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Karakteristik Fisiko-Kimia Selulosa Dari Limbah Batang Kelapa Sawit (Elaeis guineensis Jacq)

Physicochemical Characteristics of Cellulose Derived from Oil Palm Trunk Waste (*Elaeis guineensis* Jacq.)

Hanifah Ulfa Azzahro [1)]*, Anania Rahmah [2)], Vivin Jenika Putri [3)], Fadel Albarra[4)], Dita Fitriani[5)]

[1)] Universitas Lancang Kuning, email: hanifahulfa@unilak.ac.id
[2)] Universitas Lancang Kuning, email: ananiarahmah@unilak.ac.id
[3)] Universitas Lancang Kuning, email: vivinjenika@unilak.ac.id
[4)] Universitas Lancang Kuning, email: fadelalbarrabakri@unilak.ac.id
[5)] Universitas Lancang Kuning, email: ditafitriani@unilak.ac.id
* Penulis Korespondensi: E-mail: hanifahulfa@unilak.ac.id

ABSTRACT

Oil palm trunk waste is a lignocellulosic biomass with great potential to be utilized as a cellulose source for various sustainable industrial applications. This study aimed to evaluate the effect of H_2O_2 and NaOH bleaching ratios on the physicochemical characteristics of cellulose isolated from oil palm trunks. The isolation process was carried out through a delignification stage using 10% NaOH solution at 80°C for 120 minutes, followed by a bleaching process using a combination of 10% H_2O_2 and 10% NaOH at ratios of 1:1 (HN1), 1:2 (HN2), and 1:3 (HN3). The study employed a non-factorial Completely Randomized Design (CRD) with three replications. The parameters analyzed included yield, moisture content, ash content, and functional group characterization using Fourier Transform Infrared Spectroscopy (FTIR). The results showed that the bleaching treatment significantly affected cellulose yield, moisture content, and ash content ($p < 0.05$). Cellulose yield decreased from 75.94% in the control treatment to 67.02% (HN1), 66.53% (HN2), and 60.53% (HN3), indicating a more intensive removal of lignin and hemicellulose. Moisture content increased after the bleaching process, with the highest value observed in HN1 at 3.63%, while ash content decreased significantly from 2.77% in the control treatment to 1.85% in both HN2 and HN3. FTIR analysis revealed a reduction in the intensity of lignin aromatic groups and an increased dominance of cellulose characteristic functional groups in the HN3 treatment. Based on the results, the H_2O_2:NaOH bleaching ratio of 1:3 was the most effective treatment for improving the purity of oil palm trunk cellulose through the removal of non-cellulosic components and mineral impurities.

Keywords: Cellulose; Delignification; Palm Oil Trunk Waste

ABSTRAK

Limbah batang kelapa sawit merupakan biomassa lignoselulosa yang berpotensi dimanfaatkan sebagai sumber selulosa untuk berbagai aplikasi industri berkelanjutan. Penelitian ini bertujuan untuk mengevaluasi pengaruh rasio bleaching H_2O_2 dan NaOH terhadap karakteristik fisikokimia selulosa yang *diisolasi dari batang kelapa sawit. Proses isolasi dilakukan melalui tahap delignifikasi menggunakan larutan NaOH 10% pada suhu 80°C selama 120 menit, dilanjutkan dengan bleaching menggunakan kombinasi H_2O_2 10% dan NaOH 10% dengan rasio 1:1 (HN1), 1:2 (HN2), dan 1:3 (HN3). Penelitian menggunakan Rancangan Acak Lengkap (RAL) nonfaktorial dengan tiga kali ulangan. Parameter yang dianalisis meliputi rendemen, kadar air, kadar abu, dan karakterisasi gugus fungsi menggunakan Fourier Transform Infrared Spectroscopy (FTIR). Hasil penelitian menunjukkan bahwa perlakuan bleaching memberikan pengaruh nyata terhadap rendemen, kadar air, dan kadar abu selulosa ($p < 0,05$). Rendemen selulosa menurun dari 75,94% pada kontrol menjadi 67,02% (HN1), 66,53% (HN2), dan 60,53% (HN3), yang menunjukkan semakin intensifnya penghilangan lignin dan hemiselulosa. Kadar air meningkat setelah proses bleaching dengan nilai tertinggi pada HN1 sebesar 3,63%, sedangkan kadar abu mengalami penurunan signifikan dari 2,77% pada kontrol menjadi 1,85% pada HN2 dan HN3. Analisis FTIR menunjukkan penurunan intensitas gugus aromatik lignin serta meningkatnya dominasi gugus fungsi khas selulosa pada perlakuan HN3. Berdasarkan hasil penelitian, perlakuan bleaching H_2O_2:NaOH rasio 1:3 merupakan perlakuan paling efektif dalam meningkatkan kemurnian selulosa batang kelapa sawit melalui penghilangan komponen non-selulosa dan mineral pengotor.*

