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ANALYSIS OF SOME TECHNOLOGICAL PROPERTIES OF TEXTILE FIBERS FROM THE BANANA TREE STALK

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ABSTRACT

The aims of the present study is to extract and characterize the fibers of Cameroonian banana tree stalk (HB) from the" faux French" variety. The fibers are extracted by retting method. Structural, functional and thermal properties where then determined. The physico-mechanical properties such as density, linear density, moisture content, water absorption rate, moisture recovery rate and tensile properties were evaluated. These values showed that the banana tree stalk has good properties comparable to certain cellulosic fibers. The structural, functional and thermal analysis showed that type 1 cellulose is the major constituent of fiber from the banana tree stalk with amorphous structure having 3.61 crystallinity degree. The elongation vibrations of functional groups such as hydroxyl groups are those present in the cellulose molecule. In addition, the degradation temperature is between 312^0C and 441^0C. Physico-mechanical analyzes have shown that banana tree stalk fibers can take up 10.57 to 11.25% of humidity and can absorb more than 100% of water. Tensile mechanical properties show that the fibers are elastic, rigid and resistant. The elongation varies from 3.73 to 3.98%, the tenacity from 0.07 to 0.17 N/Tex, the breaking force from 3.13 N to 4.32 N and the initial modulus from 2.17 to 5.84 GPa. Banana tree stalk fiber can be used for similar applications as flax, sisal and ramie fibers.

Keywords: Banana tree stalk, retting, crystallinity degree, amorphous, elastic modulus.

INTRODUCTION

Banana tree is a ligneous plant which can reach several meters in height, cultivated in the intertropical regions, it belongs to the Musaceae family (Dhed'a, 2019). Very popular in the food industry, it is classified into two main groups of edible bananas: dessert bananas and cooking bananas, in plantains there are four morphological types: Horn, False Horn, French and Bâtard ('Faux French')(Kwa and Temple, 2019). The plantain banana is a widely consumed product in Central and West Africa (Thiémélé *et al*., 2017).

Banana's by-products, in particular the trunks, shafts and spines, can be subject to fiber extraction to make ropes, boat ropes, baskets, card board boxes, carpets, roofing materials. After harvest, the banana tree stalk is also used to make an organic fertilizer that can be used in banana plantations, but also to make thermal insulation(Kwa and Temple, 2019).

Today, the very growing interest is focused on biomass materials. Fibrous materials surround us, they protect us against bad weather, they are linked to our well-being, and they are at the center of our daily life. Although chemical fibers have almost imposed themselves given their low cost and also their mass production, natural fibers, such as sisal, abaca, hemp and flax are used in the automotive sector given their intrinsic and unequaled properties (Roussel, 2006). The incorporation of plant fibers (wood, flax, hemp) in thermoplastic or thermosetting materials to replace glass fibers is a concept that has already been marketed (Bewa, 2012).

Plant fibers are still booming in the textile, automotive and civil engineering sectors. In this context, this work is part of the logic of valuing the banana tree stalk which are generally abandoned in the banana plantations after the harvest (Fagbemigun, 2016; Bakri *et al*., 2017; Chengoué *et al*., 2020; Libog *et al*., 2021). As part of the work already carried out, it appears that the physicochemical properties of the stems have not been addressed.

This present work focuses on the realization of a structural, functional and thermal analysis followed by a study of the physico-mechanical properties of the fibers of banana tree stalk (HB) plantain "Musa sapientum" of the species "faux French" variety cultivated in Cameroon to guide their use for textile applications.

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MATERIALS AND METHODS

Materials

Sampling

The banana tree stalk was sampled at the CARBAP (African Center for Research on Banana and Plantain) located in the Littoral region of Cameroon, Moungo Department, Djombé Penja district with geographical coordinates:
Latitude: 4.548437 and Longitude: 9.619688
4°32'54.4"North and 9°37'10.9"East

The chemicals reagents

Benzene use for density determination was provided by the firm Sigma-Aldrich. The extraction is done by retting using distilled water. The prolonged resting of the fibers experienced the influence of microorganisms which accelerated the extraction process.

