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Extraction and Characterization of Cellulose from Banana Pseudo Stem for the Development of Biodegradable Cellulose Based Thin Films

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Banana pseudostem is an abundant agricultural by-product that represents a promising renewable source of cellulose for the development of sustainable materials. This study aimed to extract cellulose from banana pseudostem waste and utilise it for the development of biodegradable cellulose-based thin films. Cellulose was extracted through successive acid treatment, alkali

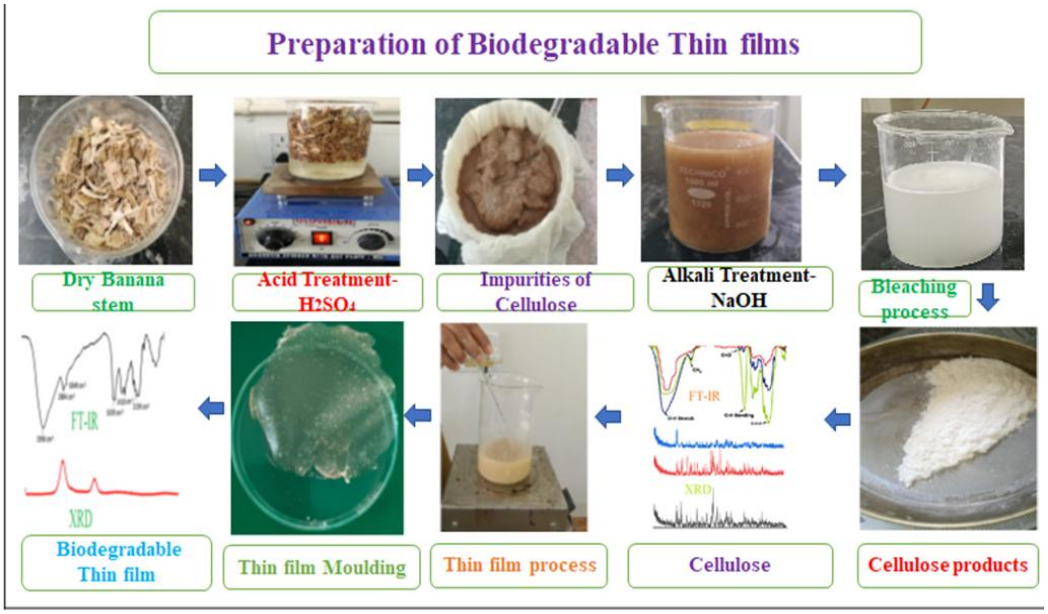
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treatment, and bleaching processes to remove hemicellulose, lignin, and other non-cellulosic components. The extracted cellulose and the developed cellulose-based thin films were characterised using Fourier Transform Infrared Spectroscopy (FT-IR) to identify functional groups and X-ray diffraction (XRD) to evaluate the crystalline structure and crystallinity of the materials. Thin films were prepared using the solvent-casting method with suitable biodegradable plasticisers and evaluated for their physical appearance and film-forming properties. The extracted cellulose was successfully utilised to prepare biodegradable thin films. Biofilms were prepared using extracted banana pseudostem cellulose blended with starch and other additives. Among the different formulations, Method 1 produced a good-quality biofilm with satisfactory pH, elasticity, toughness, and biodegradability, showing better performance than the other formulations. The development of cellulose-based thin films from banana pseudostem provides a sustainable alternative to conventional petroleum-based plastics and promotes the value addition to agricultural waste. This study contributes to waste valorisation, environmental sustainability, and the development of biodegradable biomaterials for potential packaging and agricultural applications.



Pic. 1. Preparation of biodegradable thin films

Keywords: Banana pseudo stem; cellulose; biodegradable thin film; biofilm; FT-IR and XRD.

