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Characterization of Alkali-Extracted Cellulose from Banana Pseudostems for Eco-Friendly Absorbent Applications: Influence of Extraction Parameters and Alkali Type on Fiber Quality

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ABSTRACT

Banana pseudostem (BPS), a plentiful agricultural by-product produced after banana harvesting, is a promising renewable source of cellulose for eco-friendly core absorbent applications in sanitary pads. However, limited information exists on optimized alkali extraction conditions and the comparative effectiveness of commercial sodium hydroxide (NaOH) and bio-derived potassium hydroxide (KOH) for Kenyan banana pseudostems. This study investigated the extraction and characterization of BPS fibres using NaOH and KOH derived from banana biomass ash. Stratified random sampling was used to collect 350 pseudostem samples from Meru, Kisii, and Kirinyaga Counties, Kenya. Fibre extraction was evaluated at alkali concentrations of 5–15% (w/v) and extraction times of 30–120 min at a material-to-solution ratio of 1:40, with response surface methodology (RSM) used to model and optimize extraction. Alkali concentration, extraction time, and temperature significantly influenced fibre yield ($p < 0.0001$). KOH obtained from biomass ash increased in purity from 66.4% in the crude extract to 88.0% after crystallization. The maximum reported fibre yield was 73.2 ± 1.9% for Kiganda treated with 5% NaOH for 120 min at 80 °C, whereas the highest KOH yield was 60.2 ± 1.0% for Sweet Banana treated with 5% KOH for 60 min. NaOH-treated fibres generally exhibited higher tenacity, a finer structure, greater fibre-length retention, and lower residual gum than KOH-treated fibres. FTIR-ATR confirmed characteristic cellulose bands at 3309–3310, 2893–2901, 1419, 1319, 1026/1018, and 895 cm^{-1}, with the 1026, 1419, and 895 cm^{-1} bands more pronounced after NaOH treatment, indicating greater cellulose purification. Cellulose extracted with NaOH and KOH demonstrated absorbency indices of 11.72 and 11.08 g/g, with average absorption values of 293.7% and 276.7%, respectively. Cellulose extracted with NaOH exhibited marginally improved absorbency and overall fiber quality. These results indicate that cellulose derived from BPS can serve as a biodegradable absorbent material for sanitary pads, while KOH sourced from ash provides a sustainable option for fibre processing and absorbent-material development.

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KEYWORDS: *Cellulose fibres, alkali extraction, banana pseudostem, response surface methodology, FTIR-ATR, biodegradable absorbents, circular bioeconomy.*

1. INTRODUCTION

Menstrual hygiene products are vital for the health, dignity, and well-being of women and girls worldwide. The widespread use of disposable sanitary pads containing petroleum-based polymers, synthetic superabsorbent materials, and non-biodegradable plastics has created a growing environmental challenge(Aujla et al., 2025). Conventional sanitary pads can persist in landfills for long periods and contribute to municipal solid waste and plastic contamination (Mogale et al., 2024). Increasing

environmental awareness and the shift towards sustainable materials have therefore stimulated research into biodegradable alternatives derived from renewable lignocellulosic biomass. Among agricultural by-products, banana pseudostems (BPS) are abundant but remain substantially underutilized (Zaini et al., 2023).

Plant fibres possess attractive characteristics including low density, stiffness, softness, biodegradability, and useful mechanical properties (McKay et al., 2024). These attributes have increased interest in replacing synthetic fibres in selected applications. Banana fibre is particularly promising because it is renewable, biodegradable, and generated as an agricultural residue. Its use in absorbent materials could simultaneously address waste-management challenges and provide a value-added use for banana production residues(Babaremu et al., 2022).

Approximately 1.8 billion women experience menstruation globally, generating substantial demand for menstrual hygiene products (Harrison & Tyson, 2023). Conventional single-use sanitary pads can contain a high proportion of plastic materials, including polyethylene, polypropylene, and superabsorbent polymers (Blignaut et al., 2025). The persistence of these materials has intensified interest in biodegradable alternatives. Banana-fibre-based absorbent cores have consequently attracted research attention because treatment can improve fibre cleanliness, softness, and functional performance (Pawar et al., 2024), while banana-fibre menstrual products have also been investigated for feasibility and acceptability (Achuthan et al., 2021).

In Kenya, bananas are important for food security, household income, and rural livelihoods. Major production areas include Meru, Kirinyaga, Embu, Murang'a, Kisii, Nyamira, Bungoma, and Kakamega (Wahome et al., 2021). Following fruit harvesting, large quantities of BPS are discarded even though the material contains cellulose, hemicellulose, lignin, pectin, and other components that can be converted into value-added products (Badanayak et al., 2023). Banana fibres have been reported to possess useful tensile, moisture-retention, biodegradability, and biocompatibility characteristics, supporting their potential use in textiles, composites, paper, hygiene products, and other applications (Kossalbayev et al., 2025).

Previous studies have used markedly different alkali-treatment conditions for banana and related plant fibres. Reported NaOH, KOH, and ash concentrations include 5%, 10%, and 20% (Kaima et al., 2023), while other studies have used NaOH concentrations ranging from 3% to 20% and different extraction durations (Koistinen et al., 2025; Massaguni et al., 2025). These differences indicate that a single standardized alkali concentration and treatment duration cannot be assumed to provide optimum fibre recovery and quality across plant-fibre systems. Differences in alkali concentration, temperature, and extraction time may affect fibre yield, cellulose retention, delignification, crystallinity, and mechanical properties (Emrith et al., 2024; Patel & Patel, 2022).

Bio-based alkalis obtained from plant or wood ash have increasingly been investigated as alternatives to commercial alkalis. Ash-derived alkalis can promote delignification and hemicellulose removal while also creating value from agricultural residues. However, direct comparisons between biomass-derived KOH and commercial NaOH under comparable extraction conditions remain limited. The relative effects of these alkalis on fibre yield, cellulose structure, mechanical properties, and residual non-cellulosic material therefore require further investigation (Gomes et al., 2024).

This study investigated BPS fiber extraction using commercial NaOH and KOH prepared from banana biomass ash. The effects of alkali concentration, extraction duration, and temperature on fiber yield were examined using response surface methodology. The extracted fibers were further characterized for tenacity, fineness, length, residual gum, and FTIR-ATR spectral features. The study provides evidence for selecting extraction conditions that balance fiber recovery and quality while assessing the potential of an agricultural-residue-derived alkali within a circular bioeconomy framework.

2. Materials and Methods

2.1. Study Area and Sample Collection

BPS were obtained from three banana-growing counties in Kenya: Kisii, Meru, and Kirinyaga. The counties were selected to represent major banana-growing areas and varietal diversity. Ten farms were randomly selected in each county through a stratified sampling approach. Meru and Kirinyaga contributed Kiganda (Uganda Green) and Sweet Banana (Lady Finger), while Kisii additionally contributed Native Red Banana (Kienyeji). Mature pseudostems were collected immediately after fruiting, labelled by cultivar and county, and transported to the laboratory for preparation and characterization shown in figure 1. The study reports a total of 350 pseudostem samples.



Figure 1: BPS samples

2.2. Sample Preparation

Harvested BPS were cut into 100 cm sections and washed with tap water followed by distilled water to remove adhering soil and impurities. Outer sheaths were separated manually, and the fibre-containing tissues were decorticated and cleaned. Samples were sun-dried and subsequently oven-dried at 60 °C until constant mass before chemical extraction (Figure 2).



Figure 2: Biomass fiber decortication and drying

2.3. Experimental Design

Alkali extraction was evaluated using alkali type (NaOH or KOH), concentration (5, 10, and 15% w/v), extraction duration (30, 60, and 120 min), and treatment temperature. Each treatment combination was conducted in triplicate. Response surface methodology (RSM) was used to model the relationship between extraction variables and fibre yield, while analysis of variance (ANOVA) was used to assess the significance of the effects and identify conditions associated with high fibre yield(Checol & Sendekie, 2025; Zambare et al., 2023).

2.4. Sodium Hydroxide Extraction

Decorticated BPS (5 g) were treated with 200 mL NaOH solution at a 1:40 (w/v) material-to-solution ratio. Analytical-grade NaOH solutions of 5%, 10%, and 15% (w/v) were evaluated for 30, 60, and 120 min in a water bath maintained at 80 °C. Following extraction, fibres were neutralized with 100 mL of 1% (v/v) glacial acetic acid and washed with distilled water until the wash water reached pH 7.0 ± 0.5. The fibres were bleached with 10% hydrogen peroxide and oven-dried at 105 ± 3 °C for 24 h(Koistinen et al., 2025). Treatments were performed in triplicate using BPS collected from the three counties.

2.5. Preparation of Potassium Hydroxide and Extraction

KOH was prepared from banana peel and BPS ash using a modified water-based ash-leaching procedure (Figure 3). Biomass residues were combusted at 500 ± 50 °C for 4 h, cooled, ground, and sieved. Ash (300 g) was mixed with 2 L of warm distilled water at 40 °C, stirred for 30 min, and allowed to stand for 24 h. The extract was filtered through muslin cloth and Whatman No. 1 filter paper. Calcium hydroxide (50 g) was added to convert potassium carbonate to potassium hydroxide, followed by settling and vacuum filtration(El-Nahas et al., 2021). The filtrate was concentrated by evaporation, and the resulting KOH crystals were rinsed with ethanol and dried at 105 ± 3 °C. KOH purity was determined by acid-base titration using standardized 0.1 M HCl and methyl orange. The prepared KOH was used to formulate 5%, 10%, and 15% (w/v) solutions and applied under the same extraction conditions as NaOH.



Figure 3: KOH solution preparation using ash

2.6. Fibre Characterization

2.6.1. Tenacity

Tensile strength was measured in accordance with ASTM D3822 using a Universal Testing Machine fitted with a 10–100 N load cell. Single fibres were trimmed to 45 ± 5 mm, and at least 20 fibres per treatment were tested (Zulkarnain et al., 2025). Fibres were aligned to minimize bending and tested at a crosshead speed of 5 mm min^{-1} until failure. Tensile strength was calculated from the maximum force and cross-sectional area.

2.6.2. Fibre Fineness

Fibre fineness was determined using a gravimetric cut-and-weigh procedure in alignment with the guidelines of ISO 1973:2021. Fibres were conditioned at 20 ± 2 °C and 65 ± 2% relative humidity, cut to 100 mm, and weighed using an analytical balance with ±0.001 g readability. Equivalent fibre diameter was calculated from fibre mass, length, and a density of 1.40 g cm^{-3} (Kouidri et al., 2024).

2.6.3. Fibre Length

Cleaned and air-dried single fibres were separated and aligned in parallel. Fiber length was assessed using the single-fiber measurement technique following the guiding principle of ISO 6989:1981. Three hundred fibers from each treatment were measured using a millimetre ruler, and mean fibre length was calculated for each cultivar and alkali treatment (Balakrishnan et al., 2021)

2.6.4. Residual Gum

Residual gum was assessed by treating extracted fibres with 2% NaOH at a 1:40 fibre-to-liquor ratio for 2 h. The fibres were washed, neutralized with 1% acetic acid, rinsed to neutral pH, dried at 105 °C for 2 h, and weighed before and after degumming. Residual gum percentage was calculated from the mass loss after degumming. Gravimetric alkaline-extraction technique was modified from documented natural-fibre degumming methods (Yadav et al., 2022).

2.6.5. FTIR-ATR Analysis

Functional groups were examined by Fourier Transform Infrared Spectroscopy with Attenuated Total Reflectance (FTIR-ATR) in accordance with the principles of ASTM E1252. Oven-dried fibers were milled into a fine powder and analysed over the reported spectral range of 4000- 400 cm^{-1} after background correction under identical operating conditions(Nascimento et al., 2023).

2.6.6. Lateral Order Index

Cellulose structural ordering was assessed using the FTIR-based Lateral Order Index (LOI), calculated from the absorbance ratio associated with the 1420 cm^{-1} and 897 cm^{-1} bands. Measurements were performed in triplicate for fibres treated with 5% NaOH and 5% ash-derived KOH (Thandavamoorthy et al., 2023).

