# PHYSICO-CHEMICAL AND THERMAL CHARACTERIZATION OF THE BANANA PSEUDO-STEM FIBERS (BF)

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**ABSTRACT**

This paper focuses on the study of the properties of banana Fibers from Penja Cameroon. The traditional use of these fibers inspired researchers to investigate their properties. This study aims at improving the state of knowledge to diversify use. The fibers are extracted after boiling fresh stems in water. Then, the diameter of the fiber was measured following ASTM 2130-90 Standard, their density following D 3800-99 (2005) ASTM code, their water absorption rate, and their moisture content were measured. Their molecular structure was studied by ATR-FTIR spectroscopy. A quantitative analysis of the chemical composition was performed according to analytical techniques for the pulp and paper industry (IPAT). A TGA/DSC analysis was also performed. The Results reveal that banana fibers diameter ranges between $80-125\mu$m; a density of about 0, 32-0,66g/C$m^3$ ; a moisture content of 11,26-13,20%. These fibers are also hydrophilic with a water absorption rate of 232-396%. The analyzed fibers exhibit functional groups that are related to the presence of hemicellulose, Cellulose, Pectin, and Lignin. The fibers have the following Chemical composition: Cellulose (59,15%), Hemicellulose (14,42%), Lignin (10,70%) , Pectin(3,79%) , Extractives (11,81%) and Ash (0,55%) . It is observed that these fibers are thermally stable up to 180°C.

**Keywords:** Banana fibers, Pseudo-Stem, operating temperature, Cellulose, Thermal Behavior,

## 1 Introduction

The choice of reinforced fibers is of the utmost importance and requires knowledge of the physical, chemical, thermal and mechanical properties of those fibers to produce good quality composite materials from the perspective of promoting the development of renewable resources. To this end, natural fibers are governed by a set of parameters including chemical composition, crystallinity index (CrI) of the cellulose, micro-fibrillar angle (MFA), good length/diameter (L/D) ratio of the fibers, good tensile strength, good elongation at the break, and low sensitivity to temperature and humidity variations (Sauvageon .T,2017).

Therefore, it is necessary to evaluate their density, porosity, chemical composition, structural characteristics (slenderness, cross-section shape, and section, microfibril angle), mechanical strength, thermal stability, and sensitivity to the absorption of moist liquids and vapors.

For decades now, natural fibers have been studied and used as reinforcement in natural fiber plastics composites. (Eloundou et al, 2004; Manorajan et al, 2011) .In Cameroon which is an important supplier of bananas, there exist a lot of banana trunks that are misused after harvesting. From the perspective of enriching material science with a well-known source of potential natural fibers and good management of ecosystem resources of our immediate environment, research can draw inspiration from the valorization of those banana stems wasted into nature. In addition to that, these materials seem to resist

severe mechanical and thermo-physical stresses (Ragavendra et al, 2017). The above potential inspired the researchers to investigate the properties of banana fibers. In their works, some of the physical, chemical, hygroscopic, and mechanical characteristics have been found.

One can find in the literature that Banana pseudo-stem fibers have a density of 1,02g/c$m^3$, the humidity rate between 64% and 15, 17% the tensile strength of 816,6 MPa, and elongation at break of 2,83% (Mbouyap,2018). The density and the humidity rate vary with the extraction process (soaking in a solution of cold caustic soda, boiling in water, and water retting). Banana fibers extraction after boiling in water revealed the best mechanical properties (Mbouyap, 2018). Another study of BF showed that the average diameter of BF fibers was found to be $167\pm0,1\mu m$ , the young's modulus 13Gpa, the tensile strength 161Mpa, the elongation at break 1, 27% (Muhammad et al, 2017). All those values of tensile properties are lower than the range of value reported for banana fibers globally (YM: 27-32Gpa; 700-800Mpa and 2, 5%-3, 7%) (Satyanarayana et al, 2007), for the fibers of diameters 10-34$\mu m$ and those used in Kerala (YM~29Gpa, UTS~540Mpa, and ~3% for fibers of diameter~80$\mu m$ ) (Indira et al,2013b). A morphology study revealed a lot of defects along the length of the fiber, their number may vary from fiber to fiber while fractured surface exhibited flat surface with intracellular fractures indicating brittle of the banana fibers, cells seen as holes were not spherical rather irregular in shape; the interior of those holes shows a longitudinal array of microfibrils with thickness seeming to be higher compared to some lignocellulosic fibers; (Satyanarayana et al, 2007) (Satyanarayana et al, 2008), the FTIR spectrum of fibers indicates that the banana fibers show aromatic character suggesting the fiber to be lingo-cellulosic with the presence of cellulose, hemicellulose, and lignin; the XRD results indicated the fibers have mainly the cellulose, about 52%; DSC and TGA of banana fiber revealed the thermal degradation details of banana fibers samples et also their thermal stability which occurred at 850°C

Banana pseudo-stem fibers were used as reinforcement of Epoxy (Muhammad et al, 2017).These fibers improved the mechanical, thermal, and hygroscopic properties of this material. They confer to Epoxy a more ductile fracture behavior and increased its kinetic of moisture adsorption, which qualifies them for comfort in painting applications. When treated, banana fibers improved the properties of the composites more than untreated ones. Banana pseudo-stem fibers were characterized and used as reinforcement of Polypropylene (PP) (Eloundou et al, 2004) .The young modulus in the raw material was 12GPa and increased with the Cellulose content (15, $8\pm2,9GPa$ at $75\pm3\%\ of$ cellulose) which in turn increased with the treatment at 10% NaOH and 10% NaClO. These fibers improved the mechanical properties of this material (the value of E for PP/BF at 50% of banana fibers was 1, $95\pm0,10MPa$ while that of pure PP was 0, $87\pm0,05MPa$). Therefore, the tensile Strength ($\sigma_{max}$) and the elongation at break (A%) decreased with increasing the fibers rate; this behavior is due to the poor wettability of the fibers in Polypropylene; as BF is water absorbent and PP is not, the PP/BF Composite becomes brittle and brittle as BF rate increases.

This work is intended to increase the mastering of these fibers by studying their physical behavior. For validation or comparison purposes, the evaluation of their properties has also been performed.

## 2 Material and Method

### 2.1 Fibers Extraction

#### 2. 1.1 Material

The main material used is illustrated in Figure 1, namely: banana pseudo-stems, cooking pot, cooked banana trunks, and fibers extraction

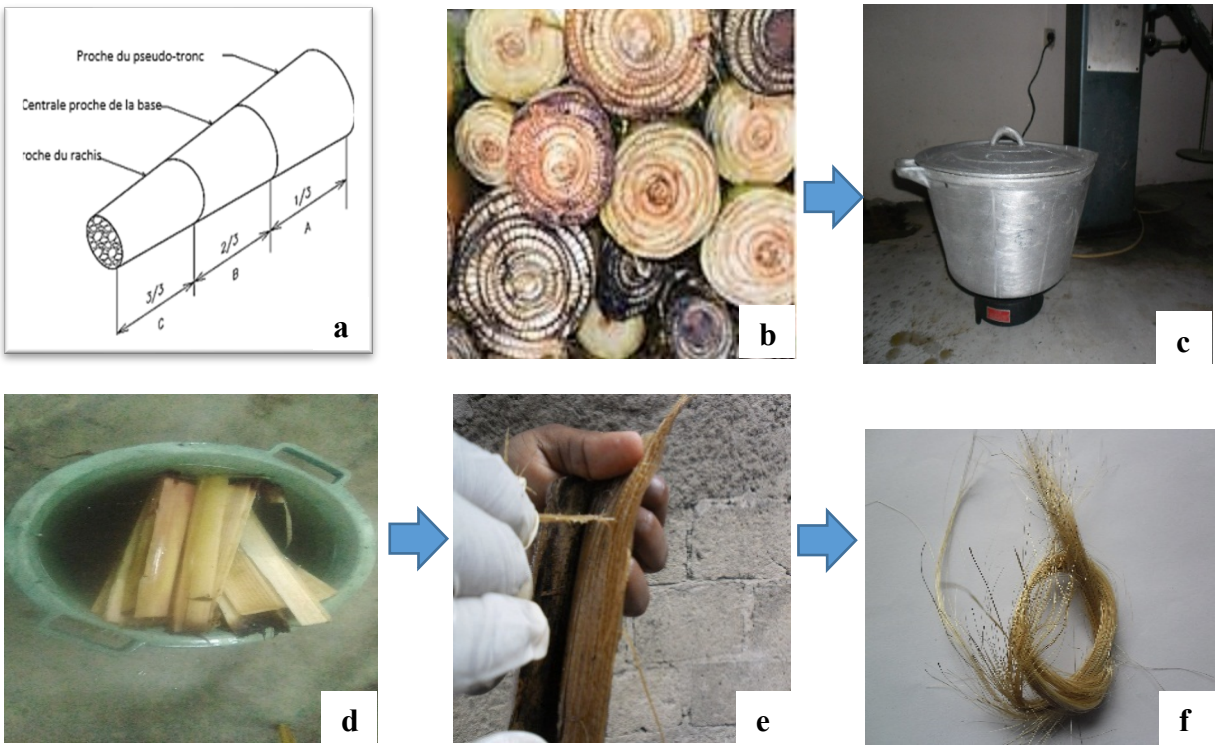


FIGURE 1 Fibers Extraction Materials: (a) Principle of the division of the banana trunk into three parts in the longitudinal direction (b) Banana trunks (c) Cooking pot (d) Banana barks in the Container (e) Fiber Extraction (f) Fibers extracted Banana trunks (f) Fibers Extraction (g) fibers extracted

### 2.1.2 Method

Banana trunks were collected from Penja Cameroon. The Extraction Technique used was that's of extracting after boiling in water.5 The trunks were cut down, divided into three parts (the bottom, the Middle, and the Head). Only the bottom part has been taken for this study and was sliced into prims of dimensions $20\times 9{,}5\times 3\ mm$ and $0{,}42 g/Cm^3$ of density. Next, the slices are introduced into a heating pot containing boiling water previously heated at 60 °C for 30 minutes. Resins, oils fats, ashes, and waxes were removed to let fibers appear. After extraction, fibers are washed and dried in the open air. Fibers extracted in this study came from the Base of the Banana pseudo-trunks. The parameters of this extraction process are presented in Table 1.

TABLE 1 (BF) fibers parameters Extraction process

| Extraction process | Parameters | Min value | Max value |
|---|---|---|---|
| **Boiling in water** | Volume of water | 5754ml | 17263ml |
| | Mass of banana trunk | 1208,35g | 2416,7g |
| | The volume of banana barks | 2877ml | 5754g |
| | Duration | 30 min | 180 min |
| | Temperature | 60°C | 100°C |

## 2.2 Physical Properties

The individual weighing operations were carried out using a 0,1mg precision balance. Each test was carried on 7 samples and the reported result is the average.

### 2.2.1 The actual density

The apparent density $d_a$ of MP fibers were calculated by dividing the mass by the volume as shown in equation (I) according to the D 3800-99 (2005) and D 792 (2013) ASTM codes. These standards allow the bulk density to be evaluated by the gravimetric method based on the Archimedes principle. First, the mass of the fiber $m_f$ previously dried at 50 °C for 24 hours was measured. The samples are made by converting these fibers by paraffin of volume $V_P$ .The volume of the samples $V_s$ was evaluated by immersion in a test tube containing a volume of distilled water $V_0$ at 25 °C.A metallic element (a nut) of volume $V_a$ . The diameter $d_a$ of the fibers was determined by equation (1) and the volume $V_f$ by the equation (2) (Betene et al, 2020).

$$d_a = \frac{m_f}{V_f} \quad (1)$$

$$V_f = V_s - (V_P + V_a + V_0) \quad (2)$$

### 2.2.2 The Diameter

The diameter of fibers was determined as per ASTM 2130-90 using twelve (12) samples of extracted fibers and Magna-Mike 8600 optical Microscope, with a minimum of measurements done at five positions along the length of the fiber (one at each end, one at each one-third of the length, one every two thirds and one at the middle of the fiber) for the twelve samples.

### 2.2.3 Water absorption Rate (%WA)

The water absorption rate (WA) of the studied fibers previously dried at 105 °C for 24 hours was evaluated using the equation (3) (Nadlene et al,2015). Seven Samples with a mass $m_0$ we're immersed in distilled water for 24 hours at room temperature. The mass $m_t$ after absorption was measured after cleaning the matter from the surface of the sample.

$$\boldsymbol{WA = \frac{(m_t - m_0)}{m_0} \times 100} \quad \textbf{(3)}$$

### 2.2.4 Moisture content (%MC)

The moisture (MC) content of banana fibers was determined using equation (4), . Seven (Nadlene et al, 2015). Samples with the mass $m_t$were placed at Room temperature, $25\mp2°C$ with 75% relative humidity for 24 hours. The hydrophilic character of these fibers favors the absorption of relative humidity from the air of the plant fibers (Baley et al, 2012). Finally, the Samples were dehumidified in an oven set for 24 hours, and the final mass $m_f$ of each sample was measured.

$$\boldsymbol{MC = \frac{(m_t - m_f)}{m_t} \times 100} \quad \textbf{(4)}$$

## 2.3 Chemical Composition of Fibers

Quantitative analyses of constituents were carried out using the IPAT (Industrial Pup Analysis Technique) method on dry powdered fibers with a mean particle size fibers of approximately $350\mu m$ Weighing operations were carried out using a 0,1mg precision balance.

### 2.3.1 Ethanol-Benzene Extractives Content (%$E_B$)

A cartridge containing an average of 1,7g of powdered fiber was introduced into a soxhlet. The letter is mounted between a flask of 1000ml containing 800ml of mixture Ethanol (96%)-Benzene (99%; $d = 878$) (1:2 v/V) solvent and a refrigerator. This assembly is fixed on a bracket. The separation of the extractives was made by regulated leaching to have a siphon every 10 minutes. Dissolution was done for 7 hours. The cartridges were removed from the soxhlet, freeze-dried at 105 °C for one hour then cooled in a desiccator. The level of Ethanol-Benzene ($E_E$) Extractives (Resins, Oil fats, and Waxes) were determined using equation (5) (Sango et al, 20018; (Youmassi et al, 2017).

$$E_B = \frac{m_0 - m_1}{m_0} \times 100 \qquad (5)$$

$m_1$ , the mass of the dry Residue 1 extracted after evaporation of Ethanol-Benzene solvent and $m_0$ the mass of the previously dried sample


FIGURE 2 Ethanol-Benzene Extraction (a) Dried Powdered of Banana fiber (b) Soxhlet (c) Residue 1

### 2.3.2 Water Extractives Content (%$E_W$)

A cartridge containing the dried mass of Residue 1(1,66g) after Ethanol-Benzene extraction was introduced into the same soxhlet. The previous assembly was reconstituted by replacing the solvent with 100 mg of distilled water. The mixture was heated under reflux for 7 hours to have a siphon every 20 minutes. The Residue 2 obtained was filtered on a weighed sintered glass crucible number 4 washed with distilled water incubated at 105 °C for 12 hours, then weighed after cooling in a desiccator. The content of hot water extractives ($W_E$) was determined with equation (6). (Sango et al, 20018; (Youmassi et al, 2017).

$$E_W = \frac{m_1 - m_2}{m_1}(1 - E_B) \times 100 \qquad (6)$$

Where $m_2$ is the dry mass of the Residue 2, $m_1$ the mass of the dry mass of residue 1 $and$ $E_B$ the Ethanol-Benzene extractives

The Extractives content ($E_S$ ) of the fibers is the sum of the hot water ($W_E$) and Ethanol-Benzene Extractives ($E_B$) and given by equation (7). These Extractives are Resins, Oil fats, Waxes, etc.

$$E_S = E_B \ + E_e \qquad (7)$$


FIGURE 3 Water Extraction (a) Residue 1 (b) Soxhlet (c) Residue 2

### 2.3.3 Pectin content (%$E_P$)

A mass of 1, 33 g of residue 2 was introduced into a flask of 250 ml; 50ml of 2 % hydrochloric acid solution is added. The mixture was heated under reflux with magnetic stirring in a water bath at 80 °C for 4 hours. Residue 3 was retained by filtration on a weighed sintered crucible N°4, washed with distilled water, dried at 105 °C for 12 hours, and weighed after cooling in a desiccator. The pectin content in the hydrochloric acid extract was determined by equation (8). (Sango et al, 20018; (Youmassi et al, 2017).

$$E_P = \frac{m_2 - m_3}{m_2}(1 - E_B - E_e) \times 100 \quad (8)$$

Where $m_3$ is the dry mass of Residue 3, $E_B$ and $E_e$ Ethanol-Benzene and Water Extractives Rate Respectively.

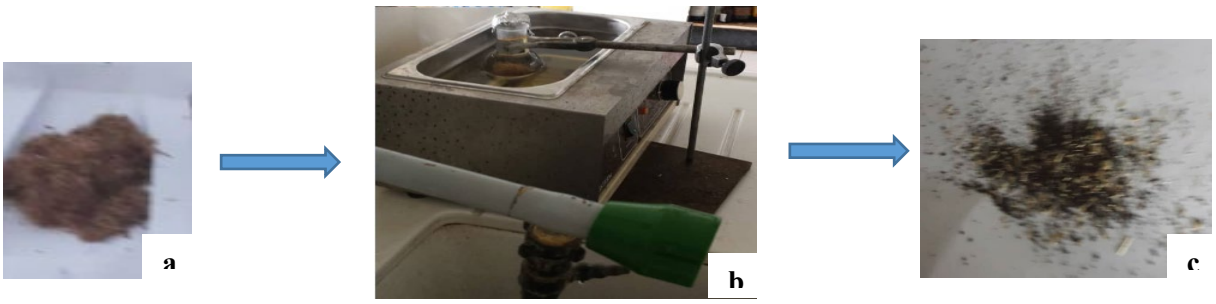


FIGURE 4 Pectin extraction (a) Residue 2 (b) Flax of 250ml and its set (c) Pectin (Residue 3)

### 2.3.4 Lignin content (%$E_L$)

A mass of 200mg of the Residue 3 (after extraction of pectin) was treated with 5ml of sulfuric acid at 72 % for one hour in a water bath at 30 °C to hydrolyze the polysaccharides. The mixture was then diluted to the acid concentration of 3 % by adding 195 ml of distilled water the brought at 120 °C in an oil bath for 2 hours. The sample has been cooled in a cool water bath then filtered by using a Buchner system. Lignin being the only insoluble component is speared from the fibers and dried at 105 °C. Then, the Lignin content ($E_L$) was determined by equation (9). (Sango et al, 20018; (Youmassi et al, 2017).

$$E_L = \frac{m_L}{m_3}(1 - E_B - E_e - E_P) \times 100 \quad (9)$$

Where $m_L$ the mass of Lignin is extracted, $m_3$ the mass of Residue 3, $E_B, E_e, E_P$ Ethanol-Benzene, Water, and Pectin Extractives respectively.

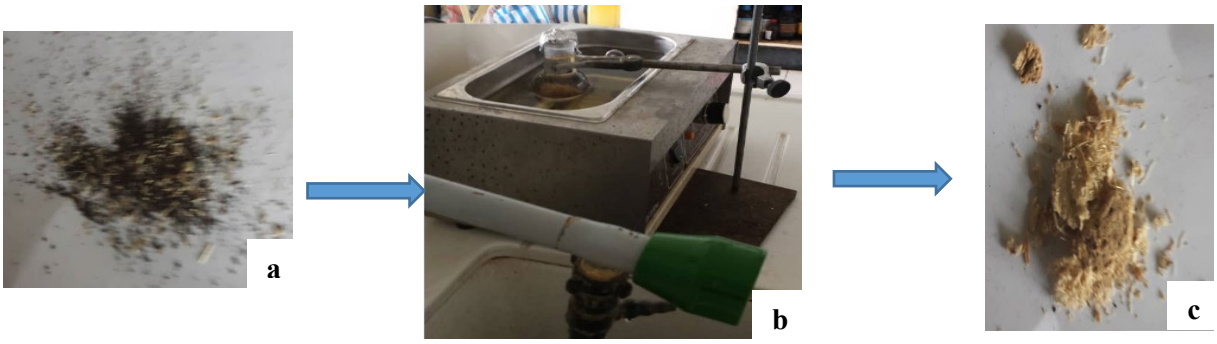


FIGURE 5 Lignin extraction (a) Residue 3 (b) Flax of 250ml and its set (c) Lignin (Residue 4)

### 2.3.5 Holocellulose content (%$E_{HO}$)

The Chemical extraction of HoloCellulose consists of completely delignification of the Lignocellulose material and recover the polysaccharide fraction (Cellulose and Hemicellulose) which also can be separated subsequently .

A mass of 1,5g of residue 3 was introduced into a flask containing 60ml of distilled water heated to 75°C. Subsequently, 0,2g of acetic acid and 15% V/V (3ml) sodium chlorite were added every hour for 7 hours. The process of adding acetic acid and sodium chlorite was repeated every hour for 7 hours until having a very white Residue. The Residue 4 obtained was filtered and washed with demineralized water and left to stand for two hours before being washed again with Ethanol. This residue was dried at 150°C.10 The Holocellulose (figure 5) was determined by using equation (10).

$$E_{HO} = \frac{m_4 - m_3}{m_4}(1 - E_B - E_e - E_P) \times 100. \quad (10)$$


FIGURE 6 Holocellulose extraction (a) Residue 4 (b) Cooking pot in the Magnetic agitaor (c) Holocellulose (Residue 5)

### 2.3.6 Cellulose content (%$E_C$)

Cellulose was isolated according to the method of Kurschner and Hoffer, (Sango et al, 20018; (Youmassi et al, 2017; Obama et al, 2012).

A mass of.1g of Holocellulose (Residue4) was introduced into an Erlenmeyer flask containing 50ml of solvent nitric acid-ethanol (1:4; V/V) prepared from Ethanol (96%) and nitric acid (16 N). The assembly was connected to a Where $m_3$ is the mass of Residue 3 extracted and $m_4$ the mass of the Residue refrigerant and then, heated in water both for one hour. The solution obtained was filtered using a weighed sintered crucible N°4, washed with ethanol, then with demineralized water, and finally with ether. The cellulose obtained was freeze-dried at 105 °C for 12 hours, cooled for 12 hours for a

desiccator, and weighed. The Cellulose contained was determined by equation (11) (Sango et al, 20018; (Youmassi et al, 2017).

$$E_C = \frac{m_C}{m_9} \times E_{HO}. \quad (11)$$

Where $m_C$is the mass of cellulose obtained and $m_9$ the mass of Holocellulose (Residue 4) was extracted.

FIGURE 7 Cellulose Extraction (a) Residue 5 (b) Cooking pot in the Magnetic agitator (c) cellulose (Residue 6)

### 2.3.7 Hemicellulose content (%$E_H$)

Holocellulose consists mainly of Hemicellulose and Cellulose the Hemicellulose contained were obtained using equation (12) (Sango et al, 20018; (Youmassi et al, 2017).

$$E_H = E_{HO} - E_C . \quad (12)$$

### 2.3.8 Ash content (%$E_A$)

The ground fibers were placed in a porcelain crucible and then, calcined at 600 °C in a kiln for 6 hours. The ash contained was estimated using equation (12). (Sango et al, 20018; Youmassi et al, 2017).

$$E_A = \frac{m_{Ac}}{m_d} \times 100. \quad (12)$$

Where $m_{Ac}$is the mass of the Ashes obtained and $m_d$ the mass of samples tested.

### 2.4 ATR-FTIR Analysis

The main purpose of this analysis was to identify the functional groups of the study's fibers. The spectra are recorded using a Brunker Alpha-P spectrometer, equipped with an attenuated total reflectance (ATR) module with a diamond crystal and driven by the opus/Mentor software. The plant fibers are dried at 50°C for 24 hours and then powdered to sizes of 315$\mu m$. A few milligrams of powder from the plant fibers studied were deposited on the diamond crystal of the ATR module. Acquisitions were carried out by scanning over a spectral region ranging from 4000 to 400$cm^{-1}$. The crystallinity of cellulose (ζ) in Banana fibers was determined by

comparing the peak intensities of FTIR spectra at 1454 $cm^{-1}$ and 893 $cm^{-1}$ as shown in equation (13) (Parida et al,2015).

$$\zeta = \frac{I_{1595,43}}{I_{890,90}}. \quad (13)$$

Where $I_{1595,43}$ and $I_{890,90}$ are the intensities of FTIR peaks at 1595, 43 $cm^{-1}$ and 890, 90$cm^{-1}$.

### 2.5 TGA-DSC Analysis

Thermal analysis was performed on asynchronous STA PT- 1000 Linseis Thermogravimetric analyzer with 0, 5$\mu g$ resolution capable of combining TG (Thermal Gravimetric) and DSC (Differential Scanning Calorimetry) information using the same samples. The device was equipped with a height resolution 0,1g loaded balance, a furnace with a maximum calcination temperature of 1000 °C, and a very fast cooling system. The device was connected to a computer and controlled by the platinum Evaluation V.1.0 182 Software.

A 3 to 5mg of powdered fibers (~31$\mu m\ of\ size$) were introduced into a platinum crucible and then, heated in the furnace of a constant heating rate of 10°C/min in a temperature range from 25 °C to 700 °C under nitrogen flow at a rate of 50ml/min.

## 3 - Results

### 3.1 Physical properties

Physical properties for the study and the same values found in the literature for some vegetable fibers (Sisal, Hamp, Rhectophyllum Camerunense (RC), Neropeltis Acuminatas (NA), Ananas Comosus (AC), Jute, Flax, Cotton, Roselle, Konaf, Teriumfeta Cordifolia (TC), and Coconut) are given in Table 2.

TABLE 2 Physical Properties of Banana and some vegetable Fibers

| Fiber types | Density ( $g/cm^3$ ) | Water Absorption (%) | Moisture content (%) | Diameter ($\mu$m) | References |
|---|---|---|---|---|---|
| Sisal | 1,5 | 150-250 | 5-10 | - | (Aizi, 2017) |
| Hamp | 1,15-1,45 | - | 6,2 -12 | - | (Aizi, 2017) |
| RC | 0,63-0,947 | - | 7,5 | - | (Beakou et al, 2008) |
| AC | 0,918 | - | 12 | - | (Aizi, 2017) |
| NA | 1,526 | 400 | - | - | (Betene et al, 2020) |
| Jute | 1,3-1,41 | 281 | 12-13,7 | - | (Baley et al, 2012) |
| Flax | 1,5 | $136\pm25$ | 12 | - | (Baley et al, 2012) |
| Cotton | 1,5-1,6 | - | 8-25 | - | (Aizi, 2017) |
| Roselle | 1,41 | 286,5 | 10,9 | - | (Nadlene et al, 2015) |
| Kenaf | 1,45 | - | - | - | (Baruk et al, 2021) |
| TC | 1,477 | - | - | - | (Betene et al, 2020) |
| Coconut | 1,261-1,422 | - | - | - | (Daluz et al, 2017) |
| RC | 0,757 | 198,17 | 12,20 | - | (Betene et al, 2020) |
| AC | 1,126 | 188,64 | 12,21 | - | (Betene et al, 2020) |
| NA | 0,843 | 276,16 | 9,37 | - | (Betene et al, 2020) |
| Banana | 1,3 | - | $11\mp0,1$ | 80 | (Indira et al, 2013) |
| Banana | 1,35 | - | - | 125-250 | (Manorajan et al, 2013) |
| Banana | 1-1,15 | - | 10-11 | - | (Joseph et al, 2002) |
| Banana | 0,59-1,02 | - | 13,64-15,17 | - | (Mbouyap et al, 2020) |
| Banana | 0,32-0,66 | 232-396 | 11,26-13,20 | 80-125 | - |

### 3.1.1 Density of fibers

The banana fiber density found (table 2) is close to those reported in the literature for the work of and small compared to , (Manorajan et al, 2013 ; Mbouyap et al,2020; Indira et al, 2013) work for the same species, small compared to those for the other species as shown in table 2 at last. This slight difference can be attributed to the botanical origin of the trunks. Banana fibers can significantly contribute to lightening the mass of composites used in the fields of packaging, clothing, textile, and leisure.

### 3.1.2 Diameter

The diameter found ($80,125\mu mm$) is close to those in the literature for the same fibers. (Manorajan et al, 2013; Mbouyap et al, 2020). Banana fibers can significantly contribute to reducing the volume of composites used in the fields of packaging, clothing, and textile.

### 3.1.3 The water absorption Rate

The values of banana fibers water Rate found (table 2) are high (above 100%). This proves that these fibers are hydrophilic, similar to Sisal, Flax, Jute, Roselle, RC, NA, and AC.

This hydrophilic character of plant fibers is generally attributed to the presence of Hemicellulose due to its many ramifications (Baley et al, 2012; Jage et al, 2017).

This capacity to absorb water often leads to a decrease in the mechanical strength of the fibers, as well as a decrease in stiffness and the appearance of cracks in the Composite (Sango et al 2018; Jage et al, 2017) .This character could be improved by surface treatments and coupling agents (Baley et al, 2012).

### 3.1.4 The Moisture content

The moisture content (Table 2), between 11, 26%, and 13, 20% is close to those reported in the literature for the same species (Manorajan et al, 2013; Mbouyap et al, 2020; Indira et al, 2011). And, it is close to the literature values of moisture content found for the other vegetable fibers table 2.This sensibility to wet vapors is attribute to the presence of free hydroxyl groups in the chemical structure of these fibers (Aizi et al,2012; Uddin et al,2017).

### 3.2. The Chemical Composition

The results of the Chemical analysis of the Banana fibers studied and of other plants, fibers are presented in table 3. The studied fibers content Cellulose ($E_C$ %), Hemicellulose ($E_H$ %), Lignin ($E_L$ %), Pectin ($E_P$ %) Extractives ($E_S$%) and Ash ($E_{AS}$%). This corresponds to the description of the chemical composition of plant fibers in the literature, (Youmassi et al, 2017; Betene et al, 2020; Ntenga, 2007). Table 3 presents the Chemical Composition of some vegetable fibers found in the Literature as well as the Chemical Composition of the fibers of our study (Current Study). TABLE 3 Chemical Composition by the IPAT method of some plant fibers as well as of Banana fibers.

TABLE 3 Chemical Composition by the IPAT method of some plant fibers as well as of Banana fibers.

| Fiber | Chemical composition (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $\%E_{HO}$ | | $\%E_L$ | $\%E_P$ | $\%E_S$ | | $\%E_{AS}$ | Ref |
| | $\%E_C$ | $\%E_H$ | | | | $\%E_W$ | | |
| Banana | 37,5 | 27.6 | 15 | 5.15 | 0.2 | 12 | - | (Sauvageon,2017) |
| Banana | 59 | - | - | - | - | - | - | (Eloundou et al,2004) |
| Eucalyptus Saligna | 48.6 | 12.4 | 38.4 | - | 2.4 | 2.6 | 0.092 | (Youmassi et al,2017) |
| Cupressus lusitnica | 48.4 | 21.6 | 34.3 | 3.4 | - | 3.2 | 0.57 | (Youmassi et al,2017) |
| NA | 39.24 | 7.22 | 20.47 | 2.07 | 18.90 | | 2.18 | (Uddin et al, 2002) |
| RC | 68.2 | - | 15.6 | - | - | | - | (Ntenga,2007) |
| AC | 67.12-82 | 9.45-18 | 4.4-15.4 | 1.2 – 3 | - | | 0.9-2.7 | (Uddin et al, 2002) |
| Jute | 61 – 75 | 13.6-20 | 12 – 13 | 0.2 | | | - | (Youmassi et al,2017) |
| Lin | 64.1 | 16.7 | 2 | 1.8 | 3.9 | | - | (Baley et al, 2012) |
| Sisal | 65.8 | 12 | 9.9 | 0.8 | 1.2 | | - | (Youmassi et al,2017) |
| AC | 68.11 | 4.90 | 12.01 | 4.15 | 0.99 | 2.08 | 0.27 | (Betene et al,2020) |
| NA | 36.08 | 15.33 | 25.15 | 7.69 | 3.20 | 9.57 | 1.53 | (Betene et al,2020) |
| RC | 65.15 | 7.42 | 16.2 | 3.45 | 2.017 | 3.05 | 0.42 | (Betene et al,2020) |
| BF | 59,15333 | 14,42 | 10,7007 | 3,7897 | 1,41897 | 11 ,3863 | 0,55 | (Curent study) |

The Extractives content (11, 39 %) in the current study is close to that obtained by (Sango et al,2018) study's (12, 2 %) as given in table 3 for the same fibers and close to the Study of) for the Sisal fibers (12 %). The difference observed between the result of the current and the other results in table 3 is not a new fact in the behavior of the vegetable fibers. The Botanic origin, where the fiber comes in the plant, the maturity of the plant, the fiber's nature, the extraction process of the fibers, etc., can justify this difference. The Lignin content (14, 28 %) is less than the values found by and (Youmassi et al, 2017) close to those reported in table 3. The Lignin content in BF could be recovered and valorized in the production of Biofuels. The Pectin content (3, 79 %) is close to those reported in table 3. The Hemicellulose content (14, 42 %) is close to the ones reported in table 3 and higher than the values of the (Betene et al, 2020) recent Study's (4, 90 %) for the NA fibers, (7, 42 %) for AC, and close to (15, 33 %) for RC. For BF, the higher Hemicellulose content obtained correlates with its water absorption rate and confirms its more hydrophilic character compared to AC, NA, and RC fibers. The Cellulose content (59, 1533 %) is close to the Study of (Betene et al, 2020) (59 %) and close to other Studies in table 3. The value obtained shows that Cellulose is the predominant Content of the Banana fibers. According to the results in table 3, Cellulose is the predominant Content of all vegetable fibers studied. According to previous studies (Ntenga ,2007), the Cellulose content of plant fibers commonly used in composites has a-Cellulose content of 50 % - 85%. Based on those results, BF can be considered as fairly good reinforcements of Matrix-like Starch, (Stanojlavic, 2006) Polypropylene (Eloundou et al, 2004), in the Elaboration of Composites Materials. The low Ash content (0, 55 %) is close to those reported in table 3 and is by the data available in the literature. Also, Cellulose, Hemicellulose, and Lignin represent about 84 % of the dried mass of the fibers studied. They represent the major constituents of all vegetable fibers as shown in table 3. Pectin extractives and Ash represent the minor ones.

### 3.3 The Molecular Structure of Banana Fibers

The Spectra from the ATR- FTIR Analysis is shown in **Figure 8.** The parameters of its identification according to the Wavenumber $\sigma(Cm^{-1})$ are showed in **table 4.**

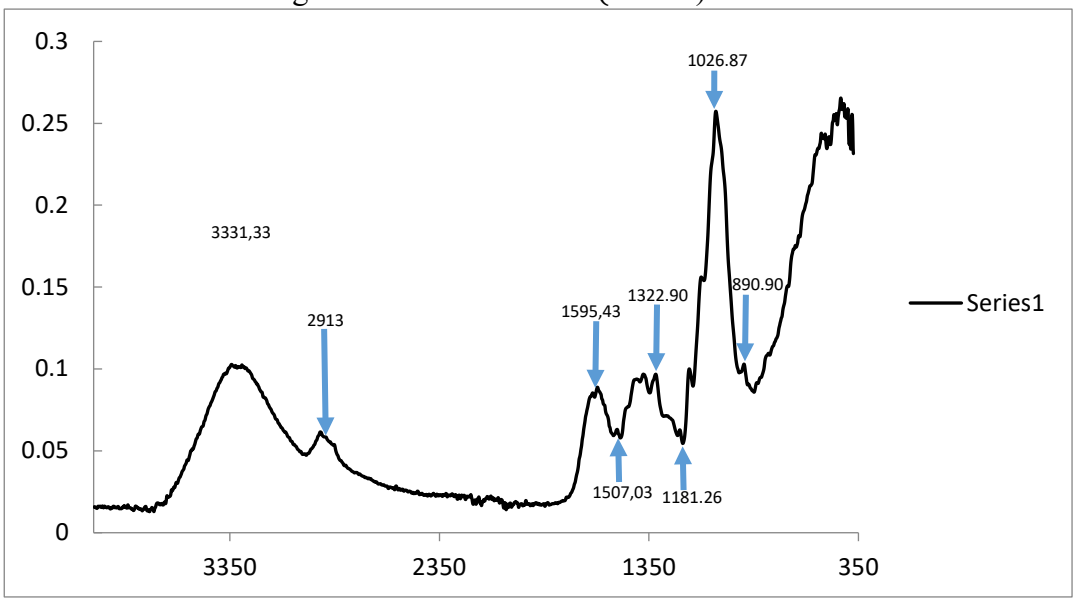


FIGURE 8 ATR-FTIR Spectra of Banana Fibers

TABLE 4 Characteristic positions of the FTIR bands of Banana Fibers of our Study and their Assignments

| Wavenumber ($Cm^{-1}$) | Assignments |
|---|---|
| 3331,33 | Elongation of OH from Cellulose and Hemicellulose |
| 2913 | Stretching of C-H and C$H_2$ of Cellulose |
| 2108,99 | Shearing of the $-OH$ bond in open water |
| 1595,43 | Symmetrical Stretching of C= $C$ of Lignin |
| 1507,03 | Bending of C$H_2$ in Cellulose and Symmetric Deformation of C$H_2$ in Cellulose |
| 1322,90 | Wagging (Cellulose and Hemicellulose) C-O Stretching vibration in ester |
| 1181,26 | C=C Stretching |
| 1026,87 | Elongation of the –$OH$and $C = O$ Bonds Of Cellulose |
| 890,90 | Symmetrical Stretching of C-H and O-H Bonds of Cellulose |

The FTIR Spectra data obtained in the present study are compared with earlier published reports in Table 5. TABLE 5 Comparison of FTIR Spectra data obtained in the present study with earlier published reports

| Hydroxyl bands (OH) en $Cm^{-1}$ | C= $O$ Stretching ($Cm^{-1}$) | C= $C$ Stretching ($Cm^{-1}$) | C-H Stretching ($Cm^{-1}$) | references |
|---|---|---|---|---|
| 3331,33 | 1026,17 | 1595,43 | 2913 | Present study |
| 3600-3100 | 1206 | 1600-1500 | 2912 | (Youmassi et al, 2017) |
| 3600-3100 | 1036 | 1700-110O | 2910 | (Guimaraes et al, 2009) |
| 3600-3100 | 1725 | 1600-1500 | 2900 | (Ibrahim et al, 20210) |
| 3600-3200 | 1644 | 1400-1300 | 2918 | (Barreto rt al, 2010) |
| 3400 | 1058 | 1635 | 2920 | (Becker et al, 2013) |
| 3600-3100 | 1654 | 1026-1244 | 2913 | (Celcino et al, 2014) |
| 3333 | 1728 | 1506 | 2917 | (Mewouli et al, 2020) |
| 3333,52 | 1030,40 | 1539 | 2916,83 | (Betene et al, 2020) |
| 3333,12 | 1032,18 | 1508 | 2929,15 | (Betene et al, 2020) |
| 3332,40 | 1031,27 | 1512 | 2996,52 | (Betene et al, 2020) |

TABLE 6 Cellulose crystallinity index of Banana fibers (BF) esteemed by FTIR and the earlier published reports.

| | Degree of crystallinity (%) | | | |
|---|---|---|---|---|
| Fiber | AC | NA | RC | BF |
| Z | 67,99 | 46,5 | 59,72 | 66,66 |
| Ref | (Betene et al, 2020) | (Betene et al, 2020) | (Betene et al, 2020) | (Current study) |

The results of table 4 show the positions of the well-defined remarkable peaks in the infrared spectrum obtained: 3331, 33 ; 2913 ; 2108,88 ; 1595, 43 ; 1507,03 ; 1322,90 ; 1181,26 ; 1026,87 ; 890,30 C$m^{-1}$ . The first one (3331, 33 C$m^{-1}$) represents the Hydrogen bonds of the

inter and intermolecular network of Cellulose as well as the free hydroxyl groups of Hemicellulose and Cellulose. It has been observed that this absorption band is characteristic of the presence of liquid water more or less bound to the polymeric network that constitutes the natural fibers (Deepa et al, 2011). The second peak (2913 C$\boldsymbol{m^{-1}}$) represents the methyl group ($-\boldsymbol{CH}$) present in Cellulose and Hemicellulose. The third peak (2108, 88C$\boldsymbol{m^{-1}}$) represents the shearing of $-\boldsymbol{OH}$ bond in open water bound to the polymeric network that constitutes the natural fibers (Tallah et al, 2014). The fourth peak (1595, 43 C$\boldsymbol{m^{-1}}$ ) is characteristic of the symmetrical aromatic elongation (C= $\boldsymbol{C}$ ) present in Lignin. The fifth peak (1507, 08 C$\boldsymbol{m^{-1}}$ ) represents the Bending of C$\boldsymbol{H_2}$ in Cellulose and a Symmetric deformation of C$\boldsymbol{H_2}$ in Cellulose (Parida et al, 2015). The sixth peak (1322, 90 C$\boldsymbol{m^{-1}}$ ) represents the Wagging (Cellulose and Hemicellulose) C-O Stretching vibration in ester and the aromatic group present in the polysaccharide (Moonart et al, 2019). The seventh peak (1181, 26 C$\boldsymbol{m^{-1}}$) is characteristic of C=C Stretching of the symmetrical elongation present in Lignin (Bilba et al, 2007).The eighth peak (1026, 87 C$\boldsymbol{m^{-1}}$) represents the Elongation of $-\boldsymbol{OH}$ and $\boldsymbol{C=O}$ bonds of Cellulose (Moonart et al, 2019), and ester group present in pectin, waxes, and hemicellulose. At last, the ninth one (890, 90 C$\boldsymbol{m^{-1}}$ ) characterizes the Symmetrical Stretching of C-H and O-H bonds of Cellulose (Parida et al, 2015). Compared with the results in table 5, the current study is close to the earlier published reports.

These results show that banana fibers (BF) are composed of Cellulose, Hemicellulose, Pectin, Lignin, Waxes, and Polysaccharides. They are therefore similar to known plant fibers such as Sisal, Coconut, and Jute.

Table 6 shows the Cellulose Crystallinity index of Banana fibers (BF) esteemed by FTIR and the earlier published reports. This result shows that the Crystallinity index (Z**)** of banana fibers esteemed by the FTIR is 8, 96 %. This shows that banana fibers are porous, more than AC, RC, and NA (Betene et al, 2020), hence their hydrophilic character.

The crystallinity index is the percentage of voids in a material. Banana fibers as shown in table 6 have a high crystallinity index; therefore, have a lot of voids that justify their hydrophilic character. This result is close to the study of (Betene et al, 2020).

### 3.4. The Thermal Properties

The thermal degradation curve (TG) and, its derivative (DTG) of Banana plant fibers measured under nitrogen flow are shown in figure 9.

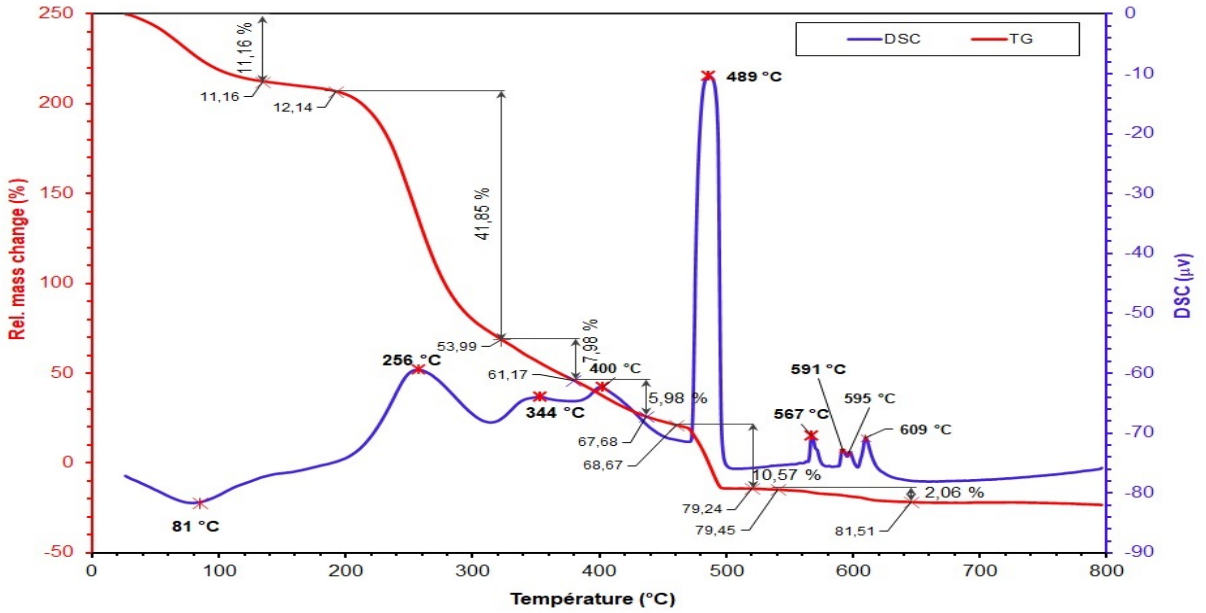


FIGURE 9 TGA and DSC Curve of Banana Fibers

TGA curve shows that the fibers understudy breaks down into six phases. This thermal Behavior is typical of plant fibers: Flax (Nadlene et al,2015), Jute(Nadlene et al,2015;Ouajai et al,2005) Sisal, Kenaf (Ouajai et al,2005) The first noticeable change starts at 10 °C and ends at 120 °C which is due to the evaporation of the fibers structural moisture and volatile extractives. The mass loss is 11, 16% in this phase. After dehydration of these fibers, it can be observed that the mass variation is almost constant up to 180 °C. The zone of thermal stability thus identified provides details on the maximum operating temperature of the Fibers under study (Teixeira et al, 2019), Table 7 shows the maximum operating temperature of Banana fibers obtained as well as those of certain plant fibers found in the literature.

The maximum operating temperature of Banana fibers as found in this study is 180°C. This value is close to those of table 7 and close to the study of (Raghavendra et al, 2017) for the same fibers. It could be taken into account during the molding while reinforcing matrix with banana fibers during the production of Composite Materials. In the second phase, a greater loss of mass was recorded (41, 85%) between 180 °C and 350 °C. This loss of mass is attributed to the Hemicellulose and Pectin between 180 °C and 250 °C (Nadlene et al,2015, than that of part of cellulose between 250 °C and 320 °C [40] The third phase between 320 °C and 409°C indicates the final loss mass of Cellulose (Teixeivera et al,2017) . The mass loss is 5, 98 %. In the fourth phase between 409 °C and 540°C, occurs the thermal decomposition of Lignin (Sauvageon, 2017) the loss of mass is 10, 57 %. In the fifth phase between 540 °C and 680 °C, occurs the final decomposition of Lignin; the mass loss is (2, 06 %). In the last phase above 680 °C, mass loss becomes very slow and a stable Residue is formed. A Residue of 20, 37 % of Banana fibers remains after heating at 800 °C.

Table 8 compares the degradation characteristics of the fibers understudy and with those of other kwon plant fibers.

TABLE 7 Maximum operating temperature of Banana fibers obtained as well as those of certain plant fibers found in the literature.

| Fiber | operating Temperature(°C) | Reference |
|---|---|---|
| Roselle | 200 | (Nadlene et al, 2015) |
| Sisal | 222 | (Nadlene et al, 2015) |
| Jute | 205 | (Nadlene et al, 2015) |
| Okra | 220 | (Nadlene et al, 2015) |
| Kenaf | 247 | (Nadlene et al, 2015) |
| AC | 205 | (Betene et al, 2020) |
| NA | 220 | (Betene et al, 2020) |
| RC | 285 | (Betene et al, 2020) |
| Banana | 200 | (Raghavendra et al, 2017) |
| Banana | 180 | - |

TABLE 8 Thermal Behaviors of some plant fibers as well as the ones of our study

| Fiber | Degradation Temperature (°C) of Cellulose | | Degradation (%) of cellulose | Residue (%) | References |
|---|---|---|---|---|---|
| | Initial | Final | | | |
| Sisal | 220 | 415 | 72 | 5,0 | (Ouajai et al, 2005) |
| Kenaf | 235 | 442 | 81,96 | 10,9 | (Ouajai et al, 2005) |
| Jute | 230 | 442 | 78,88 | 11,83 | (Ouajai et al, 2005) |
| Roselle | 220 | 400 | 76,66 | 10,3 | (Parida et al, 2015) |
| TC | 235 | 420 | 72 | 12,69 | (Mewouli et al, 2020) |
| Banana | 263 | 374 | 51, 5 | 24, 3 | (Deepa et al, 2011) |
| Banana | 220 | 400 | 39 | 20,02 | (Raghavendra et al, 2017) |
| Banana | 180 | 489 | 46, 15 | 20,37 | ( Current Study) |

It can be observed that Banana fibers have an important Residue compared to other plant fibers which could confirm a better Temperature Resistance. The values obtained in table 5 by the Thermal study are correlated with the values of the Chemical study of the studied fibers using the IPAT (Industrial Pup Analysis Technique) method (Cellulose content, Lignin, Hemicellulose, and Pectin).

## 4. CONCLUSION

The study examined the potential of Banana fibers as bio-based fibrous Reinforcements for Composites Materials used in various fields, including packaging. First, the Density, the Diameter, the Water absorption rate, and the Moisture content of Banana Fibers were evaluated following the recommendations of ASTEM D3800-792 (Nadlene et al, 2015) after extracting fibers from the pseudo-stems (Mbouyap et al,2020). The results obtained show that banana fibers have a small diameter so that they can significantly contribute to reducing the volume of composites used in the fields of packaging, clothing, and textile, the density (0,32-0,66g/C$m^3$) is small compared to other studies of other vegetable fibers; Banana fibers can significantly contribute to lightening the mass of composites used in the fields of packaging, clothing, textile, and leisure once more time; Banana fibers are hydrophilic because of the Hemicellulose's presence similarly as Sisal, Flax, Jute, Roselle, RC, NA, and AC; the water Rate found

is high (above 100%). ; they have the sensibility to wet vapors because of the presence of free hydroxyl groups in the chemical structure of these fibers, Moisture content is considerable ( 11, 26% - 13, 20% ). The Chemical Composition of the Banana fibers was obtained using the IPAT method on powdered fibers. The content in polysaccharides (Cellulose and Hemicellulose) is about 74%, which shows that these fibers could be interestingly used as Reinforcement Materials of Bio Source Materials or as raw materials in the paper industry. The Cellulose content (59, 15%) could give a high tensile strength; the Lignin content (10, 70%) could be recovered and valorized in the production of Biofuels. The Spectra recorded ATR-TFIR Analysis indicated the functional. According to the FTIR Spectra, the crystallinity index of Cellulose in BF is 66, 66%. The Thermal Character of those Banana fibers was studied using DSC and TGA. The Thermal degradation of the constituents was observed above 180°C. Thermal transition phases observed from DSC and TG/DTG thermos grams exhibited six major zones related to the degradation of the fibers structural moisture and volatile extractives (11, 16% of mass loss), Hemicellulose/Pectin, Cellulose, and Lignin the maximum operating temperature of the Fibers understudy was 180°C. Further Studies could focus on the tensile, XRD, and SEM Characterization of BF. The investigation could also be done on the Characterization of treated fibers, Reinforcement of starch Matrix Composites.

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**Conflict of Interest**

The authors declare no Conflict of Interest regarding the Publication of this Paper.

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