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Application of Fourier Transform Infrared Spectroscopy and X-Ray Diffraction in the Characterization of Bamboo Stalks

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Abstract: Bamboo stalks have recently attracted increasing attention as sustainable agricultural by-products because of their rapid growth cycle, self-regeneration ability, and low maintenance requirements. Bamboo is widely distributed across tropical and subtropical regions of Nigeria, with Oxytenanthera abyssinica being one of the most dominant species. In spite of its extensive use in construction and craft applications, the material potential of bamboo stalks for engineered wood products remains underexplored. This study investigates the suitability of bamboo stalks as an eco-friendly precursor for particleboard production using Fourier Transform Infrared Spectroscopy (FTIR) and X-ray Diffraction (XRD) methods. FTIR analysis result revealed that characteristic absorption bands associated with cellulose, hemicellulose, and lignin, with prominent peaks observed at 1737 cm^{-1}, 1511 cm^{-1}, and 1379 cm^{-1}. Also, XRD analysis result showed distinct diffraction maxima at 2θ angles of approximately 15° and 22°, indicative of a high degree of cellulose crystallinity. Chemical composition analysis established that the bamboo biomass contained 52.61% cellulose, 19.16% hemicellulose, and 24.27% lignin, with negligible amounts of extractives (2.21%) and ash (1.75%). The combined FTIR and XRD results prove that bamboo stalks possess favourable chemical and structural properties, supporting their potential application as sustainable raw materials for particleboard manufacturing.

Keyword: Bamboo Stalks, Fourier Transform Infrared Spectroscopy, FTIR, Particleboard, Sustainable Materials, X-Ray Diffraction.

INTRODUCTION

The growing demand for environmentally sustainable materials has make stronger research into the use of agricultural residues for value-added products. Biomass-based materials are increasingly being discovered as alternatives to conventional wood resources in response to deforestation and increasing environmental concerns (Gautam et al., 2023). According to Shu et al. (2020), bamboo, a fast-growing perennial grass, has appeared as a promising renewable resource because of its short maturity period of approximately four to five years and its excellent mechanical performance.

Bamboo displays high strength-to-weight ratios, dimensional stability, and the ability to regenerate after harvesting, making it suitable for repeated industrial utilization (Goh et al., 2020). It has been reported by Emenike et al., 2022 that traditionally, bamboo has been employed in furniture production, construction, paper manufacturing, and energy generation. However, the scientific understanding of its chemical and crystalline structure is essential for expanding its utilization in engineered wood products such as particleboards.

The characterization of material plays a critical role in determining the performance of lignocellulosic feedstocks. Fourier Transform Infrared Spectroscopy (FTIR) offers insight into the functional groups and chemical bonding existing within biomass materials, while X-ray Diffraction (XRD) make known information about crystallinity and molecular ordering, predominantly of cellulose microfibrils (Jakob et al., 2022). Previous studies have established the effectiveness of FTIR and XRD in characterizing bamboo-based materials for adsorption, composite, and construction applications (Beriber et al., 2023; Alencar et al., 2023).

This study uses FTIR and XRD techniques to characterize bamboo stalks and appraise their suitability as a sustainable precursor for particleboard production. By means of correlating chemical composition with structural characteristics, the study aims to provide scientific justification for the utilization of bamboo biomass in eco-friendly engineered wood products.

METHOD

Raw Materials Collection and Preparation

Bamboo stalks utilized in this study were obtained from a local forest agent in Benin City, Nigeria which is shown in Figure 1. The stalks were thoroughly washed to remove adhering impurities including dust and sand and subsequently, were air-dried for 30 days to attain an average moisture content of approximately 12% (Amenaghawon et al., 2016a). The dried bamboo stalks were milled using a laboratory hammer mill and sieved to obtain particles of 0.8 mm size.

To achieve the improvement of bonding performance, alkaline mercerization followed by silane treatment were carried out to reduce lignin content. The biomass was soaked in 1 M NaOH for one (1) hour, neutralized with acetic acid, rinsed with deionized water until neutral pH was achieved, and afterward treated with a methanol-water silane solution preceding to drying (Nwobi-Okoye et al., 2020).