2.6.7. Cellulose Absorbency

The absorbency capacity of the cellulose samples was assessed by adapting the ASTM D570 standard procedure for water absorption of polymeric materials(Islam et al., 2025)

3. Results and Discussion

3.1. Purity of Ash-Derived KOH

The purity of KOH obtained from biomass ash increased from 66.4% in the crude extract to 88.0% after crystallization(Sun et al., 2025). The lower purity of the crude extract indicates the presence of impurities such as carbonates, silicates, and mineral salts commonly found in biomass ash, whereas recrystallization improved the quality of the alkali. The result demonstrates that banana biomass ash can provide a recoverable potassium-containing alkali for fibre processing and offers an additional route for valorizing agricultural residues (Peixoto et al., 2026).

3.2. Effect of Temperature and Alkali Concentration on Fibre Yield

Fibre yield increased with temperature up to approximately 80 °C and declined at higher temperatures (Cao et al., 2022) (Table 1 and Figure 1). Temperature and extraction duration significantly affected fibre yield ($p < 0.0001$). NaOH consistently produced higher yields than ash-derived KOH under comparable conditions. The highest yield in the temperature series was 73.0 ± 0.5% at 5% NaOH, 80 °C, and 60 min, compared with 59.5 ± 0.6% for KOH under the same conditions. Increasing alkali concentration from 5% to 15% generally reduced fibre recovery, indicating that stronger alkaline treatment promoted removal of non-cellulosic constituents but could also increase cellulose loss(Tesfay & Welegebreal, 2025). The reduction in yield at temperatures above 80 °C is consistent with excessive treatment severity causing degradation or dissolution of susceptible carbohydrate fractions (Figure 4).

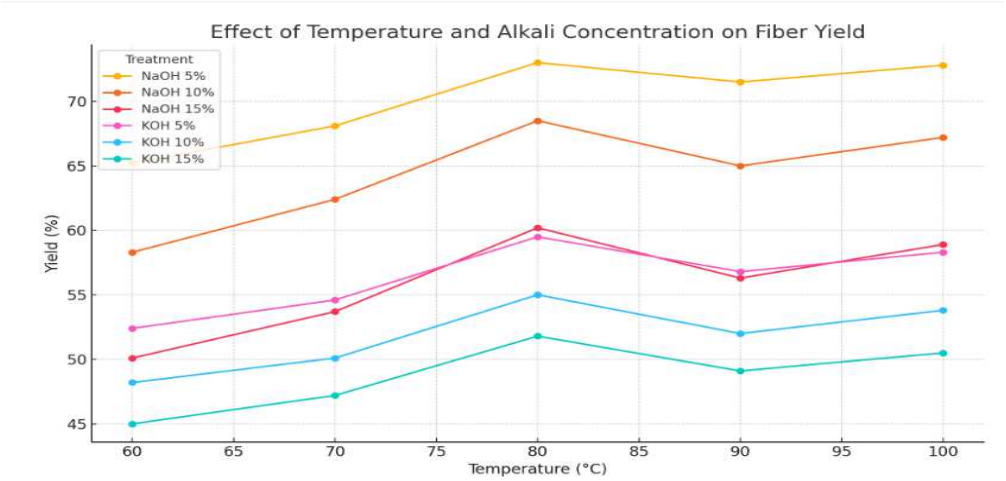


Figure 4: Effect of temperature and alkali concentration on fibre yield.

Moderate extraction temperatures increased fiber yield by facilitating fiber expansion, partial delignification, and improved cellulose accessibility, while a slight reduction in yield at 90°C was linked to partial degradation and dissolution of cellulose and hemicellulose. In the same way, raising alkali concentration from 5% to 15% gradually lowered fiber yield, suggesting that higher alkali levels enhanced cellulose loss even though they removed non-cellulosic components more efficiently (Liu et al., 2025).

