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Effect of NaOH Treatment and Solvent Extraction on the Chemical Composition and Morphology of False Banana (*Ensete ventricosum*) Fibers

Michael Ayele Gebremichael[1,2] | Belete Sirahbizu Yigezu[2,3]

[1]Department of Space Engineering Research and Development, Aerospace Engineering, Space Science and Geospatial Institute, Addis Ababa, Ethiopia | [2]Department of Mechanical Engineering, College of Engineering, Addis Ababa Science and Technology University, Addis Ababa, Ethiopia | [3]Nano Center of Excellence, Addis Ababa Science and Technology University, Addis Ababa, Ethiopia

Correspondence: Belete Sirahbizu Yigezu (belete.sirhabizu@aastu.edu.et)

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ABSTRACT

Natural fibers have attracted increasing attention as sustainable alternatives to synthetic reinforcements due to their biodegradability, renewability, and low environmental impact. False banana (*Ensete ventricosum*) fibers, however, contain significant amounts of noncellulosic components such as hemicellulose, lignin, and extractives, which can limit their interfacial performance in composite materials. This study investigates the effects of sodium hydroxide (NaOH) pretreatment at concentrations of 2%–8% combined with Soxhlet benzene–ethanol (2:1 v/v) extraction on the chemical composition and surface morphology of these fibers. Chemical analysis revealed that NaOH treatment substantially reduced extractives from 1.28% to 0.35% and hemicellulose from 16.21% to 9.44%, while lignin content decreased from 19.65% to 15.50%, indicating partial delignification. Thus, the calculated cellulose content increased from 62.87% in untreated fibers to 74.71% after 8% NaOH treatment, reflecting the progressive removal of noncellulosic components rather than an absolute increase in cellulose. Scanning electron microscopy revealed progressive surface cleaning, increased fibrillation, and enhanced surface roughness with increasing NaOH concentration. Fibers treated with 4%–6% NaOH exhibited the most favorable balance between chemical purification and structural integrity, whereas treatment with 8% NaOH resulted in surface microcracks and partial structural degradation due to excessive alkali attack. These findings reveal that the combined NaOH/Soxhlet pretreatment effectively improves both the chemical purity and surface morphology of *E. ventricosum* fibers, thereby improving their potential as sustainable reinforcement materials for biocomposite applications.

1 | Introduction

Nowadays, natural fibers are widely used as sustainable alternatives to synthetic, petroleum-based reinforcements, owing to their renewability, biodegradability, and lower environmental impact [1]. Natural fibers originate from plant or animal sources, with plant-based fibers being the most commonly used in engineering applications because of their availability, low cost, and favorable mechanical performance [2]. In particular, false banana fibers derived from *Ensete ventricosum*, a plant widely cultivated in Ethiopia and other tropical regions, have gained increasing attention as a promising reinforcement material [3]. False banana fibers possess a high cellulose content, low density, and, in some cases, exhibit favorable mechanical properties [4].

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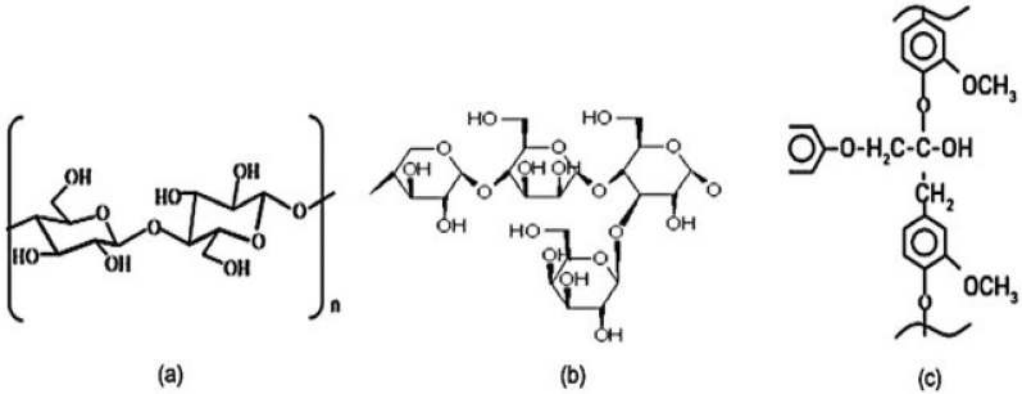

FIGURE 1 | Chemical structures of the main cell wall structural components of natural fibers: (a) cellulose, (b) hemicellulose, and (c) lignin [7].

Moreover, false banana fibers offer a cost-effective solution for various applications, making them suitable for use in textiles, polymer composites, and other environmentally friendly engineering products [5].

Despite these advantages, raw false banana fibers, similar to other plant-based fibers, contain considerable amounts of noncellulosic components, such as hemicellulose, lignin, waxes, and other water-soluble extractives [6]. The main challenge is not merely the presence of these components, but their relatively high proportion in untreated fibers, which masks the cellulose surface and limits the effective utilization of the fibers in engineering applications. The chemical structures of these components of natural fibers, including those found in false banana fiber, are presented in Figure 1. These components hinder fiber–matrix adhesion, reduce thermal stability, and compromise mechanical performance in composite applications. Therefore, reducing the proportion of these noncellulosic constituents is essential to enhance cellulose exposure, improve fiber–matrix interaction, and optimize the performance of the fibers in composite systems. Consequently, surface and structural modifications are essential to enhance the functional properties of these lignocellulosic fibers [8].