Kata kunci: *Delignifikasi; Limbah Batang Kelapa Sawit; Selulosa*

INTRODUCTION

Based on data from the Directorate General of Plantations, the Ministry of Agriculture, and the Central Statistics Agency, the total area of oil palm plantations in Indonesia reached 14,996,010 hectares in 2020. Riau is one of the provinces with the largest oil palm plantation areas in Indonesia, covering approximately 1.733 million hectares or 17.84% of the total oil palm plantation area in Indonesia in 2022 (Khotimah and Martin, 2023). This significant oil palm production generates large amounts of biomass waste, such as empty fruit bunches and oil palm trunks, which have considerable potential for further utilization (Hariani and Fatmayati, 2024; Rasid et al., 2021).

Oil palm trunk waste is often considered merely as a residual by-product that has not been optimally utilized and is commonly left accumulated in plantation areas after replanting activities (Rendy, 2021). Oil palm trunk waste has high potential as a lignocellulosic source composed of cellulose, hemicellulose, and lignin (Anggoro et al., 2024). The utilization of oil palm trunk biomass can be carried out through cellulose isolation, as cellulose is the main structural component of plant cell walls and has wide applications in various industries (Amna et al., 2024).

The delignification and bleaching processes are important stages in the isolation of cellulose from lignocellulosic biomass, aiming to remove non-cellulosic components such as lignin and hemicellulose in order to obtain highly purified cellulose (Sucaga and Rani, 2025). Delignification using alkaline solutions such as NaOH has been proven effective in breaking down the complex lignocellulosic bonds, thereby significantly increasing the cellulose content from 31.11% to 84.35% (Gunawan et al., 2021). Furthermore, the bleaching process using H_2O_2 is applied to oxidize residual lignin and organic pigments, resulting in purer and brighter white cellulose fibers (Ritonga et al., 2023). Therefore, the utilization of oil palm trunk waste as a cellulose source has promising prospects for various industrial applications, including the production of environmentally friendly bioplastics and value-added pulp (Hariani and Khairiah, 2022; Saputra et al., 2023).

Although numerous studies have reported cellulose extraction from oil palm biomass, limited studies have specifically evaluated the effect of different H_2O_2:NaOH bleaching ratios on the physicochemical properties of cellulose derived from oil palm trunk waste from Riau. This study highlights the influence of peroxide-alkaline bleaching on cellulose yield, moisture content, ash content, and FTIR characteristics, providing important information for the development of oil palm trunk cellulose as a sustainable raw material for biodegradable materials and biocomposites. Therefore, the aim of this study was to investigate the physicochemical characteristics of cellulose extracted from oil palm trunk waste in order to explore its potential utilization as a sustainable industrial raw material by identifying the cellulose content present in oil palm trunks. as an environmentally friendly source of cellulose suitable for applications in various industrial products, such as biocomposites and biodegradable materials.

MATERIALS AND METHODS

Materials and Equipment

The main material used in this study was oil palm trunk waste obtained from replanting activities. The chemicals used included sodium hydroxide (NaOH), hydrogen peroxide (H_2O_2), and distilled water. The main equipment used consisted of an analytical balance (OHAUS PA214), oven, 60-mesh sieve, magnetic stirrer, beaker glass, desiccator, grinder, muffle furnace, and Fourier Transform Infrared Spectroscopy (FTIR) instrument.