Table 1: Fibre Yield at Different Temperatures and Alkali Concentrations

Alkali	Conc. (%)	Time (min)	60 °C	70 °C	80 °C	90 °C	100 °C
NaOH	5	120	62.1 ± 1.8	65.3 ± 1.5	71.0 ± 0.8	68.7 ± 1.2	71.2 ± 1.0
	5	60	65.2 ± 1.5	68.1 ± 1.2	73.0 ± 0.5	71.5 ± 0.9	72.8 ± 0.7
	5	30	63.8 ± 1.6	66.5 ± 1.3	72.5 ± 0.6	70.1 ± 1.0	71.9 ± 0.8
	10	120	55.2 ± 2.0	59.0 ± 1.7	66.3 ± 0.9	62.4 ± 1.4	64.8 ± 1.1
	10	60	58.3 ± 1.8	62.4 ± 1.5	68.5 ± 0.8	65.0 ± 1.3	67.2 ± 1.0
	10	30	56.7 ± 1.9	60.8 ± 1.6	67.0 ± 0.9	63.5 ± 1.3	65.9 ± 1.1
	15	120	47.5 ± 2.2	50.8 ± 1.9	58.0 ± 1.1	53.7 ± 1.6	56.2 ± 1.3
	15	60	50.1 ± 2.0	53.7 ± 1.7	60.2 ± 1.0	56.3 ± 1.5	58.9 ± 1.2
	15	30	48.9 ± 2.1	52.0 ± 1.8	59.1 ± 1.1	54.8 ± 1.5	57.5 ± 1.3
KOH	5	120	49.8 ± 1.2	51.9 ± 1.0	57.0 ± 0.6	53.8 ± 0.9	55.5 ± 0.7
	5	60	52.4 ± 1.0	54.6 ± 0.9	59.5 ± 0.6	56.8 ± 0.8	58.3 ± 0.7
	5	30	50.5 ± 1.1	52.8 ± 1.0	58.2 ± 0.6	55.0 ± 0.8	56.7 ± 0.7
	10	120	45.3 ± 1.4	47.2 ± 1.2	52.5 ± 0.8	49.0 ± 1.1	50.8 ± 0.9
	10	60	48.2 ± 1.2	50.1 ± 1.1	55.0 ± 0.7	52.0 ± 1.0	53.8 ± 0.9
	10	30	46.8 ± 1.3	48.7 ± 1.2	53.8 ± 0.8	50.6 ± 1.0	52.3 ± 0.9
	15	120	42.5 ± 1.6	44.3 ± 1.4	49.5 ± 1.0	46.0 ± 1.3	47.8 ± 1.1
	15	60	45.0 ± 1.5	47.2 ± 1.3	51.8 ± 0.9	49.1 ± 1.2	50.5 ± 1.0
	15	30	43.8 ± 1.6	45.7 ± 1.4	50.7 ± 1.0	47.6 ± 1.2	49.2 ± 1.1

3.3. RSM Optimization of Fibre Extraction

RSM optimization indicated that the extraction variables jointly influenced fibre yield and that the quadratic models for NaOH and KOH were highly significant ($p < 0.0001$). Under the reported optimized conditions, the

highest NaOH yield was obtained from Kiganda (Uganda Green) at 5% NaOH, 60-120 min, and 80 °C, with a maximum yield of 73.2 ± 1.9%. The highest KOH yield was 60.2 ± 1.0% for Sweet Banana (Lady Finger) at 5% KOH, 60 min, and 80 °C.

Table 2: Optimized Conditions for Extracting Banana Pseudostem Fibres

Parameter	NaOH (best yield)	KOH (best yield)
Concentration	5%	5%
Time	60–120 min	60 min
Species	Kiganda (Uganda Green)	Sweet Banana
Maximum yield	73.2 ± 1.9%	60.2 ± 1.0%

Table 3: Comparative NaOH and KOH Fibre Yields at Selected Experimental Conditions