Methods

The banana tree stalk is scraped and cut manually with a knife, the upper surface is removed to facilitate the extraction process. The extraction method chosen is the so-called biological one, i.e., water retting (Fig. 1) which consists of soaking the strips of banana tree stalk cut in distilled water, each test is carried out at a temperature of 23ºC for a period of 20 to 30 days. The fibers are extracted by the combined action of microorganisms and bacteria. On leaving the soaking bath, the fibers are rinsed with distilled water, then dried in the oven at a temperature of 60°C for 6 hours for the different samples of the extracted HB fibers.

Linear Density

Linear density (T) of HB fibers is determined according to NF G 07-007 standard (Michel, 2014). The fibers are weighed with a 0.001mg precision microbalance. Fiber length is measured using the 0.001mm precision digital caliper. Linear density is calculated on each sample using equation (1) (Mejouyo *et al*., 2021).

$$T(tex) = \frac{m}{L} \times 1000 \quad (1)$$

Density

Density is obtained by the mass to volume ratio. The banana tree stalk samples are weighed with a 0.001mg precision microbalance and the volume is obtained using a pycnometer with benzene. The density is obtained on each sample using equation (2).

$$\rho_{abs} = \frac{m_0 . \rho_{eau}}{m_0 + m_1 - m_2} \quad (2)$$

Moisture content

The moisture content (MC) is obtained according to the gravimetric method in accordance with NF G 08001-4 standard (Dubis *et al*., 1999). The samples are dehydrated in an oven for 24 hours, at a temperature of 103°C, until a constant anhydrous mass (Ms) is obtained. The samples are placed in a desiccator at a temperature of 22°C and a relative humidity of 62%. The HB samples are weighed every 15 min until two successive constant weighings are obtained. The moisture content of each sample (MC) is calculated using equation (3) (Danso, 2017).

$$MC(\%) = \frac{m_t - m_f}{m_t} \times 100 \quad (3)$$

Water absorption rate

The water absorption rate (WA) is obtained by the gravimetric method in accordance with NF EN 1097 standard (Dubis *et al*., 1999), which consists of dehydrating the HB fibers in an oven for 24 hours at a temperature of 105°C. The fibers are cut to a length of 10 mm, they are introduced into the pycnometer using a glass rod, then the pycnometer is filled with water and weighed. The water absorption rate of each sample is calculated using equation (4) (Nadlene et al., 2015).

$$WA(\%) = \frac{m_t - m_0}{m_0} \times 100 \quad (4)$$

X-ray diffraction (XRD)

X-ray diffraction (XRD) of banana tree stalk fibers was carried out to analyze the crystallographic structure. The X-ray powder diffraction spectra were measured in the interval $2° < 2\theta < 50°$ by using a Panalytical, Netherlands (Model: PW3040/60 X'pert PRO) equipped with a Cu anode (kλ radiation, λ = 1.54056 Å) using a voltage of 40 KV and a current of 30 mA. Deflection 2θ of the beam is obtained according to Henry Bragg's law, using equation (5)(Kaygili and Tatar, 2012).

$$2d\sin\theta = n\lambda \quad (5)$$

The degree of crystallinity is calculated according to the following formula:

$$xc = \frac{Kc}{\beta 1/2} \quad (6)$$

Fourier transform infrared spectroscopy (FTIR)

Fourier transform infrared spectroscopy (FTIR) was used to determine functional groups, as well as bonds and in banana tree stalk (HB) samples.

The fibers were tested with the Alpha spectrometer from Bruker, the resolution was fixed at 4 cm^{-1} in a spectral range of 4000 –400 Cm^{-1}.

Thermogravimetric analysis

Thermo gravimetric analysis (TGA) was performed with an asynchronous STA PT-1000 Linse is device. The initial mass of the sample is approximately 10 mg. The heating rate was adjusted to 10° C/min, with a temperature range which varies from 25° C to 700° C under nitrogen at a flow rate of 50 mL/min.

Static tensile test

Tensile tests on single fibers are carried out in accordance with standards NFT 25704 and ASTM 3379-75 "Standard Tensile Method" (Sedan, 2007).

The Microsoft office 2019 software allowed us to enter the data collected in order to highlight the different stress (σ) and deformation (ε) curves, to calculate the stresses at break (σr), the elongations at break (εr), the breaking forces (F) and the different moduli of elasticity (E) of each sample of HB.

Certain parameters such as gravity (G), linear density have been associated to facilitate the various calculations.

- Strain(ε) is obtained from equation (8):

$$Strain = \frac{Length}{InitialLength} \quad (7)$$

- Tenacity or specific stress is obtained from equation (9):

$$SpecificStress\ \left(\frac{N}{Tex}\right) = \frac{Strength}{Tex} \quad (8)$$

- Initial Young's modulus (E) is obtained from equation (10):

$$Initial\ Modulus = \frac{Specific\ Stress}{Strain} \quad (9)$$

Fig.1. Retting process of banana stalk fiber. (a) Longitudinal view of raw banana tree stalk, (b) Banana tree stalk in distilled water, (c) Extracted fibers.

Table 1. Tensile mechanical properties of HB fibers.

Banana tree stalk fiber	Elongation (%)	Breaking Force (N)	Tenacity (N/Tex)	Initial Modulus (Gpa)
H1	3.98	3.13	0.07	2.17
H2	3.91	4.32	0.17	5.27
H3	3.73	3.84	0.17	5.84

Table 2. Properties of plant fibers.

Fibers types	Density (g/cm^3)	Water Absorption (%)	Moisture Content (%)	References
Sisal	1.5	150-250	5-10	(Aizi and Kaid-Harche, 2020)
jute	1.3-1.41	281	12-13.7	(Baley et al., 2012)
Cotton	1.5-1.6	-	8-25	(Aizi and Kaid-Harche, 2020)
RC	0.757	198.17	12.20	(Betene et al., 2020)
Banana	1.3	-	11	(Neelamana et al., 2013)
Banana	1-1.15	-	10-11	(Joseph et al., 2002)
Banana	0.59-1.02	-	13.64-15.17	(Chengoué et al., 2020)
Banana	0.32-0.66	232-396	11.26-11.20	(Libog et al., 2021)
Banana tree stalk fiber	0.812-0.964	176.07-247.41	10.56-11.24	This Work

RESULTS AND DISCUSSION

Structural, functional and thermal analysis

X-ray diffraction (XRD)

In Figure 2 shows X-ray diffraction of fibers from banana tree stalk. The X-ray diffraction pattern of HB fibers shows an intense peak at 2θ = 22.14° attributable to the type 1 cellulose peak in a (200) crystallographic deviation plane.

The degree of crystallinity is 3.61. This low value exhibiting the amorphous character of banana tree stalk fibers cellulose.

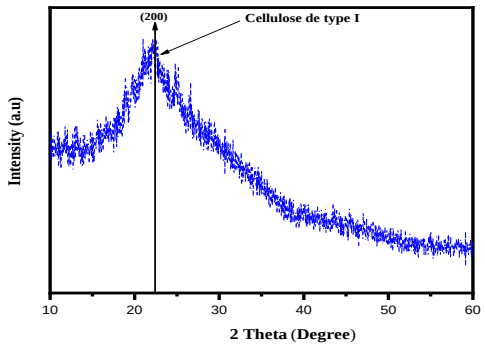

Fig.2.Diffraction pattern of fibers extracted from HB.

Fourier transform infrared spectroscopy (FTIR)

Figure 3 shows the spectra of different samples of banana tree stalk fibers. The spectra obtained share the absorption bands common to the main lingo cellulosic fibers in terms of bonds and functional groups (Aizi and Kaid, 2015).The band which is between 3000 and 3500 cm^{-1} attributed to the hydroxide group (O-H) elongation of the hydroxyl bond. Other peaks show the presence of cellulose such as those observed at 2918 and 2844 cm^{-1}, attributed to the stretching vibration of the C-H bond and the CH_2 group. The theoretical value of 2918 is the asymmetrical stretch while that of 2844 cm^{-1} is the symmetrical stretch. We notice the appearance of the theoretical value 2841 for the H2 treatment (25 days).

The peak at 1725 cm^{-1} observed in the H3 treatment (30 days) fibers associated with the stretching vibration of the C=O carbonyl group indicates the presence of pectins.

The characteristic wavelength of lignin (COOH) is at peak 1615.

The peak at 1422 Cm^{-1} corresponds to the bending vibration of the CH_2 group. The peaks at 1316 cm^{-1} and 1320 cm^{-1} are linked to the deformation of the cellulose, indicating the presence of the alcohol group.

The peak at 1234 Cm^{-1} characterizing hemicellulose corresponds to the elongation vibration of the CO group.

