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A review study on Banana Pseudostem Fibre as a Renewable Alternative to Single-Use Plastic Packaging: A Sustainable Approach Towards Circular Bioeconomy

[1]Manali Kumari, [2]Avshesh Kumar and [3]Rajkumar Yadav

[1,2,3]Department of Botany,T.D.P.G.College,Jaunpur Affliated to VBSP University,Jaunpur (U.P.)222002.

ABSTRACT

Significant environmental problems, such as ongoing pollution, greenhouse gas emissions, and ecological deterioration, have been brought about by the widespread usage of petroleum-based single-use plastics. Packaging materials that are sustainable, biodegradable, and renewable are therefore in high demand. An underutilized biomass rich in cellulose, hemicellulose, and natural fibers is the banana pseudostem, an agricultural leftover left over after fruit is harvested. This biomass can be converted into biodegradable packaging materials like paper, molded containers, films, composites, and packaging based on nanocellulose rather than being thrown away or burned. This review objectively assesses banana pseudostem fiber's physicochemical characteristics, extraction methods, processing strategies, packaging uses, environmental advantages, economic viability, and contemporary difficulties. Recent technological developments such as bio-based coatings, active packaging solutions, and nanocellulose reinforcement are also highlighted in the paper.

KEYWORDS
Circular bioeconomy, cellulose, banana pseudostem, natural fiber, biodegradable packaging, agricultural waste, sustainable materials, and green packaging

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1. Introduction

One of the most urgent environmental issues of the twenty-first century is the sharp rise in the manufacture and usage of single-use plastics. Due to its resistance to degradation and hundreds of years in the environment, conventional plastic packaging—which is mostly made from petroleum-based resources—causes serious pollution on land and in the sea, microplastic contamination, and greenhouse gas emissions. In order to promote the shift towards a circular bioeconomy, governments, businesses, and researchers are actively looking for sustainable, biodegradable, and renewable alternatives to traditional plastic packaging (He et al., 2023; Vinay et al., 2024).

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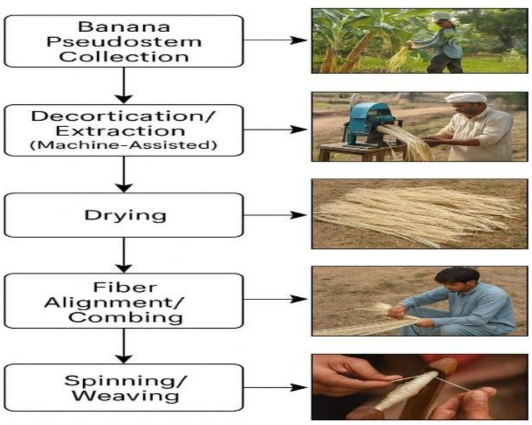
Banana pseudostem is one of several lignocellulosic agricultural leftovers that has shown promise as a renewable biomass for environmentally friendly packaging. India is the world's largest producer of bananas (Musa spp.), one of the most widely grown fruit crops. Despite being rich in cellulose, hemicellulose, and natural fibers, around 60–80% of the banana plant biomass—mainly the pseudostem—is thrown away as agricultural waste after harvest. When this biomass is improperly disposed of by burning or open-field decomposition, it adds to resource waste and environmental contamination. An eco-friendly option that simultaneously addresses plastic pollution and agricultural waste management is the valorization of banana pseudostem into biodegradable packaging materials (Badanayaka et al., 2023; Vinay et al., 2024).

High cellulose content, outstanding tensile strength, low density, biodegradability, renewability, and exceptional thermal stability are just a few of the favorable characteristics of banana pseudostem fibers. Paper-based packaging, biodegradable films, molded trays, fiber-reinforced composites, nanocellulose materials, shopping bags, and food packaging containers can all be made with them thanks to these qualities. The mechanical strength, barrier qualities, and durability of banana fiber-based packaging have been further enhanced by recent developments in nanotechnology and fiber surface modification, increasing its commercial potential as a substitute for traditional single-use plastics (Badanayaka et al., 2023; Vinay et al., 2024).