Figure 1. Bamboo stalks used in the characterization

Chemical Composition Analysis

The standard National Renewable Energy Laboratory (NREL) analytical procedures was used to determined cellulose, hemicellulose, and lignin contents of the bamboo biomass (Sluiter et al., 2012). A refractive index detector was used to quantified the structural carbohydrates through acid hydrolysis followed by High-Performance Liquid Chromatography (HPLC) analysis.

The determination of lignin content was as the sum of acid-insoluble and acid-soluble lignin, with UV-visible spectrophotometry used for acid-soluble lignin determination at 205 nm. Extractives were measured via Soxhlet extraction using ethanol, in addition, ash content was determined by furnace combustion at 600 °C following NREL protocols (Sluiter et al., 2008a; 2008b; 2008c).

Fourier Transform Infrared Spectroscopy (FTIR) Analysis

FTIR spectroscopy was carried out using a Shimadzu FT-IR spectrometer. Samples preparations were done by mixing the bamboo biomass with potassium bromide (KBr) and compressing the mixture into pellets. Spectra were noted in the range of 400 - 4000 cm-1 to detect functional groups present in the biomass.

X-Ray Diffraction Analysis (XRD)

X-ray diffraction analysis was accomplished using a Philips diffractometer equipped with Cu-Kα radiation. Diffraction patterns were noted and interpreted by means of comparison with standard Joint Committee on Powder Diffraction Standards (JCPDS) data to evaluate cellulose crystallinity

RESULT AND DISCUSSION

Chemical Composition of Bamboo Stalk

Table 1 shows the chemical composition of the bamboo stalks feedstocks. The chemical composition analysis carried out revealed that bamboo stalks contained 52.61, 19.16, and 24.27% of cellulose, hemicellulose, and lignin, respectively, with extractives and ash contents of 2.21 and 1.75%, respectively. The high content of cellulose is advantageous for particleboard production, as cellulose contributes significantly to mechanical strength and structural integrity (Essid et al., 2021). Hemicellulose improves dimensional stability, while lignin, although beneficial for natural rigidity, may hinder inter-particle bonding if not appropriately treated (Younesi-Kordkheili & Pizzi, 2023).The discussion section should answer the research problem or hypothesis that has been formulated previously.

Tabel 1. Chemical composition of the bamboo stalks feedstocks

Component	Bamboo Stalks samples (%)
Cellulose (%)	52.61
Hemicellulose (%)	19.16
Holocellulose (%) (Cellulose + Hemicellulose)	71.77
Lignin (%)	24.27
Extractives (%)	2.21
Ash content (%)	1.75

Fourier Transform Infrared (FTIR) Spectral Analysis

FTIR spectral of bamboo biomass is presented in Figure 2. The FTIR spectra showed broad absorption bands between 3600 and 2800 cm^{-1} corresponding to O–H and C–H stretching vibrations. The peak at 1737 cm^{-1} was credited to acetyl and ester groups linked with hemicellulose, whereas the peak at 1511 cm^{-1} corresponded to aromatic C=C stretching in lignin. This akin to the findings of Alemdar and Sain, (2008); Čabalová et al. (2023). The peaks observed at 1379 cm⁻¹ and within the 1200–950 cm⁻¹ range were allotted to C–H deformation and C–O stretching vibrations, respectively. These functional groups confirm the lignocellulosic nature of bamboo biomass and support its suitability for particleboard manufacturing. This is in agreement with the finding of Biswas et al. (2022).