Three bands are located in the band of low wavelengths at 1159, 1103, and 1030 cm^{-1}, they correspond to the mode of stretching vibration of the C-OH group, of symmetric stretching vibration of the glycosidic group COC and finally the major absorbance peak reflecting the cyclic structure of carbohydrates.

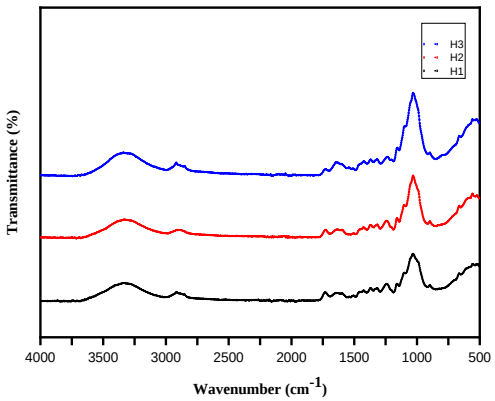

Fig. 3. Vibration spectra of the functional groups present in the different samples of extracted fibers (H1: 20 days, H2: 25 days, H3: 30 days).

Thermogravimetric Analysis (TGA/DSC)

The illustrative thermal analysis curves shown in the figure below (Fig. 4) show the behavior of the fibers extracted under the effect of heat. The degradation of the various fiber components takes place in three stages. This thermal behavior is typical of fibers of plant origin: flax, jute (Nadlene *et al*., 2015). In the first phase, fiber degradation starts at 61°C, this could be due to vaporization of moisture and removal of waxy material from the fiber (about 5.38%). Corresponding to an exothermic effect confirmed at the level of the DSC curve. The second peak shows that the mass loss (about 51.53%) takes place in the second phase at the temperature of 312°C where most of the cellulose, hemicellulose and lignin content is degraded at this phase. Many studies in the literature agree that cellulose degrades between 300 and 420°C (Duncan *et al*., 1988) while pectins and hemicelluloses degrade between 250 and 320°C (Yang *et al*., 2007). The final phase of cellulose degradation occurs in the temperature range of 401°C - 441°C which corresponds to the degradation of lignin which leaves ash as a residue.

Physico-mechanical analysis

Linear density

The behavior of the fibers extracted from the shaft presents a behavior in terms of linear density as shown in Figure 5. A large variation in the linear density of H1 compared to H2 and H3 is observable, the difference is so important that this could be explained by the duration of the treatment (number of retting days). Longer is the treatment time, lower is the linear density. The values obtained are in the range 22.20 and 42.20Tex.

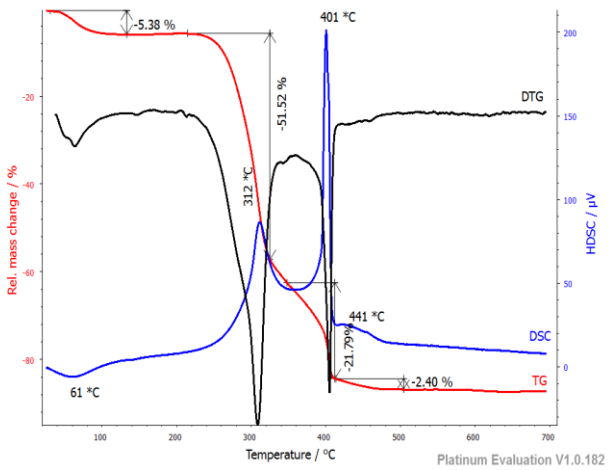

Fig. 4. TGA/DSC of H2 sample HB fibers.

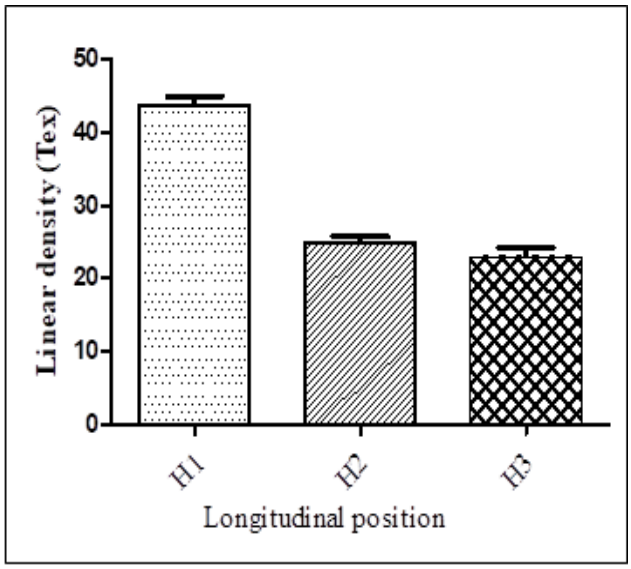

Fig. 5. Linear density of fibers extracted from HB.