1. Introduction

Banana (*Musa acuminata*) (Qamar & Shaikh, 2018; Yadav, 2021) is one of the world's most significant fruit crops (Elayabalan *et al.*, 2017) due to its high nutritional value, year-round availability, and significant contribution to food security and rural livelihoods (Jamaldin, 2024; Adeoye & Samuel, 2025). India is the leading producer of bananas (Evans *et al.*, 2020), producing substantial amounts of agricultural residues such as pseudostems, leaves, peels, and rachis after harvest (Alzate Acevedo *et al.*, 2021; Gupta *et al.*, 2023). Among these, the banana pseudostem represents the major proportion of biomass and is often discarded, causing environmental pollution and disposal challenges (Li *et al.*, 2016). Effective utilisation of this abundant waste is important for sustainable agriculture and the development of a circular bioeconomy (Sarangi *et al.*, 2023). Banana pseudostem is a lignocellulosic biomass rich in cellulose (35-45%) (Liebl *et al.*, 2019), along with hemicellulose, lignin, and pectin, making it an excellent renewable source for cellulose extraction (Sango *et al.*, 2018). Cellulose is the most abundant natural biopolymer and possesses desirable properties including biodegradability, biocompatibility, renewability, high mechanical strength, and excellent film-forming ability (Romão *et al.*, 2022). These characteristics make cellulose a promising alternative to petroleum-based plastics while encouraging the value addition of agricultural residues (Ojelade *et al.*, 2026). The extensive use of conventional plastics has raised serious environmental concerns due to their non-biodegradable nature, resulting in soil and water pollution and the build-up of microplastics (Kelaniyagama *et al.*, 2024). Accordingly, biodegradable cellulose-based materials have received increasing attention as sustainable alternatives (Cho *et al.*, 2025). Cellulose-based thin films display excellent mechanical properties, transparency, biodegradability, and non-toxicity, making them suitable for applications in food packaging, agriculture, biomedical products, and other eco-friendly materials (Paudel *et al.*, 2026; Paudel & Janaswamy, 2026). Cellulose extraction from banana pseudostem usually involves alkali treatment, bleaching, and purification to remove non-cellulosic components (Waithaka *et al.*, 2025). The extracted cellulose is characterised using analytical techniques such as Fourier Transform Infrared (FT-IR) spectroscopy and X-ray diffraction (XRD) to confirm its chemical structure and crystallinity (Montoya-Escobar *et al.*, 2022). These analyses are essential for assessing the suitability of cellulose for biodegradable film production.

Recently, banana pseudostem-derived cellulose has emerged as a promising raw material for producing biodegradable films, nanocellulose, composites, paper products, and agricultural mulching materials. Converting banana waste into high-value biodegradable products not only reduces environmental pollution but also supports sustainable waste management and resource

utilisation (Kumari *et al.*, 2025). Recent literature on agricultural biomass valorisation identifies banana pseudostem as a lignocellulosic residue with potential for conversion into value-added products, supporting its relevance within circular bioeconomy approaches (Giwa *et al.*, 2025). Cellulose has also been highlighted as a renewable polymer for biodegradable packaging films, with film performance influenced by formulation and blending with other materials (Ramesh & Kulkarni, 2025). Recent work on banana pseudostem has shown that chemical processing can effectively isolate cellulose and that structural changes following treatment can be evaluated using techniques including XRD (Ardila A. *et al.*, 2024). Microcrystalline cellulose recovered from banana pseudostem has been incorporated into biofilm formulations, supporting the feasibility of using this agricultural residue as a cellulose source for film development (Sachcha *et al.*, 2024). In addition, banana-pseudostem nanocellulose bioplastics have been examined for structural changes during biodegradation, providing further evidence for the characterisation of biodegradable materials derived from this biomass (Faradilla *et al.*, 2024).

Accordingly, a practical research gap remains in linking the sequential chemical extraction of cellulose from banana pseudostem with its structural characterisation and subsequent conversion into biodegradable thin films within a single experimental workflow.

1.1 Objective

Therefore, the current study focuses on the extraction and characterisation of cellulose from banana pseudostem waste and its use in developing biodegradable cellulose-based thin films. This approach offers an eco-friendly route for converting agricultural waste into value-added products with potential applications in sustainable packaging and agricultural sectors.