Material Preparation

Oil palm trunk waste was cut into small pieces to facilitate the subsequent processing stages. The trunk pieces were then thoroughly washed to remove dirt and adhering foreign materials. Afterward, the oil palm trunks were dried until reaching a minimum moisture content, which is important to maintain sample stability during the experiment. Subsequently, the logs were smoothed using a wood planer, cut into smaller sizes, and dried. The dried trunk pieces were then ground using a grinder to further reduce their size. The next stage involved sieving using a 60-mesh sieve to separate particles according to the desired size, followed by moisture content analysis. For cellulose extraction, the moisture content of the material was targeted to be within the range of 4–5% (Saputri and Sukmawan, 2020).

Delignification Process

The delignification process of oil palm trunk aimed to remove lignin and other non-cellulosic compounds in order to increase the purity of cellulose fibers. The delignification process was carried out using a hot plate equipped with a magnetic stirrer at a solid-to-liquid ratio of 1:20 (w/v). In this method, 50 g of finely ground oil palm trunk was weighed and soaked in a 10% sodium hydroxide (NaOH) solution at a temperature of 80°C for 120 minutes. NaOH acted as a chemical agent capable of breaking down lignin bonds, thereby opening the biomass structure and preparing it for the subsequent processing stages. After the process was completed, the solid residue was thoroughly washed with distilled water until reaching neutral pH to remove any residual NaOH remaining in the material (Mutyanto et al., 2016; Hartati et al., 2023).

Bleaching Process

In the subsequent stage, the bleaching process was carried out using a mixture of 10% H_2O_2 and 10% NaOH under alkaline conditions (pH 10–11) with volume ratios of 1:1, 1:2, and 1:3 using a hot plate heating system. The bleaching treatments were coded as HN1, HN2, and HN3, representing the different volume ratios of hydrogen peroxide (H_2O_2) to sodium hydroxide (NaOH). Treatment HN1 used an H_2O_2:NaOH ratio of 1:1, HN2 used a ratio of 1:2, and HN3 used a ratio of 1:3. After the bleaching process was completed, the cellulose was washed with water until a neutral pH was achieved to ensure that no chemical residues remained. The final stage involved drying at approximately 60°C to obtain purified cellulose ready for further processing or characterization analysis (Utomo et al., 2017).

Cellulose Yield Analysis

Cellulose yield is defined as the percentage of cellulose obtained from the initial biomass after undergoing a series of extraction and purification processes (Suhartini et al., 2021). To analyze cellulose yield, the first step involves the preparation of oil palm trunk waste through an alkaline delignification process (Matullessya et al., 2026; Nurdiansyah and Rahayu, 2024). Subsequently, the extracted and purified cellulose is dried to a constant weight. The cellulose yield is then calculated by comparing the dry weight of the obtained cellulose to the initial dry weight of the raw material. This parameter is important for evaluating the efficiency of the extraction process and determining the potential of oil palm trunk waste as a viable source of cellulose.

Moisture Content Analysis

Moisture content in cellulose is an important parameter that indicates the amount of water present in the material. A low moisture content reflects good stability, which is essential for applications such as biofilm production or other fiber-based products. Conversely, high moisture content can affect the mechanical and chemical properties of cellulose and may lead to material degradation during storage. Therefore, controlling moisture content is crucial in the cellulose processing stage. A commonly used method for determining moisture content is the oven-drying method. In this method, the sample is placed in an oven at a temperature of approximately 100–105°C until a constant weight is achieved, indicating that all moisture has been evaporated. This measurement helps determine the amount of water present in the material, which directly influences the stability and quality of the final product (Widyasanti et al., 2020).