Various chemical treatments have been reported in the literature to improve fiber quality and purity [9]. Among these, alkali treatment using sodium hydroxide (NaOH) is one of the most widely employed and effective methods for structural modification. NaOH treatment induces fiber swelling, breaks intermolecular hydrogen bonds, and facilitates the removal of amorphous constituents such as hemicellulose, lignin, and other impurities. This process increases cellulose exposure, improves crystallinity, and enhances the fiber's compatibility with polymer matrices [10]. The reaction mechanism involves the ionization of hydroxyl groups into alkoxide ions, as represented in Equation (1).

$$\text{Fiber} - OH + NaOH \rightarrow Fibre - O - Na + H_2O \qquad (1)$$

In addition to alkali modification, solvent purification using the Soxhlet extraction technique plays a crucial role in further improving fiber quality. Soxhlet extraction with benzene–ethanol mixtures is particularly effective in removing surface waxes, oils, lipids, resins, and other low-molecular-weight extractives that cannot be fully eliminated through alkali treatment alone [11]. The continuous reflux and solvent cycling in the Soxhlet apparatus ensure efficient and thorough extraction, thereby increasing fiber wettability and enhancing its interfacial adhesion in composite applications. When combined, alkali treatment and solvent extraction significantly improve the chemical cleanliness, surface energy, and overall performance of natural fibers in composite applications.

Previous studies have investigated the chemical composition of untreated and chemically treated *E. ventricosum* fibers. For instance, Berhanu et al. [3] reported cellulose content of 59.59%, hemicellulose at 27.88%, and lignin at 10.53%, along with extractives at 4.44%. Addis et al. [12] found cellulose values ranging from 56.37% to 59.95%, while documenting hemicellulose and lignin contents between 23.51%–23.77% and 9.95%–12.29%, respectively. Broader compositional variability has also been documented. Lemma et al. [13] reported cellulose content as high as 70.5%, with values up to 68.28% also reported in the same study. Bekele, Lemu, and Jiru [14] noted lower cellulose (56.05%) and higher hemicellulose (24.04%) and lignin (12.21%) values. Similarly, Negawo et al. [15] and Esayas, Agon, and Assefa [16] found cellulose contents ranging from 56.05% to 62%, and lignin levels between 2.21% and 5%. These variations are attributed to factors such as plant maturity, geographical origin, processing techniques, and chemical treatment protocols.

However, most existing studies have either focused on untreated fibers or investigated single-step chemical modifications, often overlooking the combined or sequential effects of alkali and solvent treatments [17]. Additionally, the morphological transformations that occur as a result of such treatments are also an important issue [9]. Surface morphology is a critical factor, as it directly influences fiber–matrix interaction, mechanical interlocking, and the overall performance of fiber-reinforced materials [18, 19]. In this context, Scanning Electron Microscopy (SEM) provides a powerful tool to visualize and quantify the surface and structural changes induced by chemical treatments [3]. SEM enables the observation of surface roughness, fibrillation, microfibril exposure, and possible degradation features such as microcracks, which provide valuable insights into the treatment efficacy and optimal process conditions [4, 20].

To address these gaps, the present study investigates the combined effects of NaOH alkali treatment and Soxhlet solvent

extraction on the chemical composition and surface morphology of false banana fibers. Specifically, the study evaluates the changes in extractive content, hemicellulose, lignin, and cellulose across varying NaOH concentrations, and correlates these changes with morphological transformations observed through SEM analysis. The novelty of this work lies in systematically investigating the combined effect of NaOH alkali treatment at different concentrations together with Soxhlet solvent extraction on the chemical composition and surface morphology of *E. ventricosum* fibers. Unlike previous studies that mainly examined untreated fibers or single-step treatments, this study correlates compositional purification (extractives, hemicellulose, lignin, and cellulose) with SEM-based morphological transformations to identify optimal treatment conditions and provide deeper insight into the structure–property relationships of false banana fibers.

2 | Materials and Methods

2.1 | Materials

In this work, false banana (*E. ventricosum*) fibers were mechanically extracted by manual decortication from the pseudostems of mature plants collected in the Hosanna area, southern Ethiopia. The extraction procedure involved longitudinally splitting the pseudostem and scraping the fibrous bundles using a stainless-steel knife to separate the fibers from the parenchymatous tissue. This method allows the recovery of continuous fiber bundles while minimizing mechanical damage. Pseudostems were selected for uniform maturity and fiber quality to ensure consistency across samples. Immediately after extraction, the fibers contained residual mucilage, sap, and adhering plant tissues. Therefore, the freshly extracted fibers were rinsed with distilled water to remove loose impurities and mucilage. The fibers were then air-washed and subsequently oven-dried at 60°C for 24 h to achieve a constant moisture content. Dried fibers were cut into uniform lengths of approximately 4–5 cm and stored in airtight polyethylene bags at room temperature until further treatment. Figure 2 shows the sequence of steps followed for the preparation of raw *E. ventricosum* fibers before treatment.

All reagents used were of analytical grade. Sodium hydroxide pellets (NaOH, ≥ 98%), concentrated sulfuric acid (H_2SO_4, 72%), benzene, and ethanol (95%) were procured from Sun Industry and Trading PLC, Addis Ababa, Ethiopia. Distilled water was used throughout the study for washing, dilution, and analytical procedures to avoid contamination and ensure accuracy.