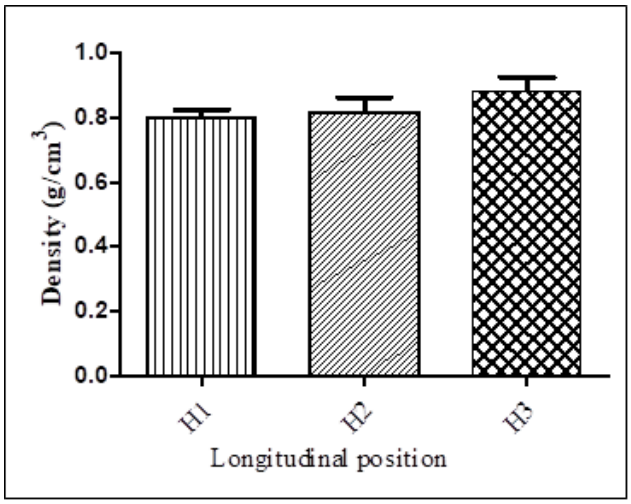

Fig. 6. Density of fibers extracted from HB.

Density

The density of banana tree stalk fibers is between 0.81 and 0.96 g/cm^3 as shown in Figure 6. The density increases with the treatment duration.

The density of banana tree stalk fibers is lower than that of plant fibers, especially cotton, which is 1.55, flax 1.53, jute 1.44, hemp 1.07, sisal 1.45; coconut 1.15 and alfa fibers 1.51 (Baley *et al.*, 2012; Ishikawa *et al.*, 1998). Consequently, they are close to and slightly higher than those obtained on fibers from the pseudo stalk of the banana tree.

Thus, banana tree stalk fibers offer an important advantage in the design of lighter textile materials.

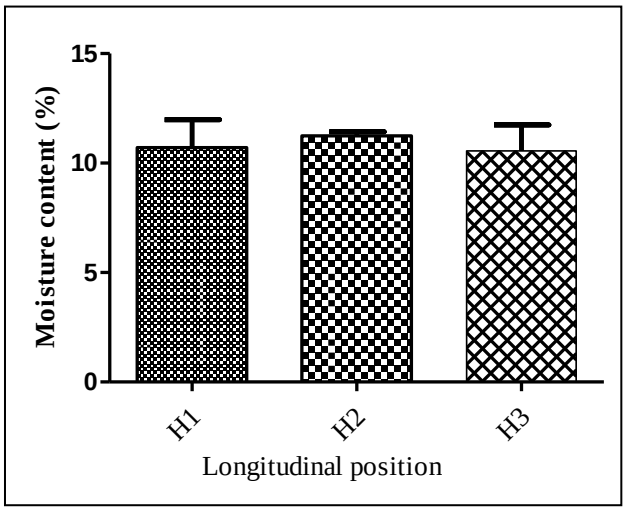

Fig. 7. Moisture recovery rate.

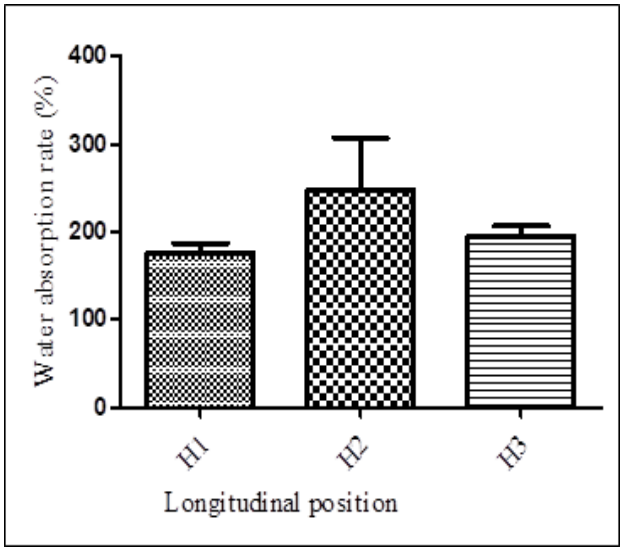

Fig. 8. Water absorption rate of HB fibers.

