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Sustainable Biomass-Derived Cellulose/HKUST-1 Composite from Purun (*Lepironia articulata*): Synthesis and FTIR Characterization

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Abstract

This study explores the fabrication of a cellulose/HKUST-1 composite derived from purun (Lepironia articulata), a wetland biomass abundant in cellulose and promising as an eco-friendly feedstock for advanced materials. HKUST-1, a copper-based metal-organic framework known for its high porosity, suffers from reduced stability in humid environments. To address this limitation, a composite integrating purun-derived cellulose with HKUST-1 was synthesized and subsequently characterized using Fourier Transform Infrared (FTIR) spectroscopy. Cellulose was isolated via alkaline delignification and peroxide bleaching with a yield of 26.68%. HKUST-1 was synthesized using a solvothermal method, producing a turquoise-blue material with a yield of 70.96%. The composite was prepared using an ex-situ method, resulting in a green-colored product with a yield of 85.90%. FTIR analysis confirmed HKUST-1 formation through the disappearance of the C=O band (~1719 cm^{-1}) and the appearance of COO^- bands (~1560-1600 and ~1450 cm^{-1}), along with Cu-O vibration (~725 cm^{-1}). FTIR analysis of the composite revealed the presence of diagnostic peaks attributable to both cellulose and HKUST-1, confirming successful incorporation without compromising structural integrity. Notably, the O-H stretching band appeared broadened and slightly shifted, indicating hydrogen-bond interactions between cellulose and HKUST-1. These results demonstrate that purun-derived cellulose is a sustainable matrix for HKUST-1 with potential in adsorption applications.

Keywords: *Cellulose, Purun (Lepironia Articulata), HKUST-1, Composite, FTIR.*

1. INTRODUCTION

In recent years, Metal-Organic Frameworks (MOFs) have drawn considerable research interest due to their wide-ranging uses in adsorption, catalysis, gas storage, and separation (Hidayat et al., 2022). Metal-organic frameworks (MOFs) represent a class of crystalline, highly porous materials formed through the coordination of metal ions or clusters with organic linkers, resulting in well-ordered three-dimensional networks. Their defining characteristics include ultrahigh surface area, adjustable pore dimensions, and remarkable structural versatility, enabling fine tuning of their physicochemical attributes for diverse applications (Hashad et al., 2025; Zeggai et al., 2025). Such characteristics make MOFs promising candidates for advanced functional materials, particularly in environmental remediation and energy-related applications.

Among the diverse range of metal-organic frameworks, HKUST-1 ($Cu_3(BTC)_2$) stands out as one of the most extensively investigated owing to its well-ordered crystalline architecture, straightforward synthesis, and superior adsorption capacity (Chen et al., 2022; Mokrzycki et al., 2024). The synthesis of this material relies on the coordination between Cu^{2+} ions and 1,3,5-benzenetricarboxylate (H_3BTC) linkers, forming a porous network endowed with accessible metal coordination sites. Such structural attributes underpin its high adsorption capacity and selectivity for a range of target analytes. Nevertheless, despite these favorable properties, HKUST-1 presents several limitations that constrain its real-world applicability. A primary shortcoming is its inadequate stability under humid conditions, wherein water molecules tend to disrupt the coordination bonds linking Cu^{2+} ions to BTC ligands. This interaction promotes structural collapse and a consequent reduction in surface area (Alvarez et al., 2017; Bertero et al., 2024). In addition, HKUST-1 has relatively low mechanical stability and tends to agglomerate, which can reduce its effectiveness and durability during application (Liang et al., 2024).

A promising strategy to address these limitations involves the design of MOF-based composite materials. Incorporating MOFs into polymeric or biopolymeric matrices can enhance mechanical robustness, increase resistance to moisture, and mitigate particle agglomeration, all while preserving the intrinsic porosity of the metal-organic framework to a substantial degree (Lestari et al., 2023; Tu et al., 2022). Beyond improving MOF stability, this approach broadens their potential for deployment under practical conditions. Among the available matrix materials, cellulose has drawn considerable attention owing to its availability, renewability, biodegradability, and eco-friendly profile. Additionally, the abundant hydroxyl (-OH) groups present in cellulose promote robust interactions with inorganic components, rendering it an excellent candidate for composite fabrication (Acharya et al., 2021).

Cellulose is a naturally occurring biopolymer consisting of glucose monomers connected by β-(1,4)-glycosidic linkages, giving rise to a linear chain with the empirical formula $(C_6H_{10}O_5)_n$. This material possesses considerable mechanical strength and structural integrity. Hydroxyl groups positioned at the C2, C3, and C6 carbon atoms facilitate extensive intra- and intermolecular hydrogen bonding, which underpins its rigidity and resilience. Furthermore, these functional groups act as anchoring sites for metal ions or MOF architectures, enabling the construction of stable composite systems (Amrillah et al., 2022; Zulfa et al., 2019). In MOF-based composites, cellulose acts not only as a structural support but also as a dispersing agent that promotes uniform distribution of MOF particles, reduces agglomeration, and enhances overall material stability. Furthermore, its fibrous morphology can function as a scaffold for MOF crystal growth, facilitating better integration between components (Abdelhamid et al., 2025).

In Indonesia, one of the promising yet underutilized sources of cellulose is purun (*Lepironia articulata*), a wetland plant commonly found in peatland ecosystems (Batubara et al., 2021; Purba et al., 2022). Purun grows abundantly, particularly in regions such as Kalimantan, but its utilization is largely limited to traditional handicrafts (Syafitri & Hamid, 2023). Previous studies have reported that purun contains approximately 32.62% cellulose, making it a suitable raw material for cellulose extraction (Pardi et al., 2025). Employing purun as a cellulose feedstock not only enhances the value of local biomass but also promotes the creation of sustainable, eco-friendly materials derived from renewable sources (Oktaningtyas et al., 2024). Therefore, exploring purun as a precursor for advanced material synthesis represents an important step toward sustainable material innovation.

Purun (*Lepironia articulata*) offers distinct advantages over common biomass sources such as water hyacinth and agricultural residues due to its relatively high cellulose content (~32.62%) combined with a dense and robust fibrous structure, which enhance mechanical strength and support better dispersion of HKUST-1, reducing agglomeration (Mueanmas et al., 2026; Sunardi & Istikowati, 2012; Ungprasoot et al., 2021).

Additionally, the high density of hydroxyl (-OH) groups promotes strong intermolecular interactions, particularly hydrogen bonding with the HKUST-1 framework (Ding & Jiang, 2021; Ucak-Astarlioglu et al., 2025). As a wetland plant, purun is also naturally adapted to moisture-rich environments, potentially improving resistance to humidity-induced degradation (Dhonanto et al., 2022). Therefore, purun-derived cellulose represents a promising matrix for stabilizing MOF-based composites.

The integration of cellulose and HKUST-1 into a composite material, referred to as cellulose/HKUST-1, provides a synergistic approach to overcome the limitations of each component. In this system, cellulose functions as a matrix that enhances mechanical stability and supports the uniform dispersion of HKUST-1 particles, while HKUST-1 acts as the active phase responsible for adsorption properties (Wijaya et al., 2022). The interaction between cellulose and HKUST-1 is mainly driven by intermolecular forces, most notably hydrogen bonding formed between the hydroxyl groups of cellulose and the oxygen-containing moieties present in the MOF framework (Silva et al., 2024). These interactions can improve the stability of HKUST-1, especially under humid conditions, and enhance the durability of the composite material.

Despite the growing interest in cellulose-based MOF composites, most studies have focused on commercially available cellulose or other common biomass sources. Despite the promise of purun-derived cellulose as a matrix for HKUST-1 composites, its application remains underexplored, especially regarding the molecular level mechanisms governing component interactions. Furthermore, the specific role of functional groups in mediating these interactions and their subsequent influence on composite formation have yet to be investigated in depth.