Ash Content Analysis

Ash content refers to the amount of mineral or inorganic residue remaining after the organic components of a material are completely combusted at high temperatures. In the context of cellulose, a low ash content indicates higher purity, as it suggests that the material is relatively free from mineral contaminants or impurities. Conversely, a high ash content may indicate the presence of processing residues, such as residual alkali or metal ions from earlier treatment stages, which were not completely removed during delignification or bleaching. The determination of ash content in cellulose is typically carried out by incinerating the sample in a muffle furnace at approximately 550°C until a constant ash weight is obtained. This method is essential to evaluate the effectiveness of the bleaching and washing processes, as well as to assess the overall quality of the processed material (Monariqsa et al., 2012).

FTIR (Fourier Transform Infrared Spectroscopy) Analysis

Fourier Transform Infrared Spectroscopy (FTIR) analysis was conducted to identify the chemical functional groups present in the extracted cellulose. This technique is effective in confirming that the delignification and bleaching processes successfully removed lignin and hemicellulose. The FTIR spectrum displays characteristic peaks corresponding to cellulose functional groups, such as C–H, C–O, and O–H vibrations, while also indicating the disappearance of peaks associated with lignin (e.g., aromatic vibrations) and hemicellulose (e.g., carbonyl vibrations). FTIR analysis also provides information regarding the purity of the cellulose, ensuring that no residual contaminants remain in the material. This is important in cellulose-based material research, such as biomaterial development, where the chemical structure greatly influences the physical properties and potential applications of the material (Dewanti, 2018).

Data Analysis

This study employed a non-factorial Completely Randomized Design (CRD) with one treatment factor and three replications. The treatments consisted of a bleaching process using 10% H_2O_2 and 10% NaOH solutions at ratios of 1:1, 1:2, and 1:3, along with one control treatment without bleaching, resulting in four treatments and a total of 12 experimental units. The obtained data were analyzed using Analysis of Variance (ANOVA) at a 5% significance level, followed by the Least Significant Difference (LSD) test when the treatments showed a significant effect.

RESULTS AND DISCUSSION

Cellulose Yield from Oil Palm Trunk

Cellulose yield represents the percentage of cellulose successfully isolated from the initial biomass and reflects the efficiency of the extraction process

(Nurdiansyah and Rahayu, 2024). The yield is influenced by several factors, including pretreatment method, solvent type, temperature, reaction time, and the ratio of raw materials to reagents used during extraction (Matullessya et al., 2026). In addition, different volume ratios of hydrogen peroxide (H_2O_2) and sodium hydroxide (NaOH) affect the resulting α-cellulose yield (Hariani and Fatmayati, 2023).

Based on Figure 1, bleaching treatments using combinations of H_2O_2 and NaOH significantly affected cellulose yield ($p < 0.05$). The highest yield was obtained in the control treatment (75.94%), while bleaching reduced the yield to 67.03% (HN1), 66.54% (HN2), and 60.54% (HN3). The decrease in yield indicates that higher bleaching ratios caused greater degradation and dissolution of non-cellulosic components during the bleaching process. This finding is consistent with the purpose of bleaching, which is to remove residual lignin and hemicellulose in order to obtain cellulose with higher purity (Amrillah et al., 2024; Susi et al., 2022).

In the control treatment, the high yield was attributed to the presence of lignin, hemicellulose, extractives, and other impurities that had not been optimally degraded, resulting in a higher final mass (Himawan, 2025). However, high yield does not necessarily indicate better cellulose quality because non-cellulosic components were still retained. The decrease in yield in HN1, HN2, and HN3 was caused by the oxidative activity of H_2O_2 under alkaline conditions provided by NaOH. Increased delignification and bleaching efficiency generally reduce cellulose yield due to greater removal of lignin and hemicellulose (Kusumawati and Haryadi, 2021; Wati et al., 2024). Nevertheless, the increase in cellulose purity accompanied by lower yield indicates effective separation of cellulose from non-cellulosic components (Safrizal et al., 2022).