2. Materials and Methods

2.1 Collection of Banana Pseudostem

The raw material was collected from Adhiyamaan College of Agriculture and Research (ACAR) farm in Krishnagiri District, Tamil Nadu, India. The pseudostems were washed thoroughly with tap water followed by distilled water to remove adhering soil and impurities. The cleaned material was cut into small pieces (2-3 cm) in the Biochemistry laboratory at ACAR, shade-dried for 5-7 days using an open-tray method, and further dried in a hot air oven at 60 °C until a constant weight was achieved. The dried material was ground into powder using a laboratory grinder and stored in airtight containers for further analysis.

2.2 Chemicals

Analytical-grade sodium hydroxide (NaOH), sulfuric acid (H_2SO_4), sodium hypochlorite (NaOCl), ethanol, glycerol, acetic acid, and distilled water were used throughout the study. All chemicals were procured from The Real Scientific Company, Krishnagiri, TN, India.

2.3 Extraction of Cellulose

2.3.1 Acid Pre-treatment

Cellulose was extracted from banana pseudostem powder/chips using chemical treatment methods. About 100 g of dried banana pseudostem powder in a 1000 mL beaker was treated with 1% sulfuric acid solution (300 mL) at 80 °C for 1 h with continuous stirring to remove pectin, soluble sugars (simple sugars), and part of the hemicellulose. The residue was filtered and washed repeatedly with distilled water until neutral pH (Ai *et al.*, 2021).

2.3.2 Alkali Treatment

The acid-treated residue was treated with 5% sodium hydroxide solution (200 mL) in a 1000 mL beaker at 90 °C for 2 h to remove lignin and remaining hemicellulose. The mixture was filtered and washed several times with distilled water until neutral pH.

2.3.3 Bleaching

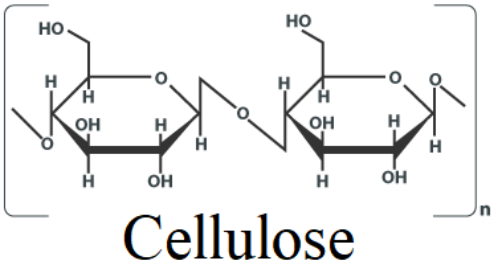
The alkali-treated cellulose fibres were bleached using 3% sodium hypochlorite solution (200 mL) in a 1000 mL beaker at 70 °C for 2 h (Benali *et al.*, 2024). The bleaching process was repeated until the fibres became white. The purified cellulose was washed thoroughly with distilled water, oven dried at 60 °C for 24 h, powdered, and stored for characterisation in glass containers with lids (Sunday, 2017). The extracted cellulose was obtained as a pure white-coloured powder and was confirmed by the iodine zinc chloride test, which produced the characteristic blue colouration. The extracted cellulose was initially analysed by thin-layer chromatography (TLC) to assess its purity. The melting point was 261 °C to 268 °C. FT-IR spectroscopy confirmed the characteristic functional groups, while XRD analysis showed good crystalline nature (Figs. 2 and 3).

2.4 Characterization of Extracted Cellulose

2.4.1 Fourier Transform Infrared (FT-IR) Spectroscopy

The functional groups in the extracted cellulose were analysed using an FT-IR spectrometer in the range of 4000-400 cm^{-1} (Manimaran *et al.*, 2018). The FT-IR spectra of banana powder, standard cellulose, and extracted cellulose were compared. Banana

powder showed characteristic O-H, C-H, and C=O bands, while extracted cellulose exhibited major cellulose peaks at approximately 3330-3440, 2890-2920, 1420-1430, 1030-1060, and 895-900 cm^{-1}. The FT-IR profile of the extracted cellulose was comparable to that of standard cellulose, confirming the successful extraction of cellulose from banana pseudostem.



Pic. 2. Molecular diagram

2.4.2 X-ray Diffraction (XRD)

The crystalline structure of cellulose was determined using an X-ray diffractometer operated with Cu-Kα radiation over a diffraction angle (2θ) range of 10°-40°. The crystallinity index was calculated using the Segal method (Bahndral *et al.*, 2024). XRD analysis showed that banana powder had relatively lower crystallinity, with broad peaks around 15-160 and 22-230 (2θ). Standard cellulose showed distinct crystalline peaks around 14.6^0,16.1^0 and 22.2^0. The extracted cellulose exhibited similar characteristic cellulose peaks at approximately 14.5^0,16.0^0 and 22.0^0, indicating improved crystallinity after removal of non-cellulosic components and confirming the successful extraction of cellulose.