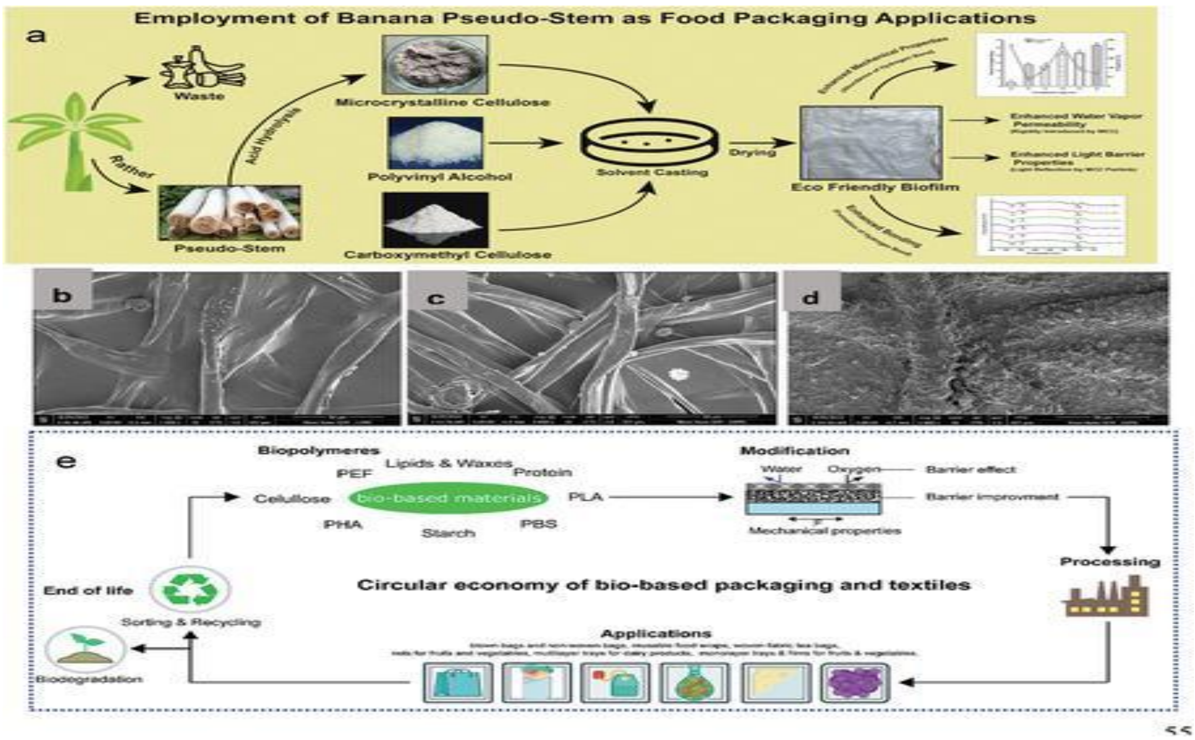
By lowering plastic waste and encouraging the effective use of renewable agricultural resources, the use of banana pseudostem fiber also supports a number of Sustainable Development Goals (SDGs), such as life below water (SDG 14), climate action (SDG 13), and responsible consumption and production (SDG 12). In order to create next-generation biodegradable packaging materials that can greatly lessen reliance on plastics derived from fossil fuels, banana pseudostem fiber is an inventive, affordable, and ecologically

friendly substitute.
Researchers are looking into renewable agricultural wastes as sustainable substitutes for packaging materials due to the growing concern over plastic pollution. A lignocellulosic by-product produced when fruit is harvested, banana pseudostem has attracted a lot of interest because of its high cellulose content, biodegradability, renewability, and superior mechanical qualities.

Banana pseudostem fibers can be transformed into high-value products such biodegradable films, paper, molded trays, nanocellulose, fiber-reinforced composites, and environmentally friendly food packaging materials, in contrast to petroleum-based plastics. In addition to reducing environmental pollution, using this agricultural waste encourages a circular bioeconomy and waste valorization (Isikgor & Becer, 2016; Deepa et al., 2018; Nanda et al., 2020; He et al., 2023; Vinay et al., 2024). Banana pseudostem fiber is a possible substitute for traditional single-use plastics since research has repeatedly shown that it has strong tensile strength, low density, and favorable barrier qualities.