The HN3 treatment produced the lowest yield (60.54%), indicating that higher bleaching ratios caused more intensive biomass degradation. Similar findings by Rasheed et al. (2024) showed that high NaOH concentration and H_2O_2 addition could lead to cellulose degradation under harsh reaction conditions. Delignification with NaOH at high temperatures cleaves ether and ester bonds in lignin, producing soluble lignin fragments in alkaline solution (Ischak et al., 2021; Marvie et al., 2022). As a result, greater mass loss occurred, reducing the cellulose yield. Overall, the H_2O_2:NaOH bleaching process effectively purified oil palm trunk cellulose through lignin and hemicellulose removal, although it also reduced cellulose yield.

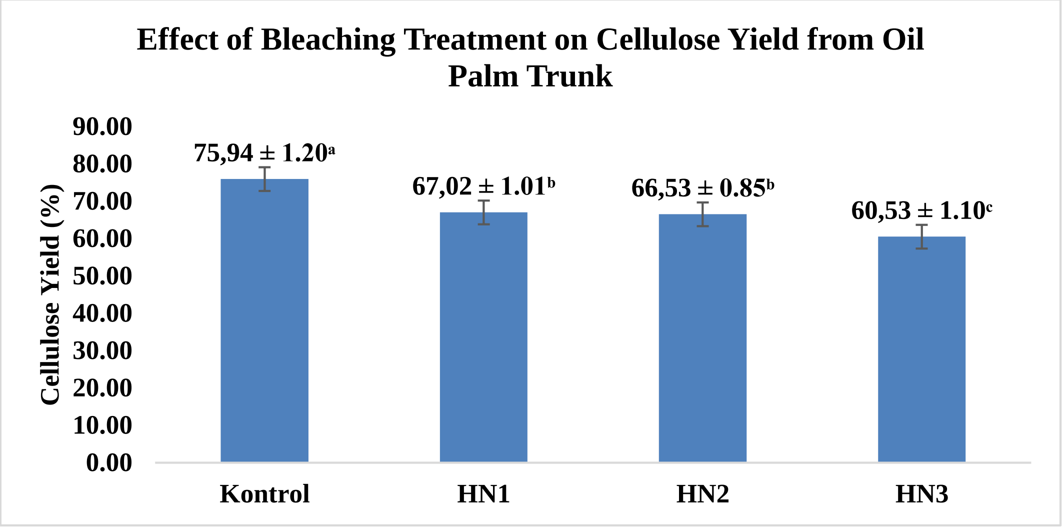

Figure 1. Cellulose Yield from Oil Palm Trunk

Moisture Content Analysis

Moisture content is an important parameter in cellulose characterization because it affects the stability, quality, and shelf life of the material (Owonubi et al., 2021). Based on Figure 2, bleaching treatments using combinations of H_2O_2 and NaOH significantly affected the moisture content of oil palm trunk cellulose ($p < 0.05$). The control treatment showed a moisture content of 2.52%, while the H_2O_2:NaOH ratios of 1:1 (HN1), 1:2 (HN2), and 1:3 (HN3) produced moisture contents of 3.63%, 3.01%, and 3.06%, respectively. The increase in moisture content indicates that bleaching affected the hydrophilic properties of cellulose.

Bleaching with H_2O_2 and NaOH removed lignin, hemicellulose, and extractive compounds from the fiber surface, exposing hydroxyl (-OH) groups and increasing the specific surface area of cellulose, thereby enhancing water adsorption capacity (Cahyani et al., 2023; Priatmoko and Rohman, 2023). The more open fiber structure increased water absorption ability compared to the control treatment (Iliyin et al., 2021). In addition, efficient delignification and bleaching exposed more hydrophilic sites within the cellulose structure, increasing the accessibility of hydroxyl groups, which is important for applications requiring high surface reactivity, such as cellulose derivative synthesis and composite materials (Han and Geng, 2023; Sutha et al., 2022).

The control treatment exhibited the lowest moisture content because the lignocellulosic structure still contained hydrophobic lignin and hemicellulose, which inhibited water penetration into the cellulose structure. The removal of these components through delignification and bleaching exposed hydrophilic hydroxyl groups, thereby increasing the water absorption capacity of cellulose (Jainal et al., 2023). In contrast, bleaching enhanced cellulose hygroscopicity by increasing the availability of free hydroxyl groups for interaction with water (Ali et al., 2023; Baraka et al., 2022).