2.5 Preparation of Cellulose-Based Thin Film

A mixture of 1 g of extracted cellulose and 1 g of starch in 100 mL of distilled water containing 2% acetic acid was prepared, and glycerol (30% w/w of cellulose) was added as a plasticiser. The blend was heated at 80 °C with continuous stirring until a homogeneous solution was obtained. The solution was transferred onto clean glass Petri dishes and dried at room temperature for 48 h. The dried films were carefully peeled off and stored in a desiccator before analysis. The biofilms were prepared using five different methods by varying the combinations and proportions of cellulose, starch, and agarose. The different formulations are presented in Table 1. Among the five formulations, Method 1 showed better biofilm-forming properties and overall performance.

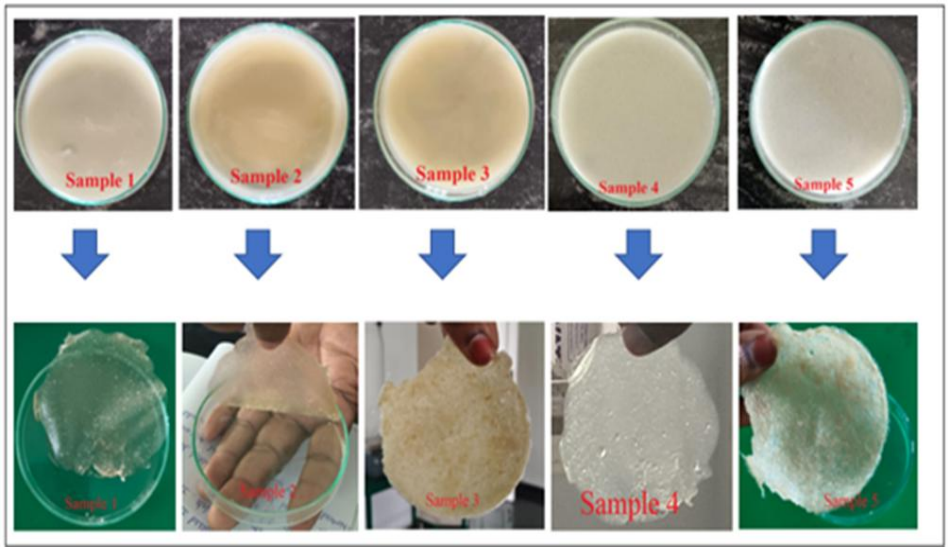


Fig. 1. Preparation of biodegradable thin film

2.6 Characterization of Cellulose-Based Thin Film

2.6.1 Fourier Transform Infrared (FT-IR) Spectroscopy

The FT-IR spectrum of the biofilm prepared from extracted banana pseudostem cellulose showed characteristic peaks at approximately 3330, 2900, 1640, 1425, 1375, 1155, 1050, and 895 cm^{-1}. These peaks correspond to O-H, C-H, C-O-C, and C-O functional groups and β-glycosidic linkages, confirming the cellulose-based structure of the prepared biofilm.

2.6.2 X-ray Diffraction (XRD)

XRD analysis of the banana pseudo stem cellulose-based biofilm showed characteristic diffraction peaks around 14-16° and 22-23° (2θ), indicating the presence of crystalline cellulose. The biofilm exhibited an approximate crystallinity index of 50-60%, confirming the semi-crystalline nature of the cellulose-based biofilm.