To address these knowledge gaps, the present study seeks to synthesize a cellulose/HKUST-1 composite using purun (*Lepironia articulata*) as the cellulose source and to assess the interaction between the two constituents via Fourier Transform Infrared (FTIR) spectroscopy. FTIR analysis is utilized to identify characteristic functional groups and to detect shifts or broadening in absorption bands that signal intermolecular interactions within the composite. The outcomes of this work are anticipated to advance the development of sustainable biomass derived composite materials and to broaden the applicability of MOF-based systems in environmentally benign technologies.

2. METHODOLOGY

2.1 Materials and Equipment

The following materials were employed in this investigation: purun (*Lepironia articulata*), distilled water, sodium hydroxide (NaOH), hydrogen peroxide (H_2O_2), copper(II) nitrate trihydrate ($Cu(NO_3)_2 \cdot 3H_2O$), 1,3,5-benzenetricarboxylic acid (H_3BTC), 96% ethanol, dimethylformamide (DMF), urea ($CO(NH_2)_2$), citric acid ($C_6H_8O_7$), and ice. The instruments used consisted of an analytical balance, fume hood, hotplate stirrer, magnetic stirrer bar, grinder, thermometer, oven, Buchner vacuum filtration system, mortar and pestle, glassware, filter paper, and a Fourier Transform Infrared (FTIR) spectrophotometer.

2.2 Sample Collection and Preparation of Purun

Purun samples were collected from the vicinity of the Peatland Science and Innovation Development Center (PPIIG), Universitas Palangka Raya, at coordinates -2.222999, 113.884009, using a purposive sampling method. The collected samples were washed with running water to remove impurities and then dried to reduce moisture content. Subsequently, the dried purun was cut into small pieces and ground using a grinder (three repetitions) to obtain fine powder suitable for further processing. No sieving process was applied; therefore, the particle size distribution was not specifically controlled.

2.3 Isolation of Cellulose from Purun

Cellulose isolation was performed via delignification followed by bleaching. Specifically, 20 g of purun powder was mixed with 200 mL of 12% NaOH solution and heated to 90-95°C for three hours under constant stirring. Subsequently, the resulting mixture was filtered and neutralized using a Buchner vacuum filtration setup. The residue was subsequently subjected to bleaching by adding 200 mL of 10% H_2O_2, followed by heating at 85-90°C for 1.5 hours. The resulting mixture was filtered and neutralized again. The isolated cellulose was subsequently dried in an oven at 60°C for three hours and then milled into fine particles.

2.4 Synthesis of HKUST-1

HKUST-1 was synthesized using a solvothermal method following Kim et al. (2020) (Kim et al., 2020). A copper precursor solution (solution A) was prepared by dissolving 0.435 g of $Cu(NO_3)_2 \cdot 3H_2O$ in 10 mL of ethanol. Separately, 0.11 g of H_3BTC was dissolved in 10 mL of DMF to form solution B. Both solutions were stirred until complete dissolution. Solution A was subsequently added to solution B, and the combined mixture was stirred for ten minutes at ambient temperature. The reaction mixture was then transferred to an oven and heated at 80°C for 20 hours. After cooling to room temperature, the resultant crystals were washed three times with a 1:1 water-ethanol mixture (15 mL per wash, each washing lasting approximately four hours). Finally, the product was dried at room temperature to yield crystalline HKUST-1 powder.

2.5 Synthesis of Cellulose/HKUST-1

The composite was prepared using an ex-situ method based on Ketheeswaran et al. (2024) (Ketheeswaran et al., 2024). 3.5 g of NaOH (7%) and 6 g urea (12%) were dissolved in 50 mL distilled water under cold conditions using ice. Following this, 1.5 g of the isolated cellulose was introduced into the mixture and stirred until fully dissolved. Citric acid (0.6 g) was then added as a crosslinking agent, and the stirring continued at 50-70°C for three hours. Subsequently, 0.25 g of HKUST-1 pre-dispersed in ethanol was incorporated, and the mixture was stirred at moderate speed for 30 minutes. The resulting blend was dried in an oven at 60°C for approximately 2.5 hours. The final composite was ground into a fine powder and stored in a sealed container.