The fiber chemical analyses were performed using precision analytical balances (±0.1 mg) and standard laboratory apparatus. Morphological characterization was carried out using a TESCAN VEGA3 SBH SEM, operated at 30 kV accelerating voltage and 32.5 mm working distance, to visualize fiber surface features.

2.2 | Alkali Treatment and Solvent Extraction

To investigate the influence of alkali concentration on fiber composition and morphology, the dried *E. ventricosum* fibers were treated with NaOH solutions at concentration levels of 2%, 4%, 6%, and 8% (w/v). These concentrations were selected based on previous studies [21]. Fiber samples (20 g per treatment group) were immersed in NaOH solution prepared at a solid-to-liquid ratio of 1:20 (w/v). The treatment was carried out at room temperature for 4 h by submerging the fiber in distilled water with a consistent alkali concentration [17]. After treatment, the fibers were thoroughly rinsed with distilled water until a neutral pH (≈7) was reached, confirmed using pH indicator strips. Neutralized fibers were then oven-dried at 60°C for 12 h and stored in desiccators until further analysis. The initial alkali pretreatment serves to remove noncarbohydrate substances and cleave ether linkages in lignin, enhancing the efficiency of subsequent hemicellulose extraction. Figure 3 shows the overall experimental workflow,

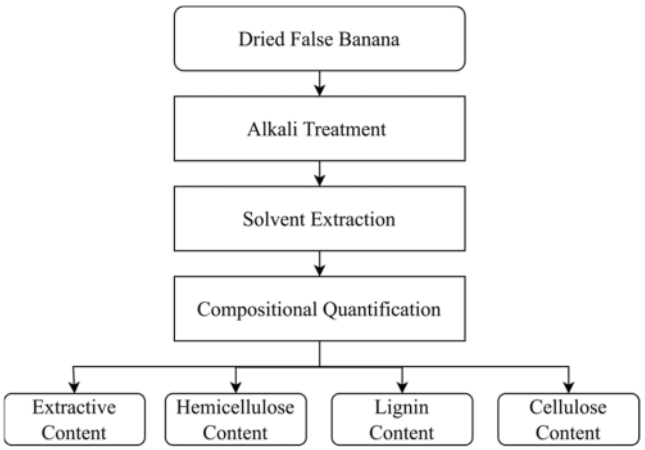

FIGURE 3 | Experimental workflow for chemical composition analysis of false banana fibers.

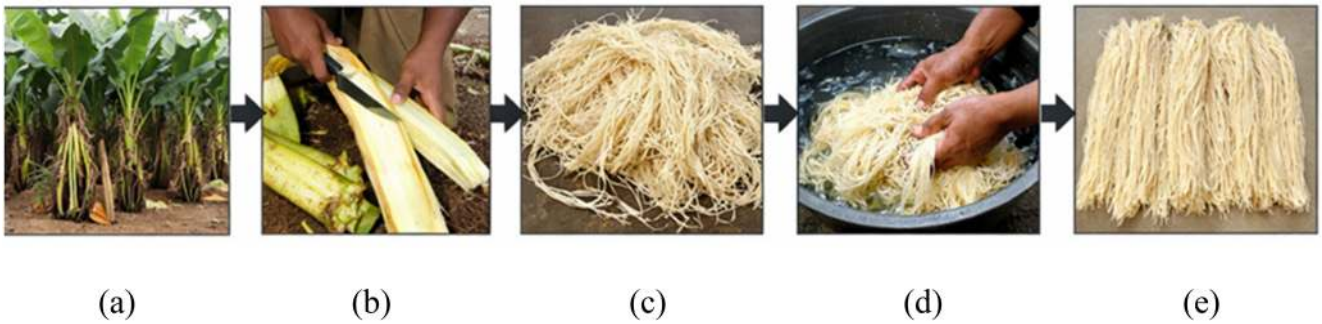

FIGURE 2 | Preparation of *Ensete ventricosum* fibers: (a) false banana plants, (b) mechanical extraction of fibers, (c) extracted fiber bundles, (d) washing of fibers with distilled water to remove mucilage and surface impurities, and (e) air-dried fibers ready for treatment.

including alkali treatment, solvent extraction, and subsequent compositional analysis.

2.3 | Extractive Content Determination

The extractive content of *E. ventricosum* fibers was determined using a Soxhlet extraction method with a benzene–ethanol mixture (2:1 v/v) following alkali pretreatment, as shown in Figure 3. Initially, empty thimbles were weighed, and their masses recorded. Each fiber sample was then placed in a thimble, and the combined weight was recorded as Thimble + Fiber. Fibers were treated with NaOH at concentrations ranging from 2% to 8% and thoroughly rinsed with distilled water before extraction.

The treated fibers were placed in a Soxhlet apparatus and refluxed for 6 h with the benzene–ethanol mixture to remove waxes, fats, and other soluble extractives. After extraction, fibers were oven-dried at 60°C until a constant weight was achieved. The mass of the thimble containing the extractive-free fiber was recorded as Thimble + Extractive-Free. The mass of extractives ($M_{\text{Extractive}}$) was calculated as:

$$M_{\text{Extractive}} = M_{\text{Thimble+Fiber}} - M_{\text{Thimble+Extractive-Free}} \quad (2)$$

The percentage of extractives in the fiber was then determined gravimetrically [22]:

$$\%\text{Extractives} = \left(\frac{M_{\text{Original Fiber}} - M_{\text{Extractive-free Fiber}}}{M_{\text{Original Fiber}}} \right) \times 100\% \quad (3)$$

All measurements were performed using a precision analytical balance with ±0.1 mg accuracy, and each experiment was conducted in triplicate to ensure reproducibility of the results. Figure 4 shows the Soxhlet apparatus used for the extraction.



FIGURE 4 | Soxhlet apparatus for determining the extractive content of *Ensete ventricosum* fibers. Due to the toxicity and flammability of benzene, all procedures were conducted under a fume hood with strict adherence to safety precautions. Proper handling of solvents was maintained throughout the procedure to ensure laboratory safety.

2.4 | Chemical Composition Analysis

In this section, the methods used to quantify hemicellulose, lignin, and cellulose contents in *E. ventricosum* fibers are described. All analyses were performed on extractive-free fibers obtained after Soxhlet extraction.

To ensure the reliability and reproducibility of the experimental results, all compositional analyses (extractive content, hemicellulose, lignin, and cellulose determination) were conducted in triplicate for each treatment condition. The reported values represent the average of three independent measurements, and the experimental procedures were repeated under identical conditions to minimize measurement variability.

2.4.1 | Hemicellulose Content Analysis

Hemicellulose was determined using an alkaline extraction method. One gram of oven-dried extractive-free fiber was treated with 150 mL of 3% NaOH solution at 70°C for 3 h under continuous stirring (150 rpm). The mixture was vacuum-filtered, and the residue was washed with distilled water until a neutral pH was reached. The residue, representing hemicellulose-free fiber, was oven-dried at 60°C to constant weight.

The hemicellulose content was calculated as:

$$\%\text{Hemicellulose} = \left(\frac{M_{\text{Hemicellulose}}}{M_{\text{Extractive-free fiber}}} \right) \times 100 \quad (4)$$

This correction accounts for the mass of extractives, providing an accurate measure of hemicellulose content.

2.4.2 | Lignin Content Determination

Lignin content was determined using a two-stage sulfuric acid hydrolysis method to quantify both acid-insoluble and acid-soluble fractions. For each sample, 0.3 g of extractive-free fiber was treated with 3 mL of 72% H_2SO_4 at room temperature (~25°C) for 2 h, with gentle agitation every 30 min. The mixture was then diluted with 84 mL of distilled water and autoclaved at 121°C for 1 h to complete hydrolysis.

The residue obtained after filtration was dried and weighed as acid-insoluble lignin. The filtrate was analyzed for acid-soluble lignin by measuring absorbance at 205 nm using UV spectrophotometry. The concentration of acid soluble-lignin (g/L) was determined as [23]:

$$\text{Acid} - \text{soluble lignin} = \frac{A}{a \times b} \times df \quad (5)$$

where A is the absorbance at 205 nm, a is the absorptivity (typically 110 $L/g \cdot cm$ for lignin), b is the path length, and df is the dilution factor.

The total lignin content was then computed as the sum of the acid-insoluble and acid-soluble fractions. The percentage lignin was calculated as:

$$\%\text{Lignin} = \left(\frac{M_{\text{Lignin}}}{M_{\text{Extractive-free fiber}}} \right) \times 100 \quad (6)$$

This method ensured accurate quantification of lignin components by accounting for both soluble and insoluble fractions.

2.4.3 | Cellulose Content Determination

Cellulose content was determined indirectly by subtracting the measured percentages of extractives, hemicellulose, and lignin from the total fiber mass. The calculation follows standard lignocellulosic analysis protocols [23]:

$$\%\text{Cellulose} = 100 - (\%\text{Hemicellulose} + \%\text{Lignin}) \quad (7)$$

This approach assumes that cellulose constitutes the remaining mass fraction in the fiber after removal of extractives, hemicellulose, and lignin, providing a reliable determination of cellulose content.

2.5 | Morphological Characterization

The surface morphology of *E. ventricosum* fibers was analyzed using SEM following sequential alkali treatment and Soxhlet extractive removal. Fiber samples were oven-dried at 60°C for 4 h and cut into ~10 mm segments. The samples were mounted on aluminum stubs with double-sided conductive carbon tape, ensuring the longitudinal fiber surfaces were exposed, and sputter-coated with a ~10 nm gold layer to prevent charging.

SEM imaging was performed using a TESCAN VEGA3 SBH instrument at an accelerating voltage of 30 kV and a working distance of 32.5 mm. The high-energy electron beam scanned the fiber surfaces in a raster pattern, revealing topographical features such as microfibrils, grooves, impurities, wavy structures, and potential defects. Micrographs were captured at magnifications ranging from 200× to 5000× to visualize both general and fine structural details.

3 | Results and Discussion

In this section, the effects of sodium hydroxide (NaOH) treatment on the chemical composition and morphological structure of *E. ventricosum* fibers are presented and discussed in detail. Emphasis is placed on correlating compositional changes with morphological modifications.

3.1 | Effect of NaOH on Extractive Content

Table 1 shows the extractive content of *E. ventricosum* fibers treated with different NaOH concentrations. The untreated fibers exhibited the highest extractive content (1.28%), whereas NaOH-treated samples showed substantially lower values ranging from 0.35% to 0.61%. The lowest extractive levels were recorded at 2% and 8% NaOH, indicating effective removal of surface impurities such as waxes, fats, and soluble organic compounds. The sharp decrease at 2% and 8% NaOH indicates that alkali pretreatment, followed by benzene–ethanol Soxhlet extraction, effectively removes waxes, fats, and other soluble extractives. This reduction reflects the efficiency of the alkali–solvent purification synergy, where NaOH opens the fiber surface, and Soxhlet extraction dissolves hydrophobic residues. Similar trends have been reported for jute and banana fibers, where alkali treatment improves surface reactivity and fiber–matrix adhesion [24, 25].