Table 1. Biodegradable film using different compositions of starch and cellulose

S. No	Composition				Mould	Elastic Nature	Length	Toughness	pH	Biodegradable
	Cellulose (g)	Starch (g)	Glycerol (ml)	Agarose (g)						
1	1.0	1.0	5	0.5	Petri Plate	good	9 cm	good	6.8 To 7.8	21 days
2	1.5	0.5	5	0.5	Petri Plate	medium	9 cm	good	6.8 To 7.8	23 days
3	2.0	-	5	0.5	Petri Plate	medium	9 cm	medium	6.8 To 7.8	25 days
4	0.5	1.5	5	0.5	Petri Plate	medium	9 cm	medium	6.5 To 7.9	23 days
5	-	2.0	5	0.5	Petri Plate	medium	9 cm	medium	6.5 To 7.9	26 days

3. Results and Discussion

3.1 Extraction of Cellulose from Banana Pseudostem

The successive acid, alkali, and bleaching treatments successfully removed non-cellulosic components such as hemicellulose, lignin, and pectin from the banana pseudostem (Al-Dabash & Al-Kahali, 2024). The extracted cellulose appeared as a white fibrous powder, indicating successful purification. The overall cellulose yield ranged from 36-46%, which is consistent with the reported cellulose content of banana pseudostem. The minor difference in yield may be attributed to differences in cultivar, maturity, and extraction conditions (Akatwijuka *et al.*, 2024). The obtained cellulose was suitable for the preparation of biodegradable thin films because of its high purity and good fibre integrity.

3.2 FT-IR Characterization of Extracted Cellulose

FT-IR analysis was performed on banana pseudostem powder, standard cellulose, and extracted cellulose. The extracted cellulose showed characteristic absorption bands around 3335 cm^{-1} (O-H stretching), 2905 cm^{-1} (C-H stretching), 1642 cm^{-1} (O-H bending), 1427 cm^{-1} (CH_2 bending), 1374 cm^{-1} (C-H bending), 1328 cm^{-1} (C-O stretching), 1048 cm^{-1} (C-O-C/C-O stretching), and 897 cm^{-1} (β-glycosidic linkage). These absorption bands were comparable to those observed for standard cellulose. The reduction or disappearance of non-cellulosic functional groups observed in the pseudostem powder indicates the removal of lignin and hemicellulose during the extraction process. The similarity between the FT-IR spectra of the extracted and standard cellulose confirms the successful extraction of cellulose and indicates that the extracted material is suitable for further biodegradable product development (Fig. 2).

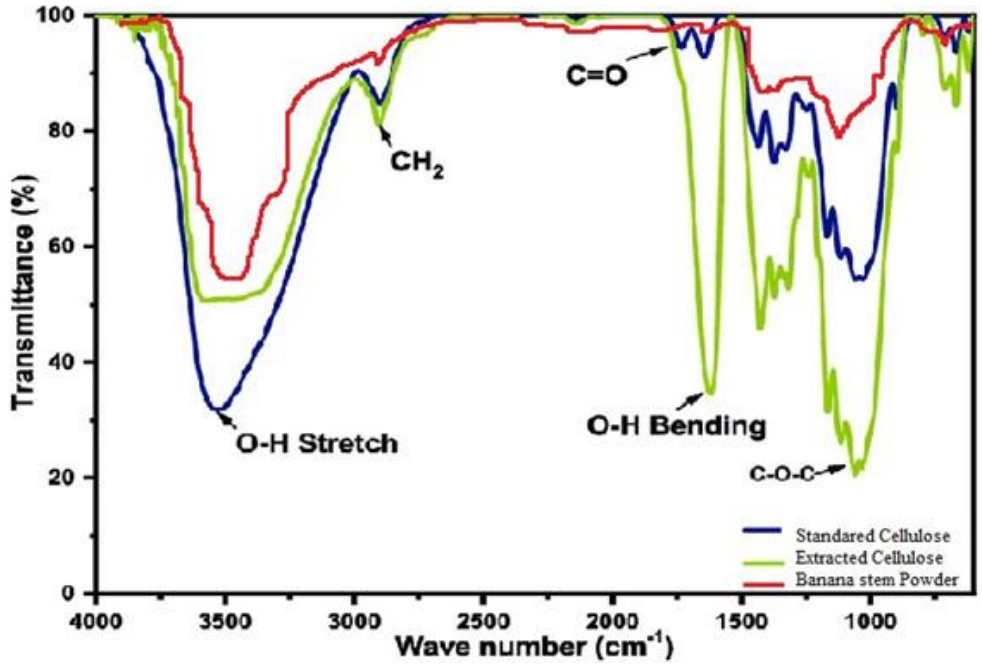


Fig. 2. The FT-IR spectra for standard cellulose, extracted cellulose and banana pseudo stem powder

3.3 XRD Analysis of Cellulose

X-ray diffraction (XRD) analysis was carried out for banana pseudostem powder, standard cellulose, and extracted cellulose to evaluate their crystalline characteristics. The banana pseudostem powder showed relatively broad and less-defined diffraction peaks, indicating the presence of both crystalline and amorphous components. The standard cellulose exhibited characteristic diffraction peaks at approximately 2θ = 16°, 22°, and 34°, corresponding to the crystalline structure of cellulose. The extracted cellulose showed similar diffraction peaks at approximately 2θ = 16°, 22°, and 34°, indicating a crystalline pattern comparable to that of standard cellulose. The similarity in the XRD patterns of the extracted and standard cellulose confirms the successful extraction and retention of the cellulose crystalline structure. These results indicate that the extracted cellulose is of good quality and has potential for further development of cellulose-based biodegradable products (Fig. 3).

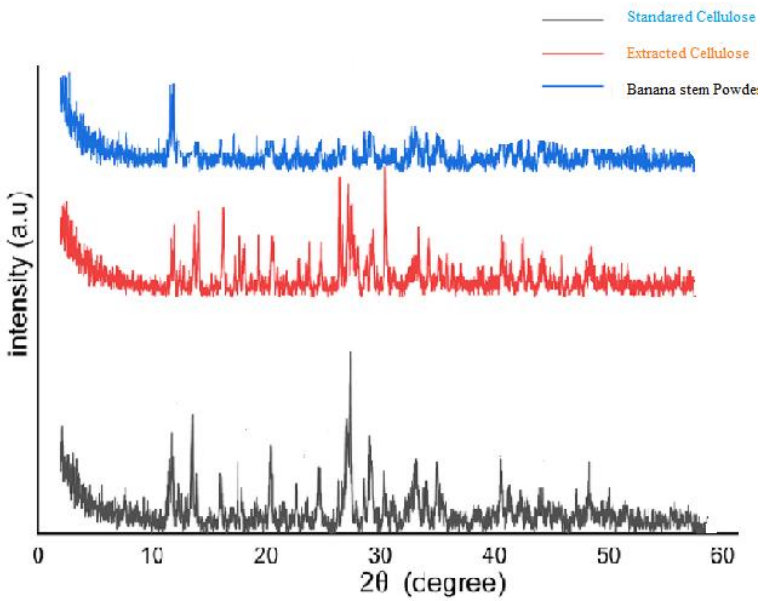


Fig. 3. Diffractogram for standard cellulose, extracted cellulose and banana pseudo stem powder

3.4 Development of Cellulose-Based Thin Films

The extracted cellulose was successfully converted into transparent, flexible, and uniform biodegradable thin films using glycerol as a plasticiser (Benitez *et al.*, 2024). The films showed smooth surfaces without visible cracks or air bubbles, representing good compatibility between cellulose and the plasticiser (Vanshpati *et al.*, 2025). The films possessed acceptable flexibility and could be easily peeled from the casting plates without damage (Douglass *et al.*, 2018). Biofilms were prepared using the extracted cellulose blended with starch and other suitable additives. Among the different formulations tested, Method 1 produced a good-quality biofilm with desirable material properties. The biofilm showed satisfactory pH, elasticity, and toughness, along with good structural stability. The biodegradability test also showed better degradation performance in Method 1 compared with the other formulations. Therefore, Method 1 was considered a promising formulation for further optimisation and development of cellulose-based biodegradable biofilms (Fig. 4).