The ex-situ method was selected to preserve the crystallinity and porosity of HKUST-1. Unlike in-situ synthesis, where MOF crystals form within the polymer matrix, the ex-situ approach enables independent synthesis under controlled conditions, ensuring a well-defined structure. This method minimizes pore blockage and structural distortion while allowing better control over composition and uniform dispersion of HKUST-1 within the cellulose matrix, thereby maintaining the structural integrity and performance of the composite (Abdelhamid & Mathew, 2022; Lu et al., 2022).

2.6 FTIR Characterization

FTIR analysis was performed to identify functional groups and evaluate interactions between cellulose and HKUST-1. The samples were prepared in powder form and placed on the sample holder. The spectra were recorded in the range of 4000-500 cm^{-1} using KBr as background. FTIR measurements were performed on pure cellulose, HKUST-1, and the cellulose/HKUST-1 composite. The resulting spectra were examined to identify characteristic absorption bands and to detect any spectral shifts or alterations indicative of successful composite formation.

3. RESULTS AND DISCUSSION

This study was conducted to synthesize a cellulose/HKUST-1 composite derived from purun through cellulose isolation and HKUST-1 synthesis. Cellulose, as an abundant, biodegradable, non-toxic natural polymer obtained from renewable sources, has witnessed a marked rise in demand in recent years owing to its extensive industrial applicability. Nevertheless, the supply of conventional raw materials for cellulose production is steadily diminishing (Irawan et al., 2015). Therefore, alternative renewable sources such as purun (*Lepironia articulata*) are needed.

Purun is a wetland plant widely distributed in Kalimantan, yet its utilization remains limited to handicrafts. Previous studies reported that purun contains approximately 32.62% cellulose and 26.4% lignin, indicating its strong potential as a cellulose source (Sunardi & Istikowati, 2012).

3.1 Cellulose Isolation from Purun

The cellulose obtained from purun had a mass of 5.335 g with a yield of 26.68%. This value is lower than the reported cellulose content of purun (~32.62%), which can be attributed to the removal of non-cellulosic components such as lignin and hemicellulose during delignification and bleaching, as well as possible partial degradation or loss of cellulose under alkaline and oxidative conditions.

Figure 1. Isolated cellulose from purun

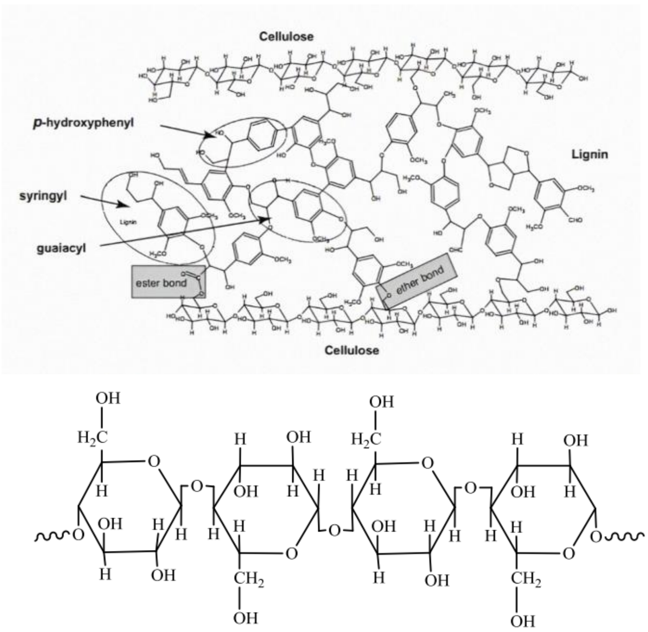

Figure 2. The molecular structure of lignocellulose (above), and cellulose (below) (Li et al., 2025; Mulyadi, 2019)

Visually, the isolated cellulose appeared as a yellowish-white fibrous material (Figure 1). The relatively light coloration suggests that the delignification and purification processes were effective, as indicated by the reduced presence of lignin and hemicellulose, which typically impart a brown to dark color to lignocellulosic biomass (Sunardi et al., 2018). This observation is consistent with previous studies reporting that cellulose isolated from lignocellulosic biomass, such as rice straw and bamboo fibers, generally appears as a white to cream-colored material, indicating good purity (Batu et al., 2024).

The high density of hydroxyl (-OH) groups on the cellulose surface increases its suitability as a matrix or support within composite systems, especially those based on metal-organic frameworks (MOFs) (Li et al., 2025). From a structural perspective, each anhydroglucose unit in cellulose bears three reactive hydroxyl groups situated at the C2, C3, and C6 positions. Those at C2 and C3 are attached to secondary carbon atoms, whereas the C6 hydroxyl group is linked to a primary carbon, leading to distinct reactivity profiles. Such functional groups offer viable sites for chemical modification, including grafting, thereby enabling improvements in the mechanical and thermal performance of cellulose derived materials (Larasati et al., 2023). Figure 2 illustrates the molecular structure of lignocellulose and cellulose.

3.2 Synthesis of HKUST-1

The synthesized HKUST-1 exhibited a mass of 0.26 g with a yield of 70.96%, characterized by the formation of a turquoise-blue precipitate (Figure 3). This distinct coloration is a defining characteristic of HKUST-1 (Cu-BTC), arising from the coordination interaction between Cu^{2+} ions and benzene-1,3,5-tricarboxylate (BTC) ligands.

The depth of the blue hue reflects successful metal-ligand coordination and the establishment of a crystalline MOF framework. This finding aligns with earlier studies indicating that HKUST-1 generally exhibits a bright blue to bluish-green appearance, whether in powder or suspended form. Such coloration stems from d-d electronic transitions occurring within Cu^{2+} ions situated in a distorted octahedral coordination geometry (Hanif et al., 2018).

Figure 3. Synthesized HKUST-1 showing a characteristic turquoise-blue color

The solvothermal synthesis route relies on the self-assembly of Cu^{2+} ions with BTC linkers to generate a three-dimensional porous architecture. Key reaction parameters including temperature, solvent composition, and duration exert considerable influence over this assembly process, which collectively determine the structural and physicochemical properties of the resulting HKUST-1 (Gonzalez-Gomez et al., 2025).

3.3 Synthesis of Cellulose/HKUST-1

The resulting cellulose/HKUST-1 composite appeared as a green colored powder weighing 10.178 g, corresponding to a yield of 85.90%. This green hue reflects the effective integration of yellowish white cellulose with blue HKUST-1, thereby confirming the coexistence of both constituents within the composite architecture, as illustrated in Figure 4.

Figure 4. Synthesized cellulose/HKUST-1 composite exhibiting a green-colored powder

This color change serves as a preliminary indicator of composite formation, as reported in previous studies involving copper-based MOFs combined with biopolymers (Yannez-Aulestia et al., 2024). The formation of the composite suggests that HKUST-1 particles were successfully dispersed within the cellulose matrix.

In this system, cellulose acts as a supporting matrix that provides abundant hydroxyl (-OH) groups, enabling interactions with Cu^{2+} ions in HKUST-1. These interactions contribute to improved dispersion, reduced agglomeration, and enhanced stability of the composite material (Li et al., 2025).

The composite was synthesized using the ex-situ method, in which HKUST-1 was first synthesized separately and then incorporated into the cellulose matrix through physical mixing (Chronopoulos et al., 2022). This approach preserves the structural integrity and porosity of HKUST-1 while enabling its integration into a flexible and stable cellulose network (Kumaraguru et al., 2022).

3.4 FTIR Analysis

Figure 5 presents the FTIR spectra of H_3BTC, HKUST-1, cellulose, and the cellulose/HKUST-1 composite, compared to verify the coordination of BTC ligands with Cu^{2+} ions and the successful embedding of HKUST-1 within the cellulose matrix. In the H_3BTC spectrum, a broad absorption feature appears in the range of 2500-3500 cm^{-1}, corresponding to O-H stretching vibrations from carboxylic acid groups. A sharp band near 1719 cm^{-1} is attributable to C=O stretching of protonated carboxyl moieties. These characteristic bands disappear in the HKUST-1 spectrum, indicating the deprotonation of carboxylic acid groups and subsequent coordination with Cu^{2+} ions to form the HKUST-1 framework (Garg et al., 2022).