Fibre species	Conc. (%)	Time (min)	NaOH yield (%)	KOH yield (%)
Kiganda (Uganda Green)	5	30	72.3 ± 2.1	58.9 ± 0.7
Kiganda (Uganda Green)	10	30	65.1 ± 0.9	58.2 ± 0.8
Kiganda (Uganda Green)	15	30	52.3 ± 1.9	56.2 ± 0.9
Kiganda (Uganda Green)	5	60	70.2 ± 1.3	60.0 ± 0.7
Kiganda (Uganda Green)	10	60	64.3 ± 1.5	57.1 ± 0.7
Kiganda (Uganda Green)	15	60	50.7 ± 2.5	55.4 ± 0.6
Kiganda (Uganda Green)	5	120	73.2 ± 1.9	58.9 ± 0.7
Kiganda (Uganda Green)	10	120	64.8 ± 1.3	56.3 ± 0.6
Kiganda (Uganda Green)	15	120	51.3 ± 1.5	55.7 ± 0.9
Sweet Banana (Lady Finger)	5	30	68.3 ± 0.9	59.5 ± 0.8
Sweet Banana (Lady Finger)	10	30	60.5 ± 0.8	57.3 ± 0.7
Sweet Banana (Lady Finger)	15	30	61.1 ± 1.3	56.2 ± 0.8
Sweet Banana (Lady Finger)	5	60	67.3 ± 0.8	60.2 ± 1.0
Sweet Banana (Lady Finger)	10	60	62.1 ± 1.5	58.3 ± 0.7
Sweet Banana (Lady Finger)	15	60	59.2 ± 0.9	56.3 ± 0.9
Sweet Banana (Lady Finger)	5	120	68.2 ± 1.0	55.7 ± 0.9
Sweet Banana (Lady Finger)	10	120	60.4 ± 1.5	59.5 ± 0.9
Sweet Banana (Lady Finger)	15	120	59.5 ± 1.1	57.2 ± 0.9
Native Red Banana (Kienyeji)	5	30	68.3 ± 1.2	54.7 ± 0.6
Native Red Banana (Kienyeji)	10	30	60.0 ± 1.2	54.4 ± 0.7
Native Red Banana (Kienyeji)	15	30	61.6 ± 1.4	50.5 ± 0.6
Native Red Banana (Kienyeji)	5	60	67.5 ± 0.7	56.7 ± 0.4
Native Red Banana (Kienyeji)	10	60	58.9 ± 0.4	53.3 ± 0.7
Native Red Banana (Kienyeji)	15	60	51.4 ± 1.0	52.0 ± 0.7
Native Red Banana (Kienyeji)	5	120	64.4 ± 0.7	55.3 ± 0.8
Native Red Banana (Kienyeji)	10	120	60.3 ± 0.6	51.4 ± 0.9
Native Red Banana (Kienyeji)	15	120	55.4 ± 0.6	49.5 ± 0.9

3.4. Fibre Characterization

3.4.1. Mechanical Properties

Banana cultivar and alkali treatment influenced fibre tenacity, fineness, length, and residual gum. NaOH-treated fibres generally exhibited higher tenacity, finer fibres, greater length retention, and lower residual gum than ash-derived KOH-treated fibres in Table 4 and Figure 5. These differences are consistent with more effective removal of lignin and hemicellulose and improved fibre separation. KOH-treated fibres retained comparatively more non-cellulosic material, which may be relevant where hydrophilicity is desired (Balakrishnan et al., 2021). Thus, NaOH was more effective for producing structurally refined fibres, whereas ash-derived KOH provides a lower-efficiency but biomass-based alternative