The main goals of recent studies have been to improve material performance and fiber extraction techniques.

Improving fiber extraction techniques and boosting material performance have been the main goals of recent research. According to Badanayaka et al. (2023), fiber cleanliness, cellulose exposure, interfacial adhesion, and tensile characteristics are all greatly enhanced by mechanical extraction in conjunction with alkali treatment, making it more suitable for biodegradable packaging. In a similar vein, Vinay et al. (2024) examined a variety of extraction methods and came to the conclusion that banana pseudostem contains roughly 15% hemicellulose and 31–45% cellulose, which makes it ideal for making grease-proof paper, biodegradable laminates, nanofibers, and nanocrystalline cellulose. The authors also emphasized that nanocellulose reinforcement significantly enhances biodegradable films' tensile strength, thermal stability, oxygen barrier performance, and moisture resistance (Badanayaka et al., 2023; Vinay et al., 2024).



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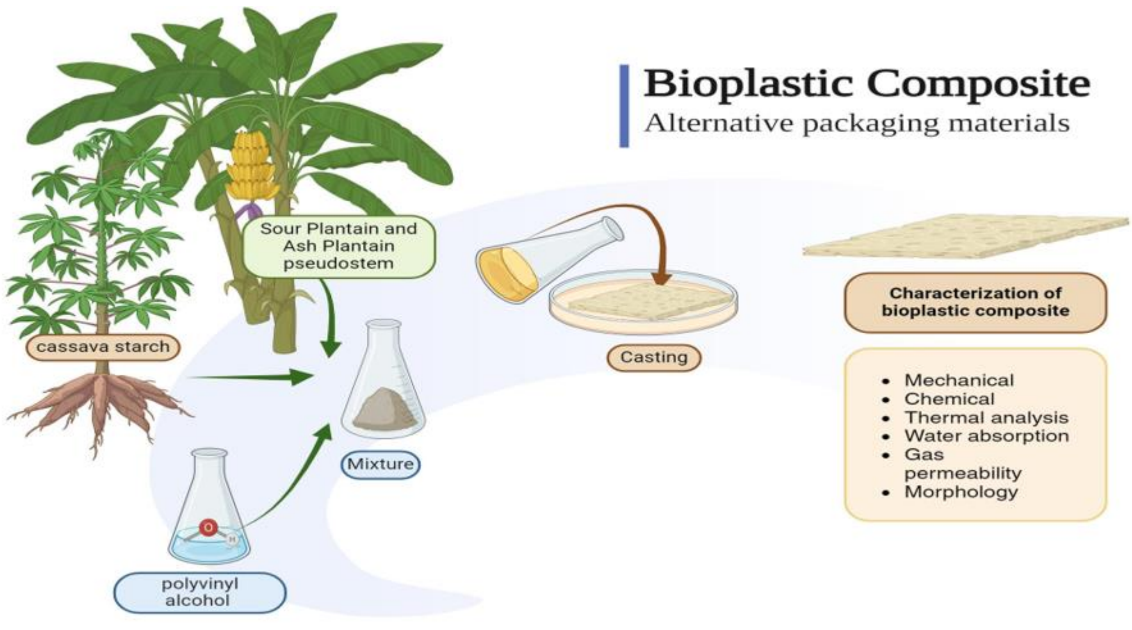
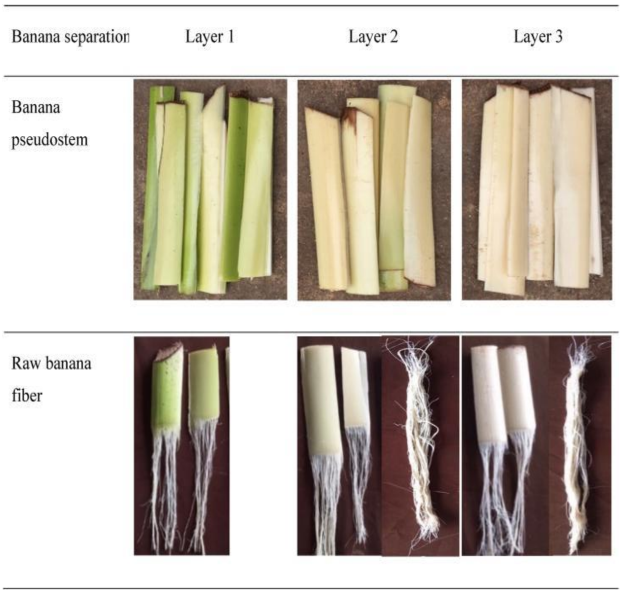
The use of cellulose generated from banana pseudostems in food packaging has been effectively proven by a number of studies. Using ionic liquid processing, Ai et al. (2021) created biodegradable cellulose films from banana pseudostem and reported superior transparency, flexibility, oxygen barrier performance, and fresh mango shelf life extension. According to He et al. (2023), cellulose derived from agricultural biomass offers an eco-friendly substitute for petroleum-based plastics due to its biodegradability, renewable source, and compatibility with antimicrobial compounds. Additionally, recent research has demonstrated that adding essential oils, chitosan, starch, and nanocellulose to banana fiber composites greatly improves mechanical durability, water resistance, and antibacterial activity resulting in better packing and food preservation (Ai et al., 2021; He et al., 2023; Nanda et al., 2020; Pelissari et al., 2017; Rhim et al., 2021).