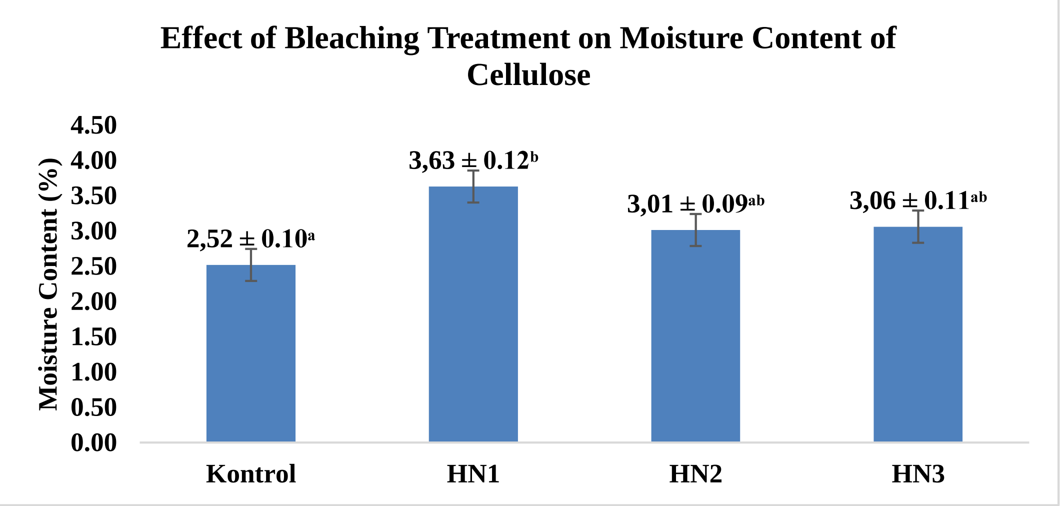

Figure 2. Moisture Content Analysis

The HN1 treatment produced the highest moisture content (3.63%), indicating that the H_2O_2:NaOH ratio of 1:1 effectively opened the fiber structure and increased hydroxyl group exposure. This condition promoted a more amorphous cellulose structure with greater water absorption capacity (Ebadi et al., 2021; Vukčević et al., 2023). Meanwhile, HN2 and HN3 showed lower moisture content than HN1, likely due to higher NaOH concentrations increasing the crystalline regions of cellulose, which have lower water-binding capacity than amorphous regions (Sari et al., 2025; Serra-Parareda et al., 2021; Martins et al., 2021; Rezeikinta et al., 2023). Overall, the increase in moisture content after bleaching indicates that the purification process successfully enhanced the hydrophilic properties and water adsorption capacity of cellulose.

Ash Content Analysis

Figure 3 shows that the ash content of cellulose was influenced by the delignification and bleaching processes. Ash content is an indicator of cellulose

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purity, where lower ash content reflects fewer inorganic impurities in the material (Sunardi et al., 2021). The synthesis of cellulose from oil palm waste involves alkaline delignification and hydrogen peroxide bleaching to remove non-cellulosic components (Sayakulu and Soloi, 2022).

The results in Figure 3 indicate that bleaching using combinations of H_2O_2 and NaOH significantly affected cellulose ash content ($p < 0.05$). The highest ash content was observed in the control treatment at 2.77%, decreasing to 2.56% in HN1 and reaching the lowest value of 1.85% in both HN2 and HN3. Post hoc analysis showed significant differences among treatments, except between HN2 and HN3.

The decrease in ash content after bleaching indicates that the H_2O_2 and NaOH treatments effectively reduced mineral and inorganic compounds in oil palm trunk cellulose (Manaf et al., 2024). Lower ash content indicates higher cellulose purity because inorganic residues such as silica, mineral salts, and metals were removed more efficiently (Muljani et al., 2023).

