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# FROM WASTE TO RESOURCE: BIBLIOMETRIC EVALUATION OF THE USE OF BANANA PSEUDOSTEMS AS BIODEGRADABLE MATERIAL

Erika Jadira ROMERO CARDENAS✉, Byron Ramiro ROMERO ROMERO, Xiomara ZUÑIGA SANTILLÁN, Diego Vladimir TAPIA NÚÑEZ, Juan Diego VALENZUELA COBOS, Edwin CARRASQUERO RODRÍGUEZ

*Facultad de Ciencias Sociales, Educación Comercial y Derecho, Universidad Estatal de Milagro, Milagro, Ecuador*

**Highlights:**

- comprehensive bibliometric analysis of banana pseudostem as a biodegradable material;
- identification of unique mechanical and chemical properties of banana fibers;
- highlighted the feasibility of banana pseudostem for sustainable biopolymer production;
- utilized VOSviewer and RStudio to map relevant journals and collaboration networks;
- sentiment analysis revealed predominantly positive and confident views in the scientific community.

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**Abstract.** The search for sustainable alternatives has positioned banana pseudostems as a promising material for the production of bioplastics, biopolymers, and eco-friendly composites. This bibliometric review of 119 publications (2003–2024) reveals growing academic interest in its use as a biodegradable material, with an annual growth rate of 8.91% and an average of 15.25 citations per article. Pseudostem fibers have superior mechanical properties, with a tensile strength of 458 MPa and a modulus of 17.14 GPa. Bioplastics derived from this biomass are not only viable alternatives to conventional plastics, especially in packaging, but also provide antibacterial and UV protection. In addition, these fibers function as efficient biosorbents, achieving up to 100% arsenic removal in water. Sentiment analysis of scientific abstracts indicates a predominant feeling of confidence and optimism, reinforcing the potential of banana pseudostems in sustainable industrial applications and highlighting their role in advancing the circular economy.

**Keywords:** banana pseudostem, biodegradable materials, bibliometric analysis, sustainability, biopolymers, biochar.

✉Corresponding author. E-mail: ***romeroc@unemi.edu.ec***

## 1. Introduction

The global demand for sustainable and environmentally friendly materials has driven growing interest in the use of biodegradable alternatives across multiple industries (Guevara-Viejó et al., 2021; Valenzuela-Cobos et al., 2020, 2023). Traditional petroleum-based fibers, while widely used, are associated with environmental concerns due to their toxicity, lack of biodegradability, and energy-intensive production processes (Das Gupta et al., 2019; Ng et al., 2021; Requiso et al., 2018). As a result, there is a shift toward natural, renewable sources that offer lower environmental impact and enhanced material performance (Torres-Ordoñez et al., 2024).

In this context, biologically enriched macromolecular resources have emerged as promising candidates for industrial applications (Maity et al., 2020; Suresh et al., 2020). Among these, banana pseudostem has gained attention due to its availability, mechanical strength, and biodegradability (Faradilla et al., 2019; Ghosh & Ghosh, 2020; Meiling et al., 2022). Banana fibers exhibit a tensile strength of 458 MPa and a modulus of 17.14 GPa, outperforming other natural fibers such as jute, coconut, and palm (Pappu et al., 2015). Their high flexibility and ease of processing expand their applicability in packaging and biocomposites (Azahari et al., 2022; Badanayak et al., 2023; Merais et al., 2022).

Beyond their mechanical properties, banana-based materials have demonstrated functional potential. Das and Velusamy (2013) showed that blending banana pseudostem extract with polyvinyl alcohol (PVA) and glycerol can yield bioplastics with improved mechanical and barrier properties. Similarly, Ahmad et al. (2023) reported that incorporating extracts from fruit and vegetable peels such as banana, orange, and spinach into edible films can improve oxidative stability in food packaging. These findings

underscore the potential of agricultural waste in the development of value added materials.

Banana pseudostem is also a promising biomass source for bioethanol production. Das and Velusamy (2013) estimated the theoretical ethanol yield from several agricultural residues, including banana, and demonstrated its feasibility based on the conversion of cellulose, hemicellulose, and starch. Other studies (Pallavi et al., 2017) support the use of lignocellulosic waste as a viable feedstock for bioenergy.

Despite its potential, the use of banana pseudostem in industrial applications remains underexplored. To address this gap, this study presents a comprehensive bibliometric review of the scientific literature on banana pseudostem as a biodegradable material (Tibolla et al., 2017). The review aims to evaluate its viability, highlight key application areas, and identify trends and opportunities that contribute to the development of sustainable solutions across industries.

## 2. Methodology

### 2.1. Data collection

The present research is based on a bibliometric review carried out using the Scopus database, whose search yielded a total of 119 documents, consisting of 71 scientific articles, 26 conference papers, 10 reviews, 9 book chapters, 1 book and 1 conference review. To ensure exhaustive coverage of the topic, a complex search string combining terms related to banana pseudostem and biodegradable materials was used, using the following Boolean operator: TITLE-ABS-KEY (("banana pseudostem" OR "banana stem" OR "banana waste" OR "banana decomposition" OR "banana biomass" OR "banana trunk" OR "banana stalk" OR "banana byproduct" OR "banana residue" OR "banana peel") AND ("biodegradable material" OR "biopolymer" OR "eco-friendly materials" OR "biomaterials" OR "biodegradable polymer" OR "natural polymer" OR "green materials" OR "biodegradable packaging" OR "cellulose extraction" OR "fiber composites" OR "polylactic acid" OR "polyhydroxyalkanoates" OR "starch-based bioplastics") AND ("pseudostem" OR "stem" OR "residue" OR "decomposition" OR "biomass" OR "biodegradable" OR "bio-degradable" OR "biodegradation")).

The search covered the period from 2003 to January 15, 2024, with the objective of compiling the most relevant and updated documents indexed up to that date. Although more restrictive filters were initially considered, the limited availability of studies focused exclusively on banana pseudostem led to include all the documents obtained, to form a representative and diverse database.

During the compilation, several challenges were faced, such as the dispersion of studies across multiple sources, the limited accessibility of certain key papers, and the difficulty in identifying research specifically focused on pseudostem products. To mitigate these obstacles, inclusion criteria were established to ensure the relevance and quality of the selected studies:

- Focus on banana-derived products.
- Presence of discussions on the biodegradability of such products.
- Relevance of the type of document for bibliometric analysis.
- Publication within the period 2003–2024.
- Availability in a language understandable to researchers.

### 2.2. Bibliometric mapping

The bibliometric analysis was conducted using specialized software such as VOSviewer, which is designed for the creation and visualization of bibliometric maps, allowing for the identification of relationships between authors, keywords, and publications (Van Eck & Waltman, 2010), and RStudio 2023.12.0 Build 369, a comprehensive development platform for R that facilitates the statistical and graphical analysis of collected data (Zeileis et al., 2020), using the Bibliometrix package and its Biblioshiny graphical interface. This combination of tools enabled the identification of trends in publication volume over time, determination of the most frequently used journals for these studies, analysis of collaboration networks among authors and countries, and highlighting of the most commonly used key terms in this field of research.

Table 1 summarizes the main metrics of the database analyzed:

**Table 1.** Main information

| Description | Results |
|---|---|
| Space of time | 2003:2024 |
| Sources (magazines, books, etc.) | