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RESEARCH ARTICLE

MORPHOLOGICAL AND STRUCTURAL CHARACTERIZATION OF NANOCELLULOSE EXTRACTED FROM BANANA PSEUDOSTEM WASTE

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Abstract

This research aimed to obtain nanocellulose (NCs) from banana pseudostem (BPs) biomass waste, and studying its morphological and structural surface characteristics. The extraction process involved treatments several physical, chemical, and mechanical, including degumming, delignification, acid hydrolysis, and ultrasonication. The banana pseudostem fiber (BPF), degummed banana fiber (DBF), banana cellulose fiber (BCF), and Nanocellulose (NCs) were analyzed using Fourier transform infrared (FTIR) and X-ray diffraction (XRD) spectroscopy. Scanning electron microscopy (SEM) was used to examine the morphology of BPF, DBF, and BCF, while transmission electron microscopy (TEM) was used to verify the format and size of NCs. The XRD results showed that the NCs had a crystallization index of 87.6%. TEM analysis revealed that the NCs contained network-connected structures as well as spherical shapes. The mean diameter and length of the NCs were 28.9 ± 16.2 nm and 166.2 ± 104.5 nm, respectively. The results of evaluating the lignocellulose content also showed that BPF consists of 55.4% cellulose, 22.3% hemicellulose, and 12.5% lignin, making it a valuable source of nanocellulose. The extraction of NCs from BPF holds great potential for applications in engineering and environmental science, particularly in the area of water treatment. Additionally, it contributes to sustainable development by managing agricultural waste and combating environmental pollution.

Keywords: Banana fiber, Cellulose, Acid hydrolysis, Ultrasonication, Nanocellulose.

1. Introduction

There is a great emphasis on the use and application of biomass materials and their by-products to achieve sustainable development and environmental conservation [1]. It is estimated that photosynthesis in a plant cell produces more than $10^{\wedge 11}$-$10^{\wedge 12}$ tons of cellulose every year [2]. As a result, interest in the exploitation of agricultural waste has increased in recent years, which has also led to increased interest in new materials derived from cellulose [3].

Cellulose-derived materials have become of great importance in various industrial sectors, including paper making, textiles, food packaging, cosmetics, pharmaceuticals and water treatment [4, 5, 6, 7]. As the demand for these applications and the need for new sources of cellulose increases, researchers must uncover alternative options to complement traditional sources. Therefore, agricultural waste has been considered an important source for cellulose production [7]. In addition to being readily available in nature, the use of agricultural wastes as a source of cellulose can also lead to obtaining nanocellulose with valuable properties [4, 8].

Nanocellulose is a biopolymer composed of cellulose nanofibers (CNFs) and cellulose nanocrystals (CNCs), each with a diameter of less than 100 nm [9]. CNCs have a purely crystalline structure, while CNFs contain crystalline and amorphous regions [10].

In addition to its unique properties, nanocellulose has captured the attention of many researchers due to its biodegradability and regenerative potential. It offers valuable advantages over untreated primary fiber, such as surface-to-volume ratio, hardness, elasticity, and mechanical and thermal properties. Also, it has abundant

availability, sustainable nature, and the possibility of extraction, which is attributed to its widespread use in various applications [11, 12, 13]. Previous studies have shown that nanocellulose has a surface rich in hydroxyl groups, which makes it easy to modify its surface and enhance its effectiveness [11,12].

There are different methods available to produce nanocellulose, including acid hydrolysis [14], mechanical process [15], and enzymatic hydrolysis [16]. These methods can be used either independently or in combination. However, acid hydrolysis is often preferred due to its simplicity and effectiveness in producing nanocellulose with excellent properties. Researches was shown that nanocellulose produced by acid hydrolysis has a higher crystallinity index compared to other methods [14,17,18].

Bananas are widely grown and consumed in various countries around the world. Until 2005, Yemen was one of the leading Arab countries in banana exports. According to data from the agricultural statistics center for the year 2019, the area cultivated with bananas was estimated at 9,431 hectares, or 10.5% of the total cultivated area in Yemen. However, a large amount of post-harvest banana waste is generated unutilized and is often disposed of by dumping, burning or disposing of it on farms, raising many environmental concerns [7,19]. Therefore, one potential way to enhance the value of banana biomass waste is to obtain nanocellulose (NCs) from this source. This is so because banana waste contains abundant lignocellulosic elements such as hemicellulose, cellulose and lignin, making it a valuable source for extraction [20].

Until now, there have been no research studies in Yemen which investigated the use of agricultural biomass waste, including banana waste, in the production of nanocellulose. Therefore, this research seeks to address this knowledge gap to provide a basis for future research in which these wastes are valued and utilized in sustainable development. In this research, nanocellulose was extracted from banana pseudostem fiber (BPF) by a series of processes, including degumming, delignification, acid hydrolysis and ultrasonication. In addition, a characterization of the samples was performed before and after the various treatments using Fourier transform infrared (FTIR) to study their structural and functional composition, X-ray diffraction (XRD) to determine the crystallinity index, and scanning electron microscope (SEM) to analyze the morphological. In addition, transmission electron microscopy (TEM) was used to characterize the surface morphology and study the dimensions of nanocelluloses (NCs).

2. Materials and Methods

2.1. Materials

Chemicals used in this study include Sodium Hydroxide (NaOH, 97%, HIMEDI, INDIA), Hydrogen Peroxide (H_2O_2, 6% w/w, SAMA PHARMA), Sodium Hypochlorite (NaClO, 5.5% w/w), Acetone (70.0% $(CH_3)_2CO$), and Ethanol (C_2H_5OH, 98.0%) purchased from a local market. Glacial Acetic Acid (100% CH_3COOH), Sodium Sulphite (Na_2SO_3), Sulfuric Acid (98.0% H_2SO_4), and Sodium Chloride (NaCl) were obtained from the university laboratory and are produced by MERCK and LOBA CHEMIE, INDIA.The chemicals were used without purification.

2.2.1. Biomass Collection and Pre-treatment

Banana pseudostem fiber (BPF), scientifically known as "***Musa SPP***", has been used in the nanocellulose extraction process. Banana pseudostem waste (BPs) used in this study was collected from Ba' Tise Area, Abyan Governorate, Yemen. The BPF was extracted using a debarking machine. BPF were sorted, cleaned four times using tap water and hot distilled water, and cut into small pieces 2–3 cm in length. Finally, the BPF was dried at 105˚C until the weight was constant. It was stored in a tightly closed container [21, 22].

2.2.2. Determination of Lignocellulose components

The chemical content of cellulose, hemicellulose, and lignin in banana pseudostem fiber (BPF) was determined according to the method used in the literature [23, 24]. To remove impurities and waxy materials, the 10 g from the cut pieces of BPF was boiled in water at 100˚C for 1 hour. Next, the dried sample was boiled in a 1 w/v % NaOH solution at 80˚C for 2 hours. After boiling, the sample was washed with distilled water and dried at 105˚C.

2.2.2.1. Determination of Holo-cellulose

3 g of dried sample was mixed and placed in a flask. Next, 160 mL of distilled water, 0.5 mL of glacial acetic acid (CH_3COOH), and 1.5 g of sodium chloride (NaCl) were added. The flask was heated to 75˚ C using a water bath for 1 h, to which an additional 0.5 mL of glacial acetic acid and 1.5 g of NaCl were added twice at hourly intervals. The flask was then cooled to <10˚C in an ice bath. The holo-cellulose was washed and filtered sequentially using Acetone $(CH_3)_2CO$), Ethanol (C_2H_5OH), and distilled water. Finally, the collected holo-cellulose was transferred to a crucible, dried in an oven at 105˚C, and weighed.

2.2.2.2. Determination of Cellulose

To determine the cellulose content, dried holo-cellulose was mixed with 10 ml of 17.5 w/v % NaOH solution in a beaker and stirred vigorously with a glass rod. More NaOH solution was added to the mixture every five minutes for thirty minutes at 20˚C. Next, 33 ml of distilled water was added to the mixture and left for 1 hour. The residue was then filtered and transferred to a crucible, where it was sequentially washed with 100 mL of 8.3 w/v % NaOH, 200 mL of distilled water, and 15 mL of 10 v/v % CH_3COOH. Then it was washed with deionized water until it neutralized. Finally, the collected cellulose was dried at 105˚C and weighed.

2.2.2.3. Determination of Hemicellulose

The determine of hemicellulose was determined using the formula (1):

Hemicellulose = Holo-cellulose - Cellulose ..... (1)

2.2.2.4. Determination of Lignin

A 2-gram sample was mixed with 15 ml of 72 v/v % sulfuric acid (H_2SO_4). The mixture was stirred for two and a half hours at a temperature of 25˚C, and then diluted with 200 ml of distilled water. The resulting solution was then boiled for two hours and then left to cool. After a 24 hours period, the lignin was transferred to a crucible and washed repeatedly with hot water. The collected lignin was then dried at 105˚ C and weighed.

2.2.3. Extraction of Nanocellulose (NCs)

2.2.3.1. Degummed process

The BPF was degummed by refluxing on a hot plate for 2 hours in a (12% w/v) NaOH. Then, it was treated with a (1% w/v) H_2O_2 for 2 hours. The sample was neutralized using (1% v/v) CH_3COOH and treated again with a (6% w/v) NaOH, followed by a (1% w/v) H_2O_2. Following neutralization, the sample was rinsed thrice using hot distilled water. The fiber-to-solution ratio was 1:15 (1 g of BPF into 15 mL of NaOH or H_2O_2). Next, they were dried in an oven at 60 ˚C for 16 hours, and the size of the degummed banana fiber (DBF) was reduced by grinding and sieving them using a sieve [21].

2.2.3.2. Delignification process

The DBF was delignified by boiling it in a (2% w/v) Na_2SO_3 for 10 minutes, and bleaching in a (5% w/v) NaOCl for 30 minutes on a hot plate with magnetic stirring at a speed of 500 rpm. Before bleaching, the pH of NaOCl was adjusted to 4-5 by adding 5% v/v acetic acid (CH_3COOH). The fiber-to-solution ratio was 1:10 (1g of DBF in 10 mL of Na_2SO_3 or NaOCl/CH_3COOH). This delignification process was repeated twice until the fiber appeared completely white, and then it was washed three times with hot distilled water. Next, the delignified fiber was soaked in a (17.5% w/v) NaOH for 1 hour to obtain pure cellulose [21, 25]. It was then neutralized with a (10% v/v) CH_3COOH and rinsed with deionized water many times until the pH of the filtrate reached (pH=7). Finally, the banana cellulose fiber (BCF) were washed with (95 % v/v) C_2H_5OH. The sample was dried for 16 hours in the oven at 60˚C.

2.2.3.3. Acid Hydrolysis and Ultrasonication

In this process, 15 grams of BCF powder were mixed with (60 % v/v) H_2SO_4, the fiber-to-solution ratio was 1:10 (1g of BCF into 10 mL of H_2SO_4) [26,27]. The mixture was hydrolyzed at 45˚C for 90 minutes with constant stirring using a magnetic stirrer at 500 rpm. The reaction was then quenched by adding twice the amount of cold deionized water (10˚C) and neutralized and brought to (pH=6-7) with (2 % w/v) NaOH [26, 28]. The sonication for the suspension (1% w/v) was done by ultrasonic bath (50-60 kHz) for 90 minutes, followed by centrifugation at 6000 rpm for 15 minutes many times with DI water. Then the sample was dried for 48 hours at 80˚C [21]. The extraction process is illustrated in figure 1.

2.2.4. Characterization

2.2.4.1. Scanning Electron Microscopy (SEM)

To analyze the morphological and surface characteristics of BPF, DBF, and BCF, a scanning electron microscope (SEM-JEOL, JSM-5200, Tokyo, Japan) was used. The samples were coated with gold using a SPI-Module TM Sputter Coater (USA) in a vacuum evaporator at an accelerating voltage of 25 kV.

2.2.4.2. Transmission Electron Microscopy (TEM)

To analyze the surface morphology and nanoscale dimensions of the NCs sample, a TEM - JEOL JEM-100CX Il was used, following the preparation method specified by Bozzola & Russell (1999) [29]. The morphology and size of the NCs were further examined through TEM imaging (JEOL JEM-1400) operating at an acceleration voltage of 80 kV across various magnification levels. The sample was dissolved in distilled water and dispersed. A drop of NCs suspension was then deposited on a carbon-coated copper grid which was dried and observed for imaging. The length and diameter of NCs were measured by an image processing analyses program (Image J), using TEM images.

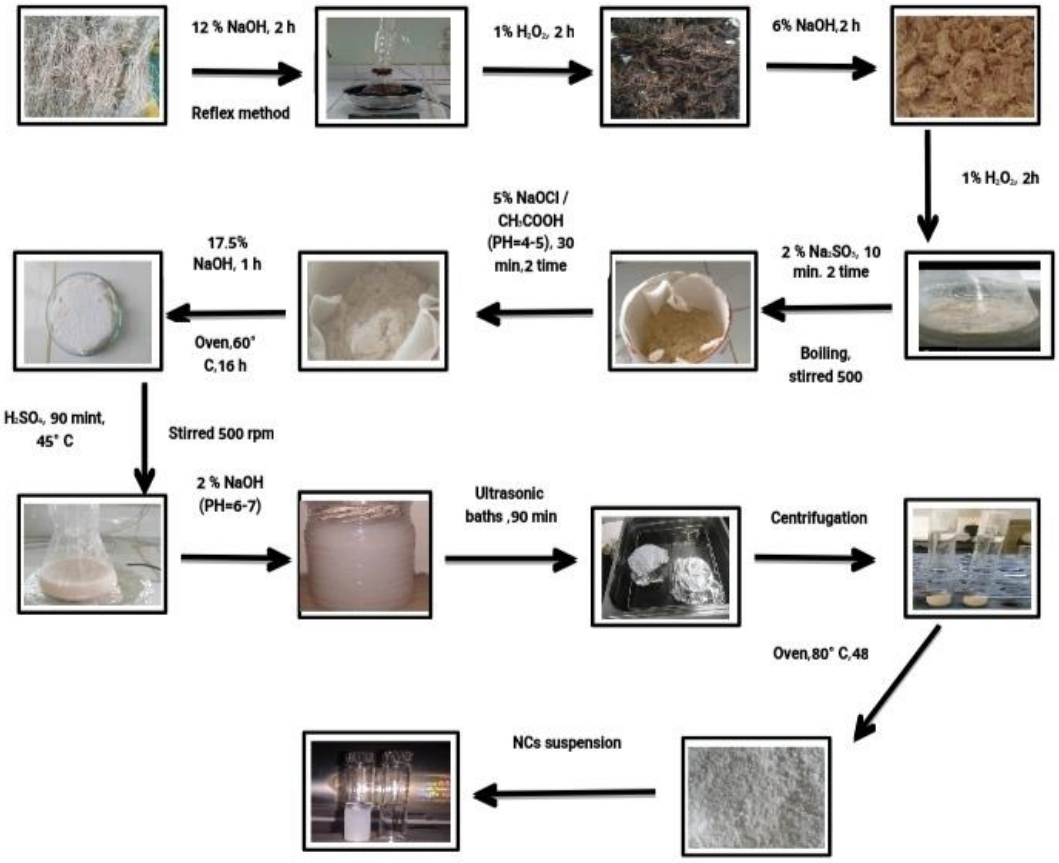

Fig. 1: A schematic illustration summarizing the extraction method used for NCs from BPF.

2.2.4.3. Fourier Transform Infrared Spectroscopy (FTIR)

To identify the chemical and functional properties of BPF, DBF, BCF and NCs, FTIR spectra were analyzed with a Nicolet-380 FTIR spectrophotometer. The analysis was conducted with KBr in a wave-number range of 4000 to 400 cm^{-1} and a resolution accuracy of 4 cm^{-1}.

2.2.4.4. X-ray Diffraction (XRD)

To analyze the crystallization degree of BPF, DBF, BCF and NCs, X-ray diffraction (XRD) was used. Recording the sample patterns using a mono-chromatic Philips PW 1710 diffractometer with a scanning rate of 1 degree per second and a step size of 6 degrees per minute was used. Measurements were taken in the range of 4<2θ<90 degrees, using monochromatic CuKα radiation (λ = 1.541838 Å). A voltage of 40 kilovolts and an influx of 30 milliamps were applied. The crystallinity index (CI) was determined using the Segal method [30], which involves measuring the peak height (I_{200}) at 200 and the minimum density (I_{am}) between the peaks 200 and 110 as shown in Eq. (2) [31].

$$CI\ (\%) = \frac{I_{200} - I_{am}}{I_{200}} \times 100 \quad \text{..... (2)}$$

3. Results and Discussions

3.1. Lignocellulose components of Banana pseudostem fiber (BPF)

This study reveals that BPF contains a high percentage of cellulose (55.4%) with relatively low levels of other lignocellulose components (22.3% Hemicellulose, 12.5% lignin). The banana pseudostem waste examined in this study is considered a valuable source of nanocellulose due to its high cellulose content. Table 1 compares the lignocellulose constituents of BPF with previous research studies [32, 33, 34].

Table 1: Comparison of lignocellulose components of BPF with previous studies

No.	Cellulose (%)	Hemicellulose (%)	Lignin (%)	References
4	55.4 ± 3.30	22.3 ± 1.50	12.55 ± 2.01	Present Study
1	60.16	20.36	13.24	[32]
2	57	24	12	[33]
3	55	23	10	[34]

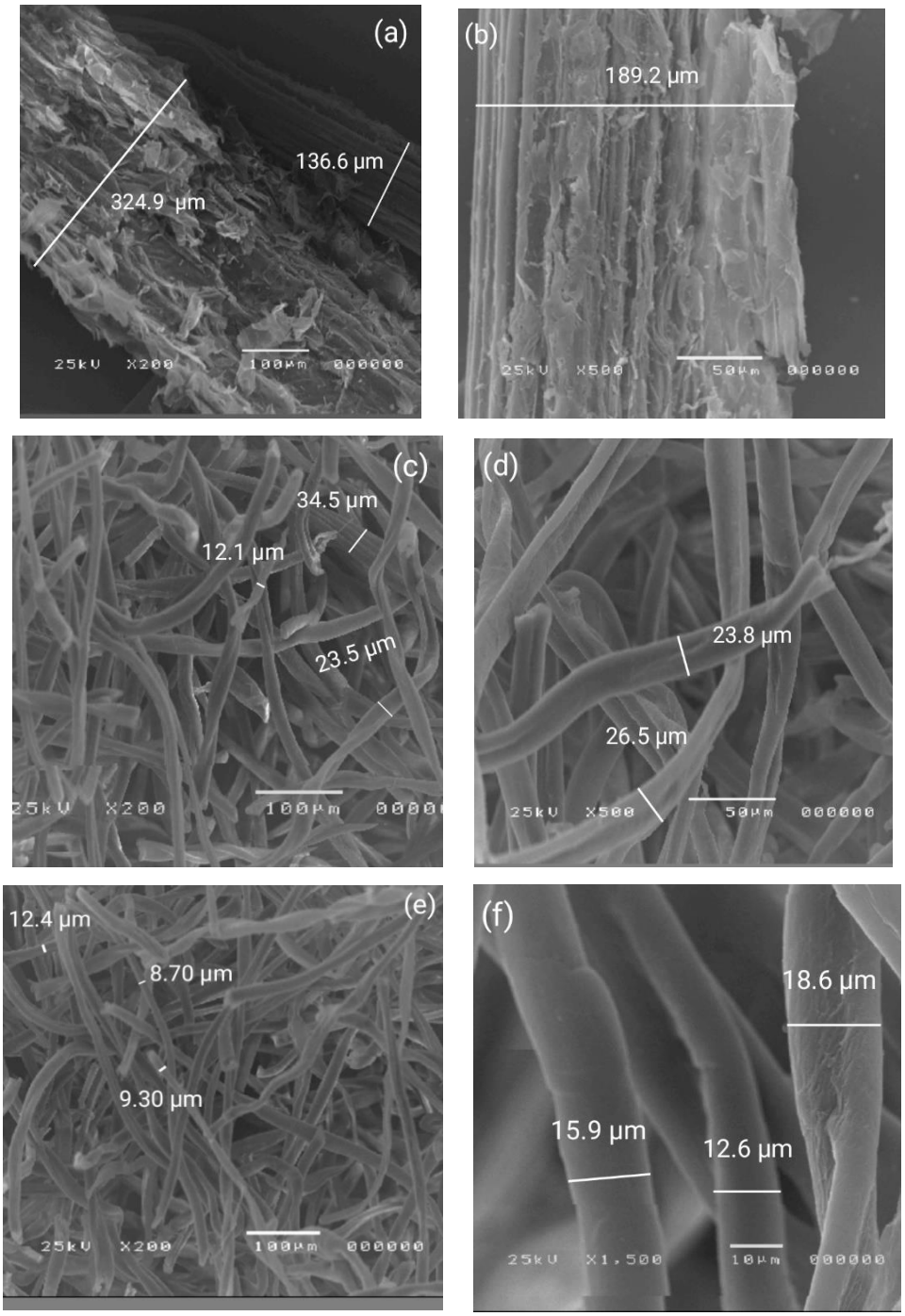

Fig. 2: The SEM images of a, b) banana pseudostem fiber (BPF), c, d) degummed banana fiber (DBF), and e, f) banana cellulose fiber (BCF).

3.2. Characterization

3.2.1. SEM Characterization

To analyze changes in the surface morphology of the banana Pseudostem fiber, as well as the fiber after degumming and cellulose, they have been checked using a scanning electron microscope (SEM). Figure 2 (a, b, c, d, e, f) displays the SEM images of the BPF, DBF, and BCF samples.

Figure 2 (a, b) displays untreated banana pseudostem fiber, which consists of large bundles with diameters ranging from 324.9 - 136.6 µm. These bundles have a sound structure but are coated with impurities such as hemicellulose, lignin, pectin, waxes, and other substances. After undergoing degumming process, untreated fiber bundles were separated into individual fine fibers with minimal residue, likely due to the presence of condensed lignin. The change in fiber diameter is evident in figure 2 (c, d), where the diameter of the BPF decreased significantly from 324.9 - 136.6 µm to 34.50 - 12.10 µm. This confirms that the alkaline and peroxide treatment effectively removed waxes, pectin and most of the hemicellulose and lignin. This is

consistent with what was reported in the study by Syafri et al. [15], Lacaran et al. [21] and Merais et al. [26]. The delignification process enhanced the texture of the fibres and imparted a glossy appearance by eliminating the residual lignin. Furthermore, there was a reduction in the fiber diameter from 34.50 - 12.10 µm to 23.32 - 6.10 µm, as displayed in figure 2 (e, f).

Overall, the results demonstrate the effectiveness of the refluxing method in removing non-cellulosic materials and speeding up fibre processing by re-condensing and utilizing steam in the process. Additionally, the treatment process has effectively reduced the fiber diameter of BPF and produced fine individual cellulose fibres. The processed BCF appears as smooth, regular threads with consistent size and texture [16, 18].

The corresponding dimensions of the BCF were evaluated using an image analysis program (Image J) of SEM microscopic images, with at least 100 microfibrils analyzed. The results showed that BCF consisted of individual microfibrils with an average diameter of 13.80 ± 4.20 µm. Figure 3 presents present the histogram of the diameter distribution of BCF.

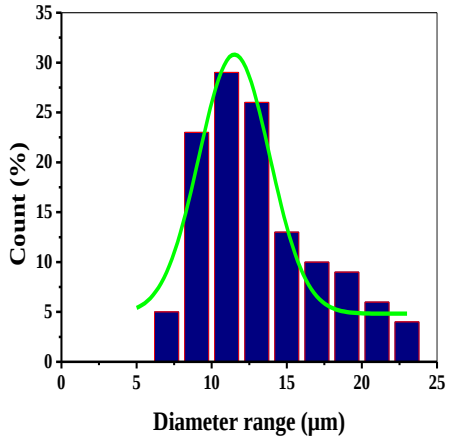

Fig. 3: Diameter distribution of BCF

3.2.2. TEM Characterization

The morphological features of the nanocellulose (NCs) produced from banana cellulose fiber (BCF) was analyzed using TEM. Figure 4 (a, b, c) displays the surface morphology of NCs observed by TEM and their nanoscale dimensions.

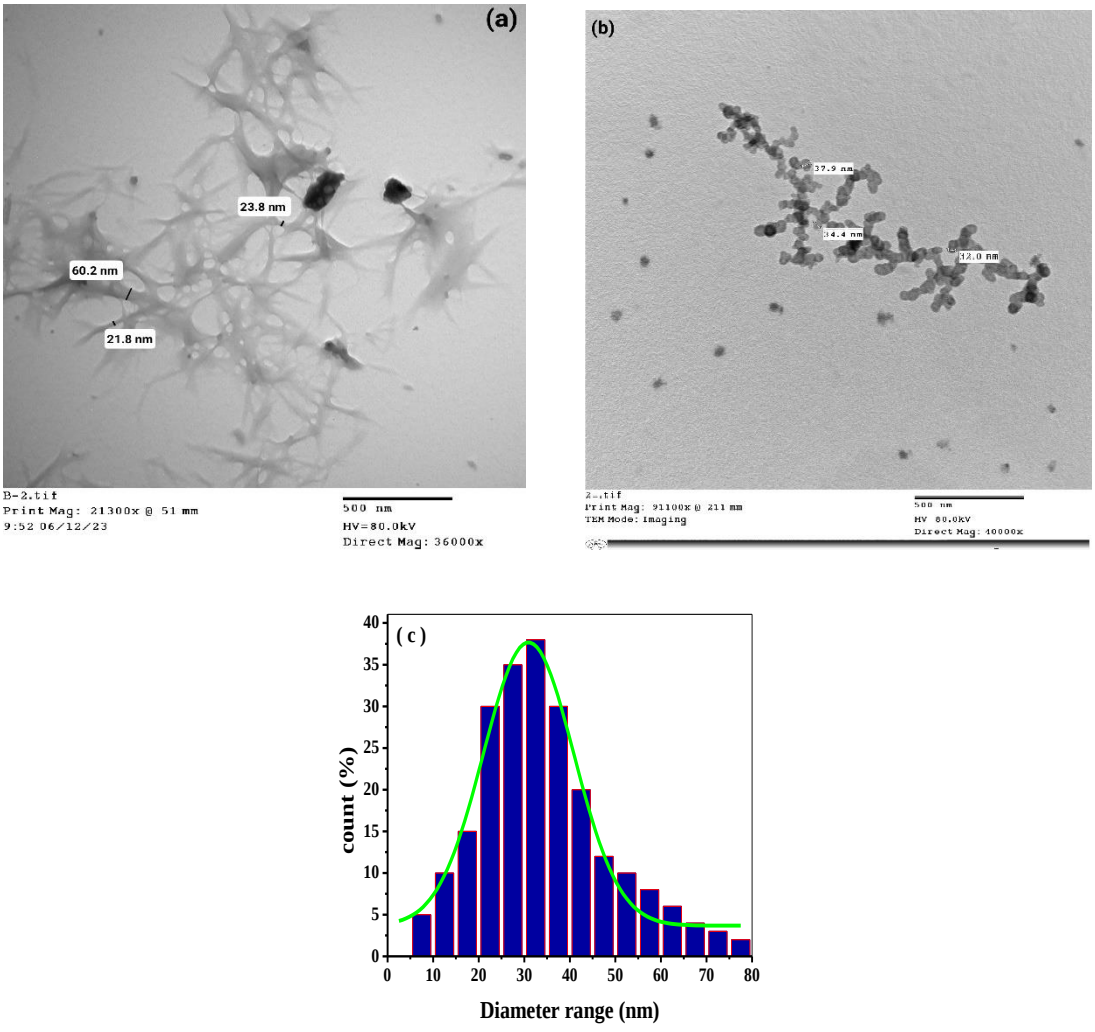

Fig. 4: The TEM images of NCs (a, b) at 17200 ×, and 91100 × magnification. The accompanying figure (c) below the TEM images represent the distribution of fiber diameter size of the NCs (a).

Figure 4 (a) displays a microscopic image of a fibrous mesh composed of interwoven strands of nanocellulose (NCs), as observed through the TEM-JEOL JEM-100CX II using the Bozzola and Russell method. The presence of the aggregated nanofibril network can be attributed to the suspensions drying process on the carbon layer that covers the copper grids, or it could indicate the natural state of the suspension. Moreover, this could result due to the strong hydrogen bonding between the nanofibrils. Certain regions within the image display distinct boundaries, and a total of 200 fibrils were analyzed using Image J software to determine the mean diameter and length of the nanocellulose. The results revealed that the mean diameter was 28.9 ± 16.2 nm, while the mean length was 166.2 ± 104.5 nm. Figure 4 (c) below the TEM images shows the diameter distribution of the NCs.

Additionally, figure 4 (b) show cases of TEM-JEOL JEM-1400 images, which reveal the presence of spherical-shaped nanocrystals cellulose with an average diameter of 37.23 ± 6.93 nm. The formation of spherical nanocrystals cellulose can be attributed to self-attraction of short cellulose rods via intermolecular hydrogen bonding, a process that may be affected by ultrasonic treatment [35]. Similar findings have been reported in previous studies conducted by Chen et al. [35], Trilokesh & Uppuluri [36], Azrina et al. [37]and Sihag et al. [38].

3.2.3. FTIR Characterization

The chemical compositions and functional properties of the banana pseudostem fiber, as well as the fiber after degumming, cellulose and nanocellulose were analyzed using FTIR. Figure 5 (a, b, c, d) illustrates the FTIR spectra of BPF, DBF, BCF, and NCs.

Figure 5 (a, b, c, d) illustrates the FT-IR spectra of BPF, DBF, BCF, and NCs derived from banana pseudostem waste. The broad band observed between 3422.32 - 3347.78 cm^{-1} is associated with the stretching vibrations of O-H and shows slight variation from the raw material to the treated samples, indicating changes in moisture content due to cellulose chain rupture. Additionally, there are distinct spectral features observed between 2924.49 - 2894.55 cm^{-1}, this expansion could be due to the vibration of the C-H bonds. The band at 1632.88-1640.50 cm^{-1} indicates the absorption of water, and similar findings have been noted by Meng et al. [39] and Gopinathan et al. [40].

The bands observed at 1732.23 cm^{-1}, 1480.36 cm^{-1}, 1259.35 cm^{-1}, and 2850.60 cm^{-1} in BPF correspond to the carbonyl units (C=O), intertwined vibration of (CH_2), stretching of the aryl group (C–O), and symmetric stretching vibration of C-H (methyl and methylene), respectively. These bands represent the stretching vibrations of lignin and hemicellulose. After the degumming and delignification process, these bands disappeared, which is consistent with similar results observed by Zope et al. [41] and Evans et al. [42].

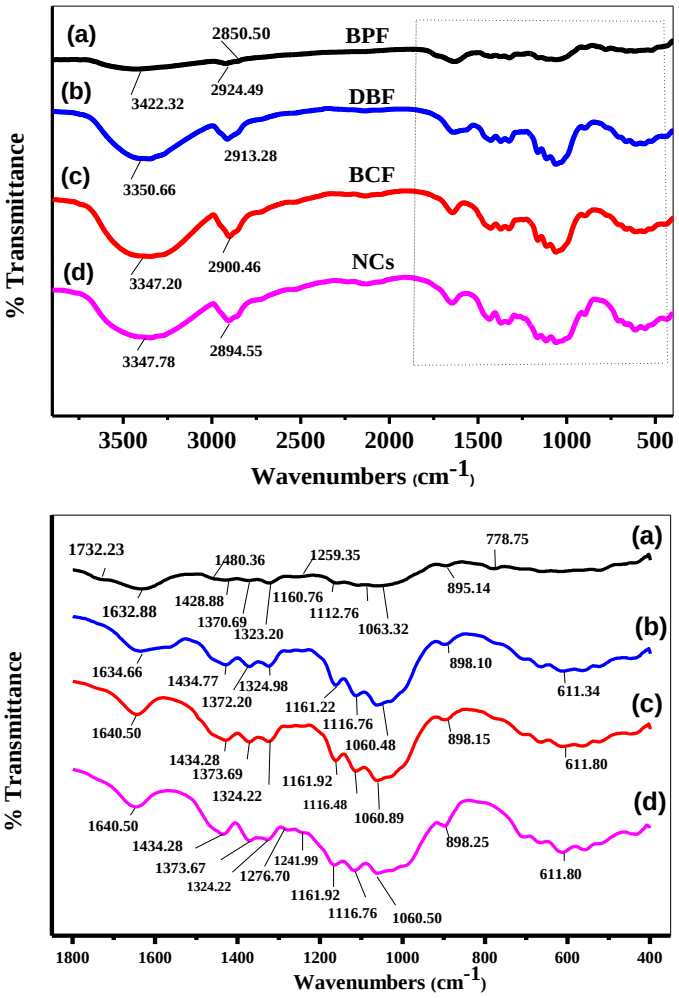

Fig. 5: The FTIR spectra of the a). banana pseudostem fiber (BPF), b). degummed banana fiber (DBF), c). banana cellulose fiber (BCF), and d). Nanocellulose (NCs).

Additionally, specific signals related to cellulose are detected at 1370.68 - 1373.67 cm^{-1} in BCF and NCs (C-H bending vibration), 1323.20 and 1324.22 cm^{-1} in BCF and NCs (CH_2 wagging), 1160.76 - 1161.92 cm^{-1} (Asymmetric vibration of C-O-C), 112.76 – 1116.76 cm^{-1} (Stretching vibration of C-O-C pyranose ring), 1063.32 – 1060.50 cm^{-1} (Stretching vibration of C-O), and 895.14 – 898.25 cm^{-1} (Symmetric vibration of C-H from β-glycosidic linkages) , consistent with similar results observed by Chen et al. [35], Samsudin et al . [43], Moosavinejad. [44], Mamudu et al. [45] and Yue et al. [46].

The appearance or increase in the intensity of certain bands, such as the 1276.70 cm^{-1}, 1241.99 cm^{-1}, and 611.80 cm^{-1} bands in the NCs spectrum, is attributed to the S=O vibration resulting from the esterification reaction, as stated in the study Mamudu et al. [45] and Ramos-Vargas et al. [47].

3.2.4. XRD Characterization

We analyzed the crystallization degree of the banana Pseudostem fiber, as well as the fiber after degumming, cellulose and nanocellulose using X-ray diffraction (XRD). Figure 6 (a, b, c, d) illustrates the XRD patterns of BPF, DBF, BCF, and NCs.

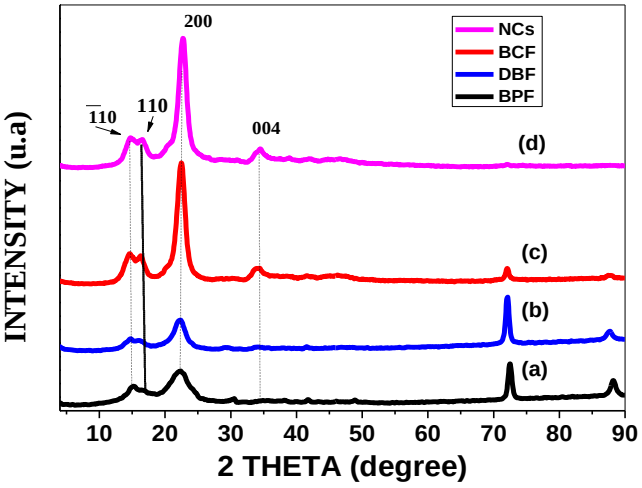

Fig. 6: The X-ray diffraction patterns for a). banana pseudostem fiber (BPF), b). degummed banana fiber (DBF), c). banana cellulose fiber (BCF), and d). Nanocellulose (NCs).

The crystalline indexes were calculated for BPF, DBF, BCF, and NCs using Eq. (2). The results are shown in Table 2.

Table 2: The crystalline indexes of banana pseudostem fiber (BPF), degummed banana fiber (DBF), banana cellulose fiber (BCF), and Nanocellulose (NCs).

No	Sample	Crystallinity Index (%)
1	BPF	59.3
2	DBF	74.3
3	BCF	82.9
4	NCs	87.6

Figure 6 (a, b, c, d) illustrates the XRD patterns of the initial BPF sample as well as the DBF, BCF, and NC samples after undergoing various treatment steps. The distinctive diffraction peak at $2\theta = 22.6^{\circ}$ in the samples patterns is characteristic of cellulose (I). The XRD analysis revealed prominent intensity peaks at $2\theta = 14.7^{\circ}$, 16.4°, 22.6°, and 34.3° in the BCF sample, indicating the presence of cellulose from the cellulose (I) structure. The XRD analysis also indicated similar diffraction patterns of nanocellulose samples, suggesting that the crystal structure remained intact after acid hydrolysis and mechanical disturbance caused by ultrasound.

The crystallinity of BPF is affected by the treatment processes used to extract NC, as we notice a high crystallinity index (Cl) from 59.3% to 74.3% after degumming and further increased to 82.9 % after the delignification process. This increase can be attributed to the dispersion and removal of non-cellulosic components found in the amorphous phases of BPF, which result from the alkali and peroxide treatments. Additionally, the delignification process helped to remove remaining lignin [21, 48].

After undergoing acid hydrolysis and mechanical perturbation with ultrasound, the crystalline index increased even further to 87.6%. This indicates that ultrasound plays a role in homogenizing and removing the amorphous phase of NCs and similar findings have been noted by Nie et al. [16] and Sosiati et al. [18]. These findings are also consistent with the results obtained from before Kumar et al. [32], in their study on isolating nanofibers cellulose from banana Pseudostem residue. However, they differ from the study of Gopinathan et al. [40], who isolated cellulose nanofibers from banana pseudostem fiber using an acid hydrolysis process directly after alkaline treatment of the crude fibers.

4. Conclusions

Nanocellulose was obtained from BPF in this study successfully through a series of processes including degumming, delignification, acid hydrolysis and ultrasonication. This methodology effectively removes non-cellulosic materials, resulting in nanocellulose with a crystallinity level of more than 20% higher than the BPF, and this increase in crystallinity index was confirmed by XRD analysis. In addition, TEM analysis demonstrates that the isolated nanocellulose particles have a web-like network structure and a spherical morphology with an average diameter of 37.23 ± 6.93 nm. The successful extraction of NCs from BPF presents opportunities for the effective utilization of banana pseudostem (BPs) waste, which otherwise poses environmental threats when burned or left on farms. In addition, it is a promising method for agricultural waste management. Nanocellulose extracted from BPF holds great potential for application in environmental sciences, especially in the fields of wastewater purification and pollution mitigation.

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مقالة بحثية

التشخيص المورفولوجي والهيكلي للنانوسليلوز المستخلص من مخلفات جذع الموز الزائف

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المُلخّص

يهدف هذا البحث إلى الحصول على السليلوز النانوي (NCs) من مخلفات الكتلة الحيوية لجذع الموز الزائف (BPs)، ودراسة خصائص سطحه المورفولوجية والهيكلية. تضمنت عملية الاستخلاص سلسلة من المعالجات الفيزيائية والكيميائية والميكانيكية، بما في ذلك إزالة الصمغ وإزالة اللجنين والتحلل المائي الحمضي والموجات فوق الصوتية. تم تحليل ألياف جذع الموز الزائف (BPF)، وألياف الموز منزوعة الصمغ (DBF)، وألياف سليلوز الموز (BCF)، والنانوسليلوز (NCs) باستخدام التحليل الطيفي للأشعة تحت الحمراء لتحويل فوريه (FTIR)، وحيود الأشعة السينية (XRD). كما تم استخدام المجهر الإلكتروني الماسح (SEM) لفحص مورفولوجية BPF وDBF وBCF، بينما تم استخدام المجهر الإلكتروني النافذ (TEM) للتحقق من تشكل وإبعاد. NCs أظهرت نتائج XRD أن NCs لديها مؤشر تبلور قدرة 87.6%. كشف تحليل TEM أن NCs لديها هياكل ليفية شبكية متصلة، بالإضافة إلى أشكال كروية. كان متوسط قطر وطول النانوسليلوز 28.9 ± 16.2 نانومتر و166.2 ± 104.5 نانومتر، على التوالي. أظهر تقييم محتوى اللجنوسليلوز أيضًا أن BPF يحتوي على 55.4% سليلوز، 22.3% هيميسيلولوز، و12.5% اللجنين، مما يجعله مصدرًا قيمًا للنانوسليلوز. يحمل استخراج NCs من BPF إمكانات كبيرة للتطبيقات في العلوم الهندسية والبيئية، وخاصة في معالجة المياه. بالإضافة إلى ذلك، فإنه يساهم في التنمية المستدامة من خلال إدارة النفايات الزراعية ومكافحة التلوث البيئي.

الكلمات المفتاحية: ألياف الموز، السليلوز، التحلل المائي الحمضي، الموجات فوق الصوتية، النانوسليلوز.

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