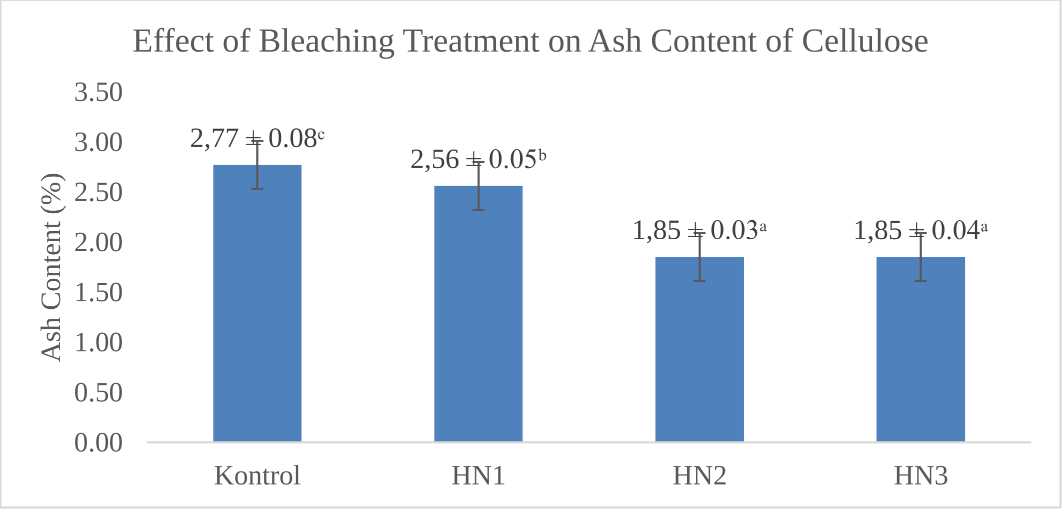

Figure 3. Ash Content Analysis

The HN1 treatment (H_2O_2:NaOH ratio of 1:1) still showed relatively high ash content, indicating incomplete removal of inorganic components (Rahmawati et al., 2025). In contrast, HN2 and HN3 reduced ash content significantly to 1.85%, demonstrating that higher NaOH ratios improved the dissolution and removal of inorganic impurities bound to cellulose fibers. This confirms the effectiveness of alkaline delignification and bleaching in increasing cellulose purity while minimizing

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residual impurities (Pereira et al., 2022; Azami et al., 2023; Sarumaha & Muchtar, 2022; Susi et al., 2023).

Overall, the bleaching process using different H_2O_2 and NaOH ratios successfully improved the purity of oil palm trunk cellulose through ash content reduction, making the cellulose more suitable for advanced biomaterial and adsorbent applications.

FTIR (*Fourier Transform Infrared*)

FTIR analysis was conducted to identify changes in the functional groups of oil palm trunk cellulose after bleaching treatments using combinations of H_2O_2 and NaOH at different ratios, in order to evaluate the effectiveness of chemical modification on the cellulose molecular structure (Zulnazri et al., 2022). FTIR spectra can indicate the reduction of lignin and hemicellulose functional groups as well as the increased intensity of hydroxyl (-OH) groups characteristic of cellulose (Syukri et al., 2025). Based on Figure 4, the FTIR spectra of the control and HN3 samples showed several similar major peaks; however, differences in peak intensity, peak shifts, and additional peaks in HN3 indicated structural chemical modifications after bleaching.

The absorption peak around 3328 cm^{-1} in both samples corresponds to the stretching vibration of hydroxyl (–OH) groups, which are characteristic of cellulose (AL-Rajabi & Haan, 2022). The lower transmittance intensity in HN3 compared to the control suggests changes in hydrogen bonding and increased exposure of free hydroxyl groups due to lignin and hemicellulose removal (Sonyeam et al., 2024). Meanwhile, the peak around 2890 cm^{-1} related to aliphatic C–H vibrations remained present in both samples, indicating that the basic lignocellulosic structure was maintained (Bichang'a et al., 2024).