For HKUST-1, characteristic carboxylate bands emerge near 1560-1600 cm^{-1} and approximately 1450 cm^{-1}, assigned to asymmetric and symmetric stretching vibrations of coordinated COO^{-} groups, respectively. These features confirm the formation of metal-carboxylate coordination bonds. Additionally, a band at roughly 1370 cm^{-1} corresponds to aromatic C-C stretching from the benzene ring, indicating that the BTC backbone remains intact following coordination (Kim et al., 2020). A well-defined band at approximately 725 cm^{-1} is assigned to the Cu-O stretching vibration, reflecting coordination between Cu^{2+} ions and oxygen atoms from the carboxylate groups.

Moreover, a prominent absorption band observed in the 580-600 cm⁻¹ region is attributed to lattice vibrations or deformations associated with the paddle wheel unit of HKUST-1. The presence of these low wavenumber bands offers robust evidence for the successful construction of the HKUST-1 framework (Morales et al., 2021).

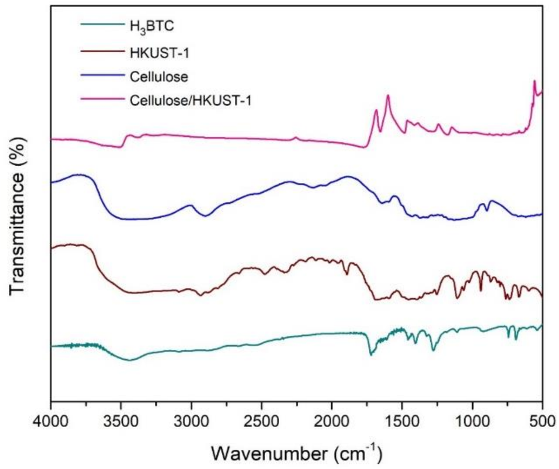

Figure 5. The FTIR spectra of H_3BTC, HKUST-1, cellulose, and cellulose/HKUST-1

The FTIR spectrum of cellulose displays characteristic absorption patterns typical of polysaccharides. A broad band spanning 3300-3400 cm^{-1} corresponds to O-H stretching, indicative of extensive intra- and intermolecular hydrogen bonding within the cellulose architecture (Acharya et al., 2021). The absorption band near 2900 cm^{-1} arises from aliphatic C-H stretching of the glucopyranose units. Further peaks at approximately 1320 cm^{-1}, 1160 cm^{-1}, 1050-1030 cm^{-1}, and 896 cm^{-1} are assigned to C-C stretching within the glucose ring, C-O-C glycosidic stretching, C-O stretching, and the β-(1,4)-glycosidic linkage, respectively. These features confirm that the cellulose backbone remains intact following the isolation procedure (Han et al., 2021; Sheng et al., 2022).

In the FTIR spectrum of the cellulose/HKUST-1 composite, characteristic bands originating from both cellulose and HKUST-1 are clearly observed, demonstrating successful integration of the two components. The retention of cellulose specific peaks at approximately 1160 cm^{-1}, 1050 cm^{-1}, and 896 cm^{-1} confirms that the cellulose structure remains unaltered following composite formation. At the same time, the presence of HKUST-1-related bands at ~1560-1600 cm^{-1}, ~1450 cm^{-1}, ~725 cm^{-1}, and ~580-600 cm^{-1} confirms that the MOF structure is retained within the composite. Notably, the O-H absorption band in the composite appears broader and exhibits a slight shift compared to pure cellulose, indicating changes in the hydrogen bonding environment. The formation of hydrogen bonding interactions is typically associated with a shift of the O-H stretching vibration toward lower wavenumbers due to weakening of the O-H bond. In this study, the observed broadening accompanied by a slight shift in the O-H region suggests the presence of intermolecular interactions between cellulose hydroxyl groups and oxygen-containing sites or coordinated water molecules in HKUST-1. However, since the analysis is based on FTIR spectra without peak deconvolution, this shift is interpreted qualitatively as evidence of hydrogen-bond-related interactions rather than as a precise quantitative measurement. In addition, the overlapping region around ~1430-1450 cm^{-1} reflects the coexistence of CH_2 bending vibrations from cellulose and symmetric COO^- stretching from HKUST-1, further confirming the integration of both components (Tu et al., 2022; Wijaya et al., 2022). Table 1 shows the comparison of the absorption spectra of H_3BTC, HKUST-1, cellulose, and cellulose/HKUST-1.