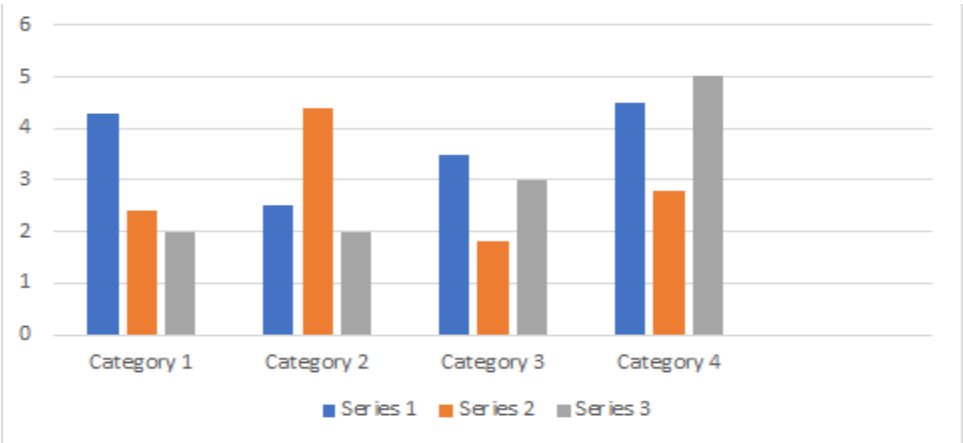


Fig. 4. Comparative studies of biofilms

3.5 Physicochemical Properties of Cellulose Thin Films

The prepared cellulose films showed uniform thickness with good structural integrity. Moisture content and water absorption remained within acceptable ranges for biodegradable packaging materials (Paetau *et al.*, 1994). The incorporation of glycerol improved film flexibility but slightly increased moisture uptake because of its hydrophilic nature (Van Nguyen & Lee, 2021). Water solubility remained moderate, indicating that the films maintained adequate stability under normal environmental conditions while remaining biodegradable (Acharya *et al.*, 2021).

3.6 Biodegradability of Cellulose Thin Films

The soil burial test showed gradual degradation of the cellulose films over a period of 30 days (Zhang *et al.*, 1996). Progressive weight loss was observed throughout the experiment, indicating microbial degradation of the cellulose matrix. The biodegradable nature of the films indicates their potential as environmentally friendly alternatives to conventional plastic packaging materials. Degradation under natural soil conditions supports their potential application in sustainable agriculture and eco-friendly packaging (Arun *et al.*, 2022).

4. Conclusion

The current study confirmed that banana pseudostem, an abundant agricultural waste, is a promising and sustainable source of cellulose for the development of biodegradable materials. Successive acid, alkali, and bleaching treatments effectively removed non-cellulosic components and yielded high-purity cellulose. FT-IR and XRD analyses confirmed the characteristic chemical structure and crystalline nature of the extracted cellulose, indicating its suitability for value-added applications. The extracted cellulose was effectively utilised to develop biodegradable cellulose-based thin films with good physical properties, satisfactory mechanical strength, and excellent biodegradability under soil burial conditions. These films offer an eco-friendly alternative to conventional petroleum-based plastics and have potential applications in food packaging, agricultural mulching, and additional biodegradable products. Overall, the study highlights an effective approach for converting banana pseudostem waste into high-value biodegradable materials, thus encouraging agricultural waste valorisation, reducing environmental pollution, and supporting sustainable resource utilisation and the circular bioeconomy. Additional research may focus on incorporating natural bioactive compounds or nanomaterials to improve the barrier, antimicrobial, and mechanical properties of cellulose-based films for advanced commercial applications. Biofilms were developed from extracted cellulose in combination with starch and other additives. Among the formulations tested, Method 1 showed better overall performance, with satisfactory pH, elasticity, toughness, and biodegradability compared with the other formulations. The results indicate that Method 1 is a promising formulation for the development of cellulose-based biodegradable biofilms.

5. Limitation

The extracted banana cellulose-based thin films have some limitations, including moisture sensitivity, limited water resistance, and reduced flexibility. The film properties may also vary depending on the cellulose, starch, and agarose composition. Further studies are needed to improve mechanical strength, durability, water resistance, and large-scale production feasibility.

Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. ChatGPT, Claude and Perplexity were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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