As seen, these findings confirm that NaOH concentrations between 2% and 6% are sufficient to significantly reduce extractives without over-degrading cellulose. The overall trend indicates that initial alkali exposure (2% NaOH) rapidly removes loosely bound surface extractives, while further increases in NaOH concentration maintain low extractive levels due to continued surface purification. The slight variation observed between 4% and 6% may be attributed to experimental variability and differences in fiber surface accessibility during treatment.

3.2 | Hemicellulose Reduction Trends

The hemicellulose content decreased consistently with increasing NaOH concentration, as presented in Table 2. Untreated fibers contained 16.21% hemicellulose, which progressively dropped to 9.44% at 8% NaOH. The largest reduction occurred between 2% and 4% NaOH, indicating that moderate alkali strength efficiently dissolves amorphous hemicellulose by disrupting hydrogen bonds. Above 6% NaOH, further reduction was minimal, suggesting near-complete hemicellulose removal. This finding is consistent with the literature, where NaOH is known to selectively target hemicellulose ahead of lignin [26, 27]. The decrease in hemicellulose enhances fibrillation and increases cellulose exposure, thereby improving fiber compatibility in composite reinforcement. This progressive reduction demonstrates that hemicellulose is the most susceptible component to alkali treatment, with significant dissolution occurring between 2% and 4% NaOH, followed by slower removal at higher concentrations

TABLE 1 | Effect of NaOH concentration on extractive content of false banana fibers.

NaOH (%)	M_{Thimble} (g)	$M_{\text{Thimble+Fiber}}$ (g)	M_{Fiber} (g)	$M_{\text{Thimble+Extractive Free}}$ (g)	$M_{\text{Extractive}}$ (g)	%Extractives (g)
0	4.7218	6.76	2.0382	6.734	0.0262	1.28
2	3.631	5.6516	2.0206	5.6445	0.0071	0.35
4	4.3	6.3575	2.0575	6.345	0.0125	0.61
6	4.4445	6.4499	2.0054	6.4395	0.0104	0.52
8	4.5045	6.551	2.0465	6.5437	0.0078	0.36

TABLE 2 | Effect of NaOH concentration on hemicellulose content.

NaOH (%)	$M_{\text{Extractive Free}}$	M_{Final}	$M_{\text{Hemicellulose}}$	%Hemicellulose
0	1.0061	0.843	0.1631	16.21
2	1.0052	0.8571	0.1481	14.73
4	1.0071	0.8914	0.1157	11.49
6	1.0071	0.9073	0.0998	9.91
8	1.0073	0.9122	0.0951	9.44

TABLE 3 | Effect of NaOH concentration on lignin content.

NaOH (%)	Acid insoluble lignin	Acid-soluble lignin	M_{Lignin}	% Lignin
0	0.301	0.0591	0.3601	19.65
2	0.307	0.0526	0.3596	17.16
4	0.305	0.0517	0.3567	16.97
6	0.303	0.04803	0.35103	15.87
8	0.305	0.0472	0.3522	15.50

as the remaining hemicellulose becomes less accessible within the fiber structure.

Hemicellulose content was determined by the standard extraction and hydrolysis method. Although the alkali pretreatment may release hemicellulose into multiple fractions, the cumulative content was calculated. For more precise profiling of carbohydrate groups, chromatographic techniques such as HPLC can be applied in future studies.

3.3 | Lignin Degradation

NaOH pretreatment caused partial delignification by cleaving ether and ester linkages in lignin–carbohydrate complexes. Table 3 shows that lignin content decreased from 19.65% in untreated fibers to 15.50% at 8% NaOH, indicating moderate delignification with increasing alkali concentration. The reduction reflects the partial solubilization of lignin fragments under alkaline conditions. This partial removal is beneficial because it increases fiber flexibility and exposes cellulose surfaces, which can enhance interfacial bonding in polymer composites. The most noticeable reduction occurs between untreated and 6%–8% NaOH treatments, suggesting progressive cleavage of lignin linkages within the lignocellulosic matrix.

Lignin content was determined as the sum of acid-insoluble and acid-soluble lignin. It should be noted that acid-insoluble lignin may contain residual ash, which can slightly affect total lignin values. Despite this, the observed trend of partial delignification with increasing NaOH concentration is clear.

3.4 | Cellulose Enrichment

Cellulose content of *E. ventricosum* fibers increased steadily with NaOH pretreatment due to the removal of extractives, hemicellulose, and partial lignin. Table 4 shows that cellulose increased from 62.87% in untreated fibers to 74.71% after treatment with 8% NaOH. This increase reflects the progressive removal of noncellulosic components rather than an absolute increase in cellulose mass. Fibers treated with 4%–6% NaOH showed a substantial increase in cellulose while maintaining structural integrity, suggesting an optimal balance between chemical purification and preservation of fiber structure.

TABLE 4 | Chemical composition of NaOH-treated false banana fibers.