Moisture recovery rate

Figure 7 shows the moisture content distribution of HB fibers. These values range from 10.56% to 11.25%. They

are close to the values obtained in the literature for other plant fibers, the values of the moisture uptake rates of the fibers extracted from the HB are very close to the fibers of the pseudo trunk of banana trees (Chengoué *et al*., 2020; Libog *et al*., 2021).

Water absorption rate

The values obtained for the absorption rates are very high and greater than 100%. They can absorb up to 247.41% of their mass in water for H2 fibers; 194.68% for H3 and only 176.07% for H1. Similar results were obtained for sisal, RC and banana pseudo tree stalk fibers (Libog *et al*., 2021). The value of H1 being the smallest, this is probably due to the presence of hydrophobic cellulosic substances (Fig. 8).

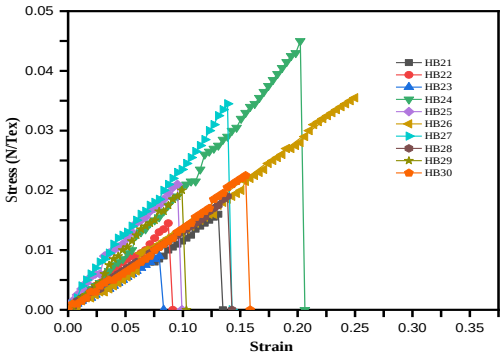

Fig. 9. Strain stress of HB H2 fibers.

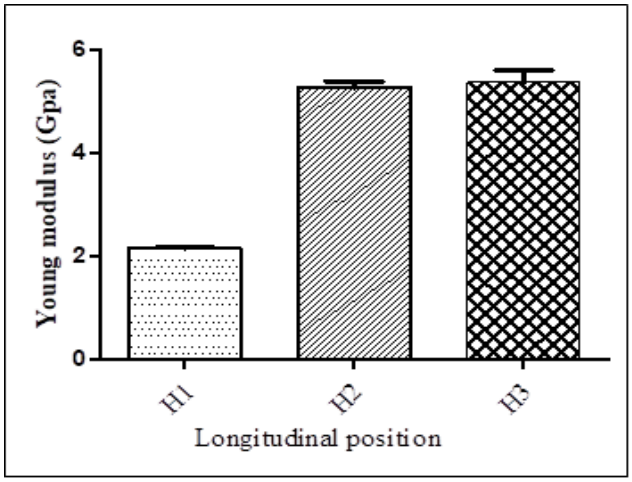

Fig. 10. Young's modulus of HB fibers.

Static tensile test

Figure 9 shows the summary of the different stress and deformation curves of the tree stalk fibers of banana trees in sample H2. While Figure 10 highlights the evolution of the modulus according to the type of treatment (retting time). Table 1 groups together the tensile properties of the HB fibers of samples H1, H2 and H3. The mechanical properties obtained for the tensile test indicate that the HB fibers have an initial modulus which varies in the interval [2.17 Gpa to 5.84 Gpa]. The extraction time has an effect on the mechanical properties because the samples H2 and H3 are more resistant than H1. The results obtained are close to cotton and coconut fibers (Baley *et al*., 2012).

Table 1 presents a summary of the results of the tensile test of the fibers extracted from the banana tree stalk.

These values show that the fibers extracted from the banana tree stalk by water retting have good tensile strength, good rigidity and are elastic.

Table 2 presents a comparative analysis of the different values of certain properties of fibers extracted from banana tree stalk and those of other plant fibers. The values thus presented show that the fibers extracted from the banana tree stalk can be used for certain textile applications.

CONCLUSION

This work made it possible to characterize the fibers resulting from HB fibers extracted by retting. Structural, functional and thermal analyzes have shown that these textile fibers are made of type 1 cellulose with a crystallinity rate of 3.61. The calculated mechanical properties made it possible to obtain Young's modulus values between [2.17 Gpa to 5.84 Gpa]. The extraction time factor has an influence on the mechanical properties such as the tensile test and the time of 25 days is taken as a reference duration in this work for good quality fibers. Thus the fibers from the banana tree stalk can be used in the field of textiles industries.

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