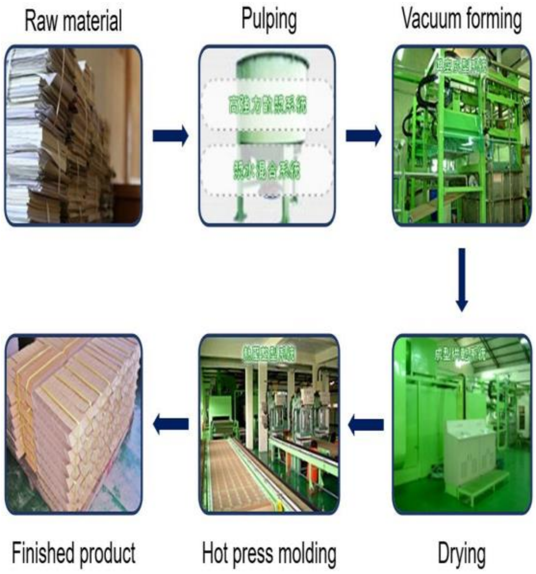
From an environmental standpoint, using banana pseudostems makes a significant contribution to climate change mitigation and sustainable waste management. According to Valenzuela-Cobos et al. (2026), a bibliometric examination of 119 scientific publications revealed an annual rise in research on the use of banana pseudostems, indicating the growing interest in biodegradable materials around the world. According to the study, banana pseudostem fibers are excellent for bioplastics, packaging composites, biosorbents, and bio-based engineered materials since they have a tensile strength of about 458 MPa. Additionally, turning pseudostem debris into packaging products lowers greenhouse gas emissions, lessens open-field burning, boosts rural industrialization, and gives banana growers extra revenue. According to Valenzuela-Cobos et al. (2026), Vinay et al. (2024), and Badanayaka et al. (2023), these results firmly support banana pseudostem as one of the most promising renewable feedstocks for substituting single-use plastic packaging while furthering sustainable development and circular economy goals.