Table 1. The comparison of the absorption spectra of H_3BTC, HKUST-1, cellulose, and cellulose/HKUST-1

Absorption Band	Wavenumber (cm^{-1})				Assignment	Reference
	H_3BTC	HKUST-1	Cellulose	Cellulose/ HKUST-1		
O-H	2500-3100	broad	3300-3400	broadened, shifted	Hydroxyl/carboxylic O-H/adsorbed water	(Acharya et al., 2021)
C-H	-	-	2900	2900	Aliphatic C-H (cellulose)	(Sheng et al., 2022)
C=O	1719-1720	-	-	-	Free carboxylic acid (H_3BTC)	(Garg et al., 2022)
COO^- (asym)	-	1561-1600	-	1561-1600	Coordinated carboxylate	(Kim et al., 2020)
COO^- (sym)	-	1450	1425	1430-1450	Carboxylate	(Kim et al., 2020; Tu et al., 2022; Wijaya et al., 2022)
C-C (aromatic)	1275	1370	1320	~1370	Benzene ring (BTC ligand)	(Kim et al., 2020)
C-O-C	-	-	1160	1160	Glycosidic bond	(Han et al., 2021).
C-O	1400-1450	~1440	1050	1050	Alcohol/carboxylate	(Han et al., 2021).
β-glycosidic	-	-	896	896	β -(1,4) linkage (cellulose)	(Sheng et al., 2022).
Cu-O	-	725	-	725	Metal-oxygen coordination	(Morales et al., 2021).

Importantly, no new characteristic peaks are observed in the composite spectrum, suggesting that the interaction between cellulose and HKUST-1 is predominantly physical or supramolecular, rather than involving the formation of new covalent bonds. This indicates that the ex-situ method successfully incorporates HKUST-1 into the cellulose matrix while preserving the structural integrity of both components. Overall, the FTIR analysis confirms that HKUST-1 was successfully synthesized and effectively incorporated into the cellulose matrix. The coexistence of characteristic functional groups, along with slight band broadening and peak overlap, demonstrates the formation of a stable composite system with intermolecular interactions between cellulose and HKUST-1.

4. CONCLUSION

This study successfully synthesized a cellulose/HKUST-1 composite derived from purun (*Lepironia articulata*) through cellulose isolation, HKUST-1 synthesis, and ex-situ composite formation. The cellulose yield of 26.68% confirms purun as a promising renewable biomass source. The successful formation of HKUST-1 was indicated by its characteristic turquoise-blue color and a yield of 70.96%, while the composite formation was evidenced by the green coloration and a yield of 85.90%. FTIR analysis confirmed the structural characteristics of each component and the successful integration of HKUST-1 into the cellulose matrix. The disappearance of the C=O band (~1719 cm^{-1}) and the appearance of COO^- bands (~1560-1600 and ~1450 cm^{-1}) verified the coordination between Cu^{2+} ions and BTC ligands. The presence of Cu-O vibrations (~725 cm^{-1}) and framework bands (~580-600 cm^{-1}) further confirmed the formation of HKUST-1. In the composite, the coexistence of characteristic peaks from both cellulose and

HKUST-1 indicates that each component retained its structural integrity after integration. The broadening of the O-H band suggests intermolecular interactions, likely hydrogen bonding, without the formation of new covalent bonds. Overall, purun-derived cellulose acts as an effective and sustainable matrix for HKUST-1, enhancing stability while preserving its functional properties. Future work should include additional characterization techniques such as X-ray diffraction (XRD) and scanning electron microscopy (SEM), as well as adsorption performance evaluation to further validate the potential of the composite.

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