% NaOH	% Cellulose	% Hemicellulose	% Lignin	% Extractives
0	62.87	16.21	19.65	1.27
2	67.76	14.73	17.16	0.35
4	70.94	11.49	16.97	0.60
6	73.71	9.91	15.87	0.51
8	74.71	9.44	15.50	0.35

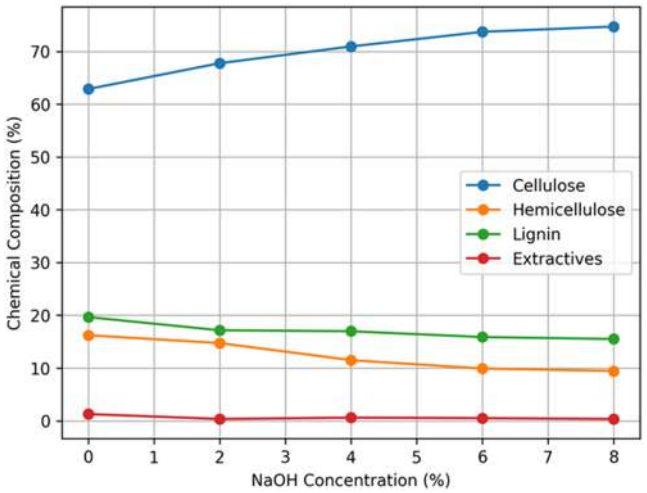

FIGURE 5 | Effect of NaOH concentration on the chemical composition of *Ensete ventricosum* fibers.

The overall compositional trend with increasing NaOH concentration is shown in Figure 5, which summarizes the variations in cellulose, hemicellulose, lignin, and extractives as a function of alkali treatment. As shown in the figure, hemicellulose content decreases markedly with increasing NaOH concentration, confirming its high susceptibility to alkaline dissolution. Lignin exhibits only a moderate reduction, reflecting its comparatively greater resistance to mild alkali conditions. In contrast, the relative proportion of cellulose increases progressively as noncellulosic components are removed from the fiber matrix. This increase does not represent an absolute formation of cellulose but rather a relative enrichment resulting from the dissolution of hemicellulose, extractives, and partial delignification. These compositional changes demonstrate that NaOH treatment effectively purifies the fiber structure by removing amorphous constituents and exposing cellulose-rich regions. Such modifications contribute to improved fiber surface characteristics and enhanced compatibility with polymer matrices for composite reinforcement applications.