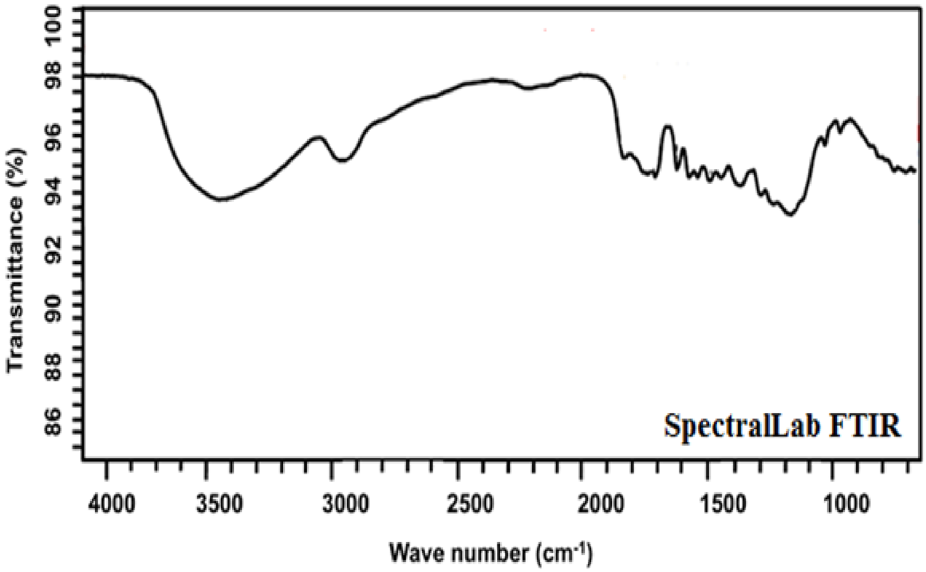

Figure 2. FTIR spectra of bamboo biomass

X-Ray Diffraction Analysis (XRD)

Figure 3 displays X-Ray diffraction pattern of the bamboo biomas. This XRD analysis revealed major diffraction peaks at 2θ angles of approximately 15° and 22°, corresponding to the (101) and (002) planes of cellulose, respectively. This is similar to the finding by Kumar et al. (2019). The sharpness of the peak at 22° shows a relatively high degree of cellulose crystallinity, which is associated with enhanced mechanical strength and water resistance in particleboard products. This supports the finding of Lin et al. (2022). A minor peak observed at 35° was ascribed to hemicellulose components, additional confirming the composite lignocellulosic structure of bamboo biomass.

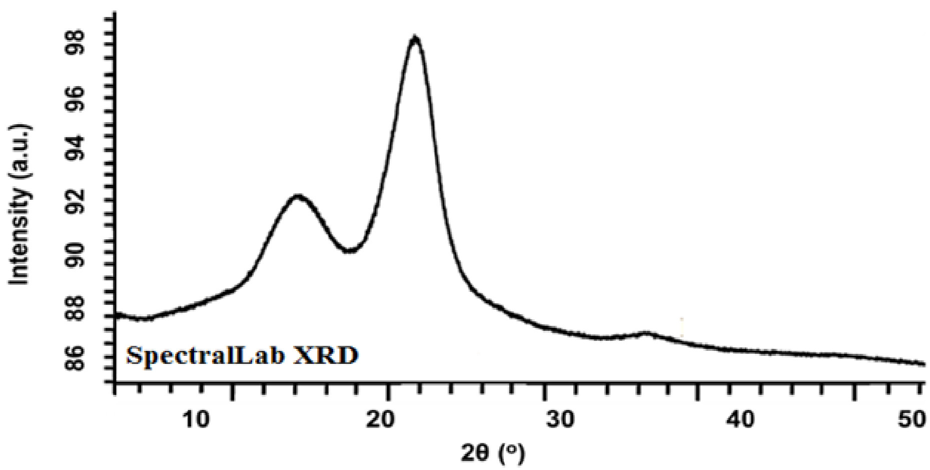

Figure 3. XRD pattern of bamboo biomass

CONCLUSION

The study for the application of Fourier Transform Infrared Spectroscopy and X-Ray diffraction in the characterization of bamboo stalks has been carried out. This study establishes that bamboo stalks possess favourable chemical and structural characteristics to utilize as sustainable precursors in particleboard production. The high cellulose content contributes to mechanical strength, while hemicellulose improves dimensional stability. FTIR and XRD analyses confirmed the existence of essential functional groups and a high degree of cellulose crystallinity. Though lignin content presents potential challenges, suitable pretreatment methods can mitigate its negative effects on bonding. Generally, the findings validate bamboo stalks as viable, renewable, and eco-friendly raw materials for engineered wood products, contributing to the advancement of sustainable construction materials.

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