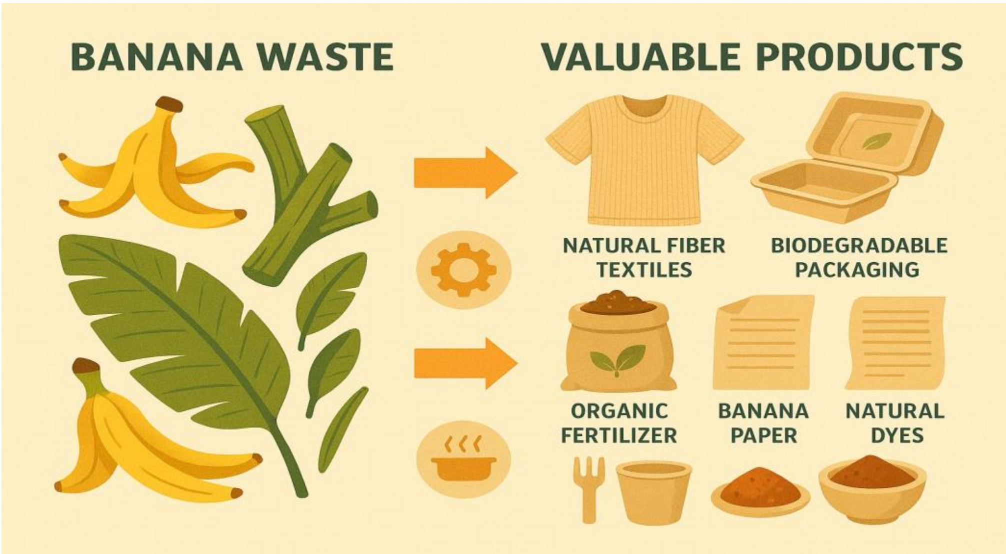
A growing amount of recent research has concentrated on using cutting-edge material engineering approaches to improve the functional performance of banana pseudostem fiber. It has been demonstrated that surface modification with alkali, silane, acetylation, and enzymatic treatments improves fiber adhesion, crystallinity, thermal stability, and moisture resistance, increasing the compatibility of banana fiber with matrices of biodegradable polymers. While Rhim et al. (2021) highlighted that cellulose-based nanocomposites have superior tensile strength, oxygen barrier qualities, and antimicrobial performance appropriate for food packaging, Anbupalani et al. (2020) found that coupling agents greatly increase the reinforcing efficiency of natural fibers in polymer composites.

Similarly, Azahari et al. (2022) showed that polylactic acid (PLA) composites reinforced with cellulosic fibers have improved dielectric characteristics, thermal stability, and biodegradability, suggesting their potential for environmentally friendly packaging applications. By overcoming the constraints of traditional biopolymers, these developments have significantly increased the economic viability of packaging materials based on banana fiber.





The creation of nanocellulose from banana pseudostem is another crucial field of study. Nanocellulose is a perfect reinforcement material for biodegradable films because of its exceptional mechanical strength, high aspect ratio, low density, transparency, and biodegradability. According to Vinay et al. (2024), while retaining full biodegradability, banana pseudostem-derived nanocrystals and nanofibers greatly enhance film strength, flexibility, thermal resistance, and barrier performance. In a similar vein, Juani and Navaranjan (2024) emphasized that banana plant feedstock can be transformed into novel packaging materials such as recyclable food packaging, edible coatings, laminated sheets, biodegradable films, and molded containers.



Additionally, life-cycle performance and environmental sustainability have emerged as top research concerns. Global interest in substituting biodegradable materials for petroleum-derived plastics is reflected in the recent bibliometric analyses that show a sharp rise in publications about the valorization of banana pseudostems. After analyzing 119 scientific publications, Romero Cardenas et al. (2026) came to the conclusion that banana pseudostem fibers have tensile strengths close to 458 MPa and have a great deal of potential for the production of bioplastics, biochar, biosorbents, biodegradable composites, and sustainable packaging materials. Additionally, research assessing banana fiber-based packaging has shown that chemical-free production methods minimize environmental effects while offering adequate mechanical strength for fruit and food packaging applications.

Overall, the available data clearly indicates that banana pseudostem fiber is a technologically promising, economically feasible, and environmentally sustainable substitute for traditional single-use plastic packaging, especially when considering the circular bioeconomy and sustainable resource management.

Conclusion

Because of its availability, high cellulose content, superior mechanical qualities, and environmental friendliness, banana pseudostem fiber has become a very attractive renewable resource for the creation of biodegradable packaging materials. According to recent research, turning this agricultural waste into packaging goods not only lessens reliance on single-use plastics derived from petroleum but also encourages resource and trash management that is sustainable. Banana fiber-based packaging now has much better strength, barrier qualities, and commercial applicability thanks to developments in fiber extraction, surface modification, and nanocellulose technology. Additionally, using banana pseudostem reduces environmental pollution, lowers greenhouse gas emissions linked to plastic production, and gives farmers new revenue opportunities—all of which support the circular bioeconomy. All things considered, banana pseudostem fiber is an environmentally friendly, economically feasible, and sustainable substitute for next-generation packaging; however, more investigation into large-scale production, cost reduction, and moisture resistance is necessary to enable its broad industrial adoption.

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