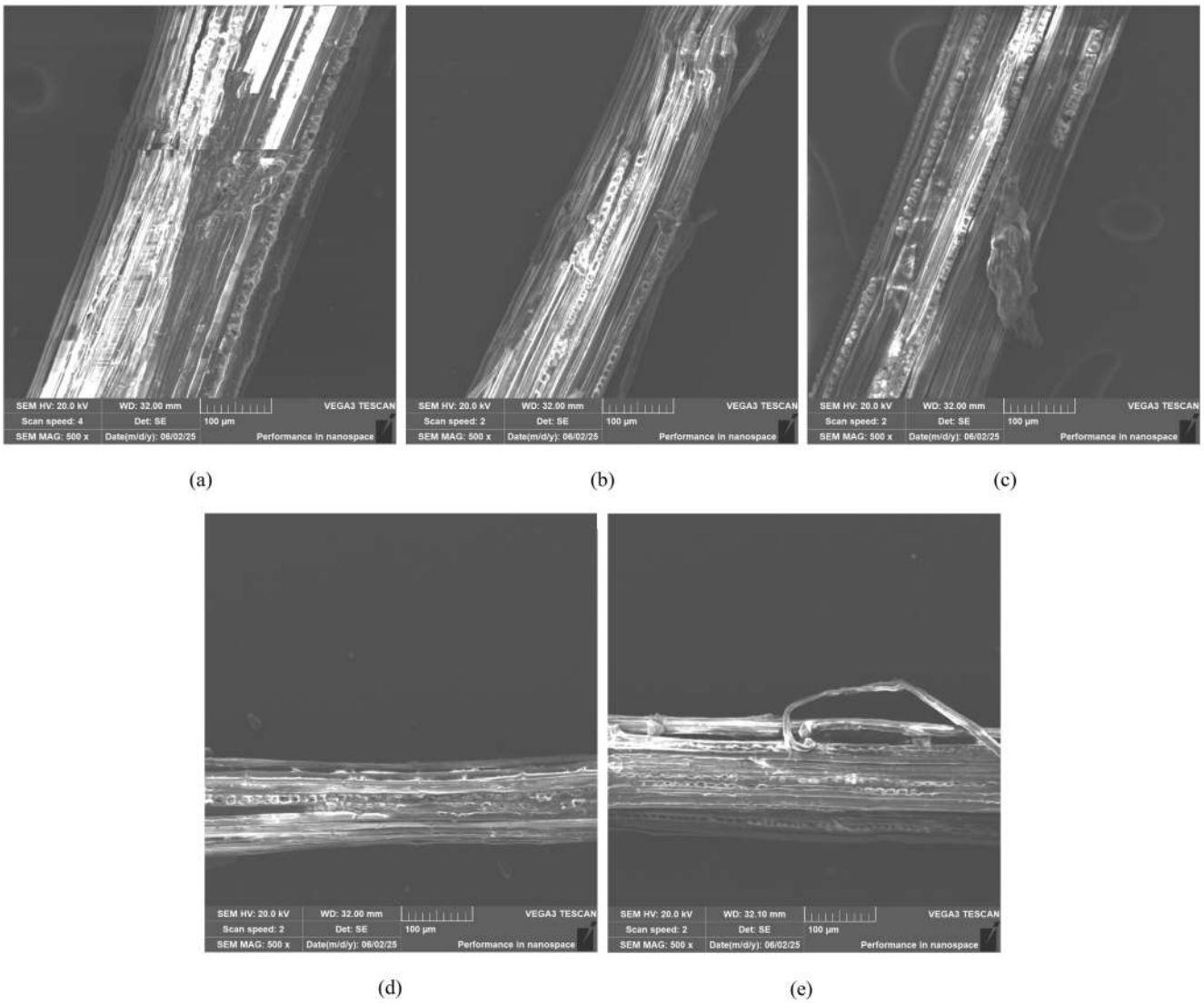

FIGURE 6 | Representative SEM micrographs of *Ensete ventricosum* fibers showing (a) untreated fiber (0% NaOH), and fibers treated with (b) 2% NaOH, (c) 4% NaOH, (d) 6% NaOH, and (e) 8% NaOH.

3.5 | Morphological Analysis

Figure 6 shows representative SEM micrographs illustrating the progressive surface modifications of *E. ventricosum* fibers as a function of NaOH concentration. The images were captured using a TESCAN VEGA3 SBH SEM operating at an accelerating voltage of 30 kV and a working distance of 32 mm. The morphological trends observed closely correspond with the chemical composition changes reported in Tables 1–4, demonstrating the influence of alkali treatment on fiber surface structure.

3.5.1 | Untreated Fiber

The untreated fiber surface, shown in Figure 6a, exhibits a relatively smooth and compact morphology covered by natural surface impurities such as extractives, hemicellulose, and lignin, which mask the underlying cellulose structure. The surface appears glossy and intact, consistent with the relatively high extractives (1.28%), hemicellulose (16.21%), and lignin (19.65%) contents identified in the chemical composition analysis. This coating of amorphous and hydrophobic substances limits direct exposure of cellulose and contributes to the naturally weak interfacial bonding of untreated fibers when incorporated into polymer matrices. Consequently, the smooth and impurity-covered surface reduces mechanical interlocking and restricts effective chemical interaction with matrix materials.

3.5.2 | Mild Alkali Treatment (2%–4% NaOH)

Upon treatment with mild NaOH concentrations (2%–4%), the fiber surfaces show partial removal of noncellulosic components, leading to noticeable surface roughening and the onset of fibrillation. At 2% NaOH, the fiber surface shown in Figure 6b begins to display small depressions and irregularities caused by partial dissolution of amorphous polysaccharides, while the overall structural framework remains largely intact.

The transformation becomes more distinct at 4% NaOH, as illustrated in Figure 6c. The fiber surface becomes significantly rougher, and microvoids start to appear as hemicellulose (11.49%) and lignin (16.97%) contents decrease following alkali treatment. The observed morphological changes primarily result from surface swelling and the exposure of cellulose-rich microdomains rather than the separation of individual elementary fibrils. In longitudinal SEM observations, individual cellulose bundles or elementary fibrils are generally not visible and can only be clearly identified in cross-sectional views. Therefore, the surface features observed in Figure 6c represent surface fibrillation and partial delamination associated with the progressive removal of noncellulosic components. These morphological modifications correlate well with the chemical composition data and indicate an improvement in surface reactivity, which is beneficial for enhancing fiber–matrix interactions in composite materials.

3.5.3 | Intensive Alkali Treatment (6%–8% NaOH)

More pronounced structural modification occurs at 6% NaOH, as shown in Figure 6d. Treatment with 6% NaOH produces highly rough and fibrillated fiber surfaces due to substantial removal of hemicellulose, extractives, and portions of lignin. At this treatment level, the microfibrillar texture of cellulose becomes more evident as the surrounding lignocellulosic matrix is progressively removed. This treatment condition provides an optimal balance between chemical purification and preservation of fiber structure, reflected by the increase in calculated cellulose content to 73.71% and the reduction of hemicellulose to 9.91%. Fibers treated at this concentration exhibit rough surfaces with well-defined microstructural features that can improve mechanical interlocking and interfacial bonding when used as reinforcement in polymer composites.

In contrast, fibers treated with 8% NaOH, as depicted in Figure 6e, show evidence of excessive chemical attack, including surface microcracks, ruptures, and partial collapse of the fibrillar structure. Although the calculated cellulose content increases further to 74.71% due to additional removal of noncellulosic components, the observed morphology indicates structural degradation caused by over-treatment with strong alkali. Such deterioration can compromise the mechanical integrity of the fibers and reduce their effectiveness as reinforcement materials. This observation demonstrates that increasing alkali concentration does not necessarily improve fiber performance and may instead damage the structural framework of the fiber.

3.6 | Correlation of Chemical and Morphological Modifications

The aim of correlating the chemical compositional changes with the observed fiber morphology is to clarify how NaOH-induced chemical modifications influence the structural evolution of *E. ventricosum* fibers and to identify the treatment conditions that provide optimal surface characteristics for composite reinforcement. Establishing this relationship enables the compositional data obtained from chemical analyses to be interpreted in terms of the physical structural changes observed in SEM micrographs.

The morphological modifications observed in the SEM images correspond closely with the chemical compositional changes induced by NaOH treatment. As the NaOH concentration increases from 2% to 8%, the progressive removal of extractives and hemicellulose results in increased surface roughness and fibrillation, while excessive alkali exposure at higher concentrations can cause structural damage such as microcracks due to degradation of the lignocellulosic matrix.