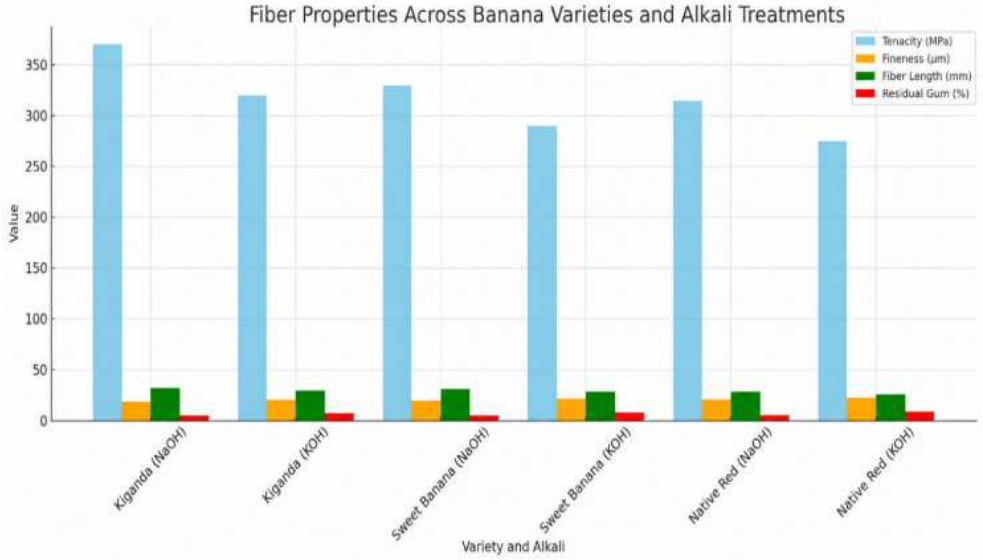


Figure 5: Fibre properties across BPS varieties and alkali treatments

Table 4: Banana Fibre Characterization after Alkali Treatment

Variety	Alkali	Conc. (%)	Tenacity (MPa)	Fineness (µm)	Fibre length (mm)	Residual gum (%)
Kiganda (Uganda Green)	NaOH	5	370.0 ± 2.2	18.5 ± 0.7	32.1 ± 1.2	4.5 ± 0.2
Kiganda (Uganda Green)	KOH	5	320.0 ± 3.7	20.1 ± 1.0	29.5 ± 0.6	7.0 ± 0.2
Sweet Banana (Lady Finger)	NaOH	10	330.0 ± 2.2	19.2 ± 0.7	30.8 ± 0.8	5.0 ± 0.2
Sweet Banana (Lady Finger)	KOH	10	290.0 ± 2.3	21.3 ± 0.6	27.9 ± 0.4	8.2 ± 0.2
Native Red Banana (Kienyeji)	NaOH	15	315.0 ± 2.8	20.5 ± 0.7	28.6 ± 0.4	5.5 ± 0.2
Native Red Banana (Kienyeji)	KOH	15	275.0 ± 2.3	22.8 ± 0.6	26.1 ± 0.6	9.0 ± 0.1

NaOH-treated fibers exhibited superior mechanical and morphological properties, including higher tenacity, a finer fiber structure, greater fiber length retention, and lower residual gum content than fibers extracted with ash-derived KOH. These improvements are attributed to more effective removal of lignin and hemicellulose, resulting in enhanced cellulose purification and fiber separation. Although KOH-treated fibers showed comparatively lower mechanical performance, they retained higher amounts of hemicellulose and pectin, which may enhance hydrophilicity and liquid absorption. Consequently, NaOH is more suitable for producing high-strength banana pseudostem fibers, whereas ash-derived KOH represents a sustainable alternative for absorbent hygiene applications, supporting the valorization of agricultural waste and circular bioeconomy initiatives.

3.4.2. FTIR-ATR Analysis

The FTIR-ATR spectra of fibres treated with 5% NaOH and 5% ash-derived KOH showed the characteristic absorption bands of lignocellulosic fibres, confirming retention of the cellulose framework after alkaline treatment (Figures 6 and 7). A broad band at 3309-3310 cm^{-1} was assigned to O–H stretching in cellulose, while bands at 2893-2901 cm^{-1} corresponded to C–H stretching. Bands at 1620-1636 cm^{-1} were associated with absorbed water and residual lignin-related structures. Additional cellulose-related bands occurred at 1419 cm^{-1} (CH_2 bending), 1319 cm^{-1} (C–H wagging), approximately 1018-1026 cm^{-1} (C–O–C/C–O stretching), and 895 cm^{-1}, associated with the β-(1→4)-glycosidic linkage of cellulose.