The decrease in peak intensity in the 1595–1597 cm^{-1} region indicates a reduction in aromatic lignin groups after bleaching. The appearance of peaks at 1228 cm^{-1} and 894 cm^{-1} indicates the presence of phenolic C–O vibrations and β-glycosidic linkages characteristic of type I cellulose (Ghahrani et al., 2022). In addition, the peak at 1428 cm^{-1} corresponds to the symmetric deformation of C–H and CH_2 groups from cellulose and hemicellulose (Niza et al., 2022). Changes in the 1020–1030 cm^{-1} region related to C–O–C vibrations indicate the reduction of amorphous hemicellulose structures after bleaching (Ndwandwa et al., 2023).

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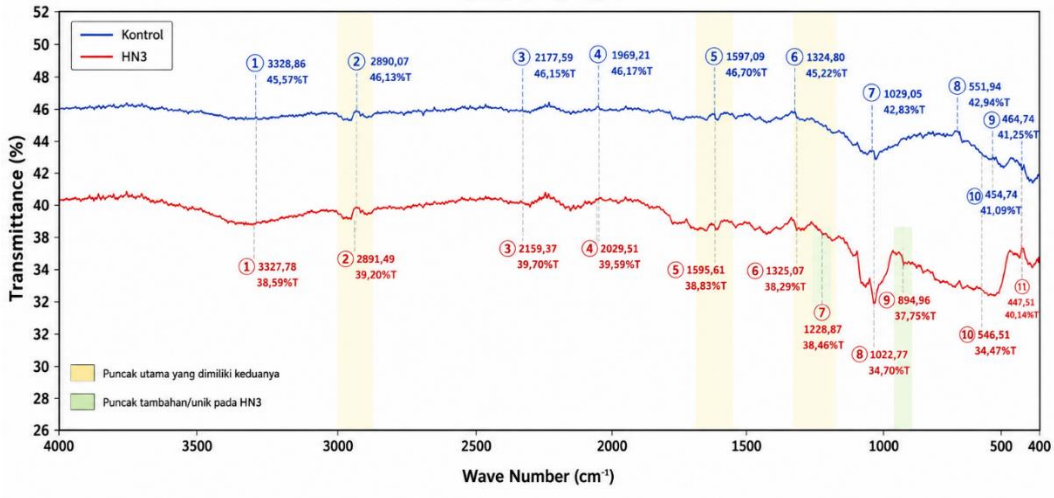

Figure 4. FTIR (Fourier Transform Infrared)

The FTIR results were consistent with the decrease in ash content from 2.77% in the control treatment to 1.85% in HN3, indicating that the bleaching process effectively removed inorganic components and impurities, thereby improving cellulose purity. Based on the FTIR and ash content results, the HN3 treatment was the most effective treatment for enhancing cellulose purity through the removal of lignin, hemicellulose, and other non-cellulosic components (Kaliappan et al., 2025).

CONCLUSION

Based on the results of yield, moisture content, ash content, and FTIR spectroscopy characterization of the different treatments (Control, HN1, HN2, and HN3), it can be concluded that bleaching treatments using combinations of H_2O_2 and NaOH had a significant effect ($p < 0.05$) on the physicochemical characteristics of oil palm trunk cellulose. Increasing the bleaching ratio reduced cellulose yield from 75.94% in the control treatment to 60.53% in HN3 due to the more effective removal of lignin, hemicellulose, and other non-cellulosic components. The bleaching process also increased cellulose moisture content, indicating enhanced hydrophilic properties resulting from greater exposure of hydroxyl groups within the cellulose structure. In addition, ash content decreased significantly to 1.85% in HN2 and HN3, indicating improved cellulose purity through the removal of inorganic compounds and mineral impurities.

FTIR analysis revealed chemical structural changes after bleaching, characterized by a decrease in the intensity of lignin aromatic groups and an increased dominance of cellulose characteristic functional groups. The HN3 treatment showed the most optimal results in improving the purity of oil palm trunk cellulose based on yield, ash content, and FTIR characteristics. Therefore, the combination of H_2O_2 and NaOH bleaching has strong potential as an effective method for producing high-quality cellulose from oil palm trunk waste for biomaterial and environmentally friendly product applications.

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