Initially, as extractives and hemicellulose are progressively removed, the fiber surface transitions from a smooth and impurity-covered morphology to a rougher and more fibrillated structure. This process exposes cellulose-rich regions of the fiber, although individual cellulose bundles and elementary fibrils are generally not visible in longitudinal SEM images and are more clearly observed in cross-sectional views. The partial removal of lignin further contributes to surface delamination and the formation of a more open microstructure, which can enhance potential fiber–matrix adhesion. It should be noted that untreated fibers contain the full lignin fraction, whereas alkali-treated fibers retain only the residual lignin remaining after partial delignification.

These structural modifications are consistent with the relative increase in cellulose content resulting from the progressive removal of noncellulosic components, which is reflected in the more pronounced surface roughness observed at higher treatment levels. The correlation between the compositional data (Tables 1–4) and SEM observations (Figure 6) confirms that NaOH pretreatment simultaneously modifies both the chemical purity and the microstructural characteristics of the fibers.

Among the tested concentrations, NaOH treatments between 4% and 6% provide the most effective balance between chemical purification, cellulose enrichment, and preservation of fiber structural integrity. Fibers treated within this range exhibit rough and fibrillated surfaces with minimal structural damage, which is consistent with trends reported in previous studies [9, 28].

Treatment at 8% NaOH, however, is excessively aggressive, leading to surface microcracks, ruptures, and partial collapse of the fibrillar structure. Although the calculated cellulose content continues to increase due to the removal of remaining noncellulosic constituents, the resulting structural degradation reduces the overall integrity of the fiber. This observation highlights that increasing alkali concentration does not necessarily improve fiber performance; instead, an optimal treatment level must be identified to enhance chemical purification while preserving the structural framework of the fiber.

Thus, the SEM observations provide clear visual confirmation of the chemical composition results and demonstrate the compositional–morphological relationship associated with increasing NaOH concentration, highlighting 4%–6% NaOH as the optimal pretreatment range for producing structurally stable and chemically purified *E. ventricosum* fibers suitable for biocomposite reinforcement applications.

4 | Conclusion

In this study, the chemical composition and morphological characteristics of false banana (*E. ventricosum*) fibers treated with various sodium hydroxide (NaOH) concentrations in combination with Soxhlet solvent extraction were investigated. Alkali treatment significantly modified the fiber composition by progressively removing noncellulosic components such as extractives, hemicellulose, and portions of lignin. Extractive content decreased from 1.28% in untreated fibers to approximately 0.35% at 8% NaOH, demonstrating effective removal of surface impurities. Hemicellulose content reduced from 16.21% to 9.44%, while lignin content decreased from 19.65% to 15.50%, indicating partial delignification under alkaline conditions. As a result, the calculated cellulose content increased from 62.87% in untreated fibers to 74.71% after alkali treatment. This increase represents the relative enrichment of cellulose due to the removal of noncellulosic components rather than an absolute increase in cellulose content. Residual ash (˜3%–4%) was also considered and was not found to significantly influence the overall compositional trends.

Morphological observations using SEM supported the compositional results and confirmed the structural modifications induced by alkali treatment. Untreated fibers exhibited relatively smooth and waxy surfaces associated with the presence of extractives and lignocellulosic matrix components, whereas treated fibers showed progressively rough and fibrillated surfaces due to the removal of hemicellulose, lignin, and surface impurities. Fibers treated with 6% NaOH exhibited pronounced fibrillation and improved surface roughness, indicating enhanced exposure of cellulose-rich regions. In contrast, treatment with 8% NaOH resulted in the formation of surface microcracks and partial structural degradation, suggesting excessive chemical attack on the fiber structure.

To this end, NaOH concentrations between 4% and 6% provided the most effective balance between chemical purification and preservation of fiber structural integrity. Moderate alkali treatment enhances cellulose exposure and surface roughness while maintaining the mechanical framework of the fibers, which is beneficial for improving interfacial bonding in composite materials. These findings confirm that controlled alkali pretreatment significantly improves both the chemical purity and surface morphology of *E. ventricosum* fibers, supporting their potential suitability as reinforcement in bio-based composite applications.

The novelty of this study lies in demonstrating the combined influence of NaOH alkali treatment and Soxhlet solvent extraction on both the chemical composition and SEM-observed surface morphology of false banana fibers, while identifying an optimal treatment range that enhances cellulose exposure without causing significant structural degradation.

In future research, the mechanical, thermal, and structural performance of the treated fibers should be further investigated to fully evaluate their potential for composite applications. Characterization techniques such as X-ray diffraction (XRD) for crystallinity analysis, thermogravimetric analysis (TGA/DTG) for thermal stability assessment, and Fourier-transform infrared spectroscopy (FTIR) for identifying chemical functional groups are recommended to confirm treatment-induced structural changes and cellulose integrity. Additionally, exploring advanced modification approaches, including combined alkali–enzymatic treatments or plasma surface modification, may further enhance fiber performance while minimizing structural degradation. Finally, incorporating treated *E. ventricosum* fibers into polymer matrix composites and evaluating their mechanical behavior will be essential to confirm their effectiveness as sustainable reinforcement materials.

Author Contributions

Michael Ayele Gebremichael: conceptualization, methodology, investigation, formal analysis, writing – original draft. **Belete Sirahbizu Yigezu:** conceptualization, methodology, validation, visualization, project administration, supervision, writing – review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Peer Review

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