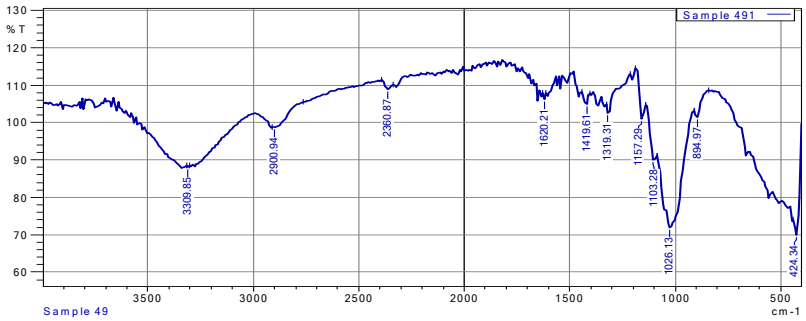


Figure 6: FTIR-ATR spectrum of 5% NaOH-treated BPS fibres

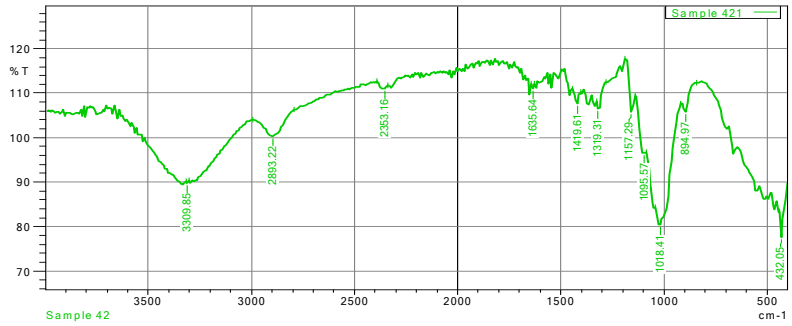


Figure 7: FTIR-ATR spectrum of 5% KOH-treated BPS fibres.

The NaOH-treated fibres showed a more pronounced band at 1026.13 cm^{-1} than the KOH-treated fibres at 1018.41 cm^{-1}. The 1419 and 895 cm^{-1} cellulose-associated bands were also more pronounced following NaOH treatment. These differences indicate more effective removal of lignin and hemicellulose and greater accessibility of cellulose after NaOH treatment. The persistence of the characteristic cellulose bands in both spectra indicates that the treatments did not substantially disrupt the cellulose framework. The FTIR findings therefore support the higher fibre yield, improved mechanical properties, and lower residual gum observed for NaOH-treated fibres.

3.4.3. Absorbency analysis

The test for absorbency is presented in Table 5

Table 5: Absorbance capacity for cellulose

Treatment	Sample	Dry wt. (g)	Wet wt. (g)	Water absorbed (g)	Absorptivity (g/g)
5% NaOH	Mean ± SD	0.50 ± 0.01	6.37 ± 0.50	5.87 ± 0.49	11.72 ± 0.79
5% KOH	Mean ± SD	0.50 ± 0.02	6.03 ± 0.15	5.53 ± 0.15	11.08 ± 0.47

Both treatments demonstrated significant water absorption, with fibres treated with 5% NaOH (11.72 ± 0.79 g/g) exhibiting marginally greater absorptivity compared to fibres treated with 5% KOH (11.08 ± 0.47 g/g). The findings show that alkali treatment enhanced the fibres' water retention capacity, with NaOH yielding superior absorbency results (Badanayak et al., 2023). In general, both methods showed promising potential as absorbent materials in eco-friendly sanitary pads.

4. Conclusion

Banana pseudostem is a viable renewable feedstock for cellulose-rich fibre production and offers an opportunity to convert an underutilized agricultural residue into higher-value biomaterials. Under the conditions investigated, response surface methodology identified 5% alkali, approximately 60 min, and 80 °C as effective extraction conditions for high fibre recovery. NaOH was more effective than ash-derived KOH, producing higher fibre yields, greater tenacity, finer fibres, better length retention, lower residual gum, and more distinct cellulose-related FTIR bands. Kiganda treated with 5% NaOH produced the highest reported yield of 73.2 ± 1.9%, while the highest KOH yield was 60.2 ± 1.0% for Sweet Banana.

Ash-derived KOH reached 88% purity after crystallization and retained the characteristic cellulose structure in the extracted fibres. Although its extraction performance was lower than that of NaOH, its use creates a pathway to convert banana biomass ash into a useful processing reagent. It strengthens the circular-bioeconomy potential of the process. The extracted cellulose-rich fibres have potential for absorbent hygiene materials and other biodegradable applications; however, product-level performance and safety should be established through dedicated prototype testing, biodegradation, and relevant standards testing before commercialization.

4.1. Industrial and Environmental Implications

The process provides a potential route for valorizing BPS while reducing dependence on petroleum-derived materials. Integrated recovery of alkali from banana biomass residues could support a circular biorefinery approach in which both pseudostem and ash are converted into useful products. Such a model is relevant to sustainable hygiene materials, waste reduction, and resource efficiency and is consistent with SDGs 3, 5, 12, and 13. Future work should focus on improving biomass-derived KOH recovery and purity, scaling the optimized extraction process, developing and testing biodegradable absorbent prototypes, and conducting techno-economic and life-cycle assessments.

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Declarations

Conflicts of Interest

The authors declare no conflict of interest.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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