin residues (Okoroigwe & Saffron, 2012). The high content of ash at the end of the test is an indicator of a correct treatment of the fiber and from which cellulose of good quality has been obtained.

CONCLUSIONS

This study showed the possibility of obtaining high-quality cellulose at the laboratory level from oil palm agroindustrial residues, applying acid hydrolysis and blanching to the cellulose fibers, and corroborating with infrared analysis and thermogravimetric analysis. These were performed both for the palm bagasse fiber and the cellulose obtained, where a decrease was observed primarily in the intensity of the peaks corresponding to the functional groups of aromatic lignin rings, and in addition, the thermal events characteristic of hemicellulose and lignin were not observed in the cellulose obtained, indicating that they were removed in greater proportion with the chemical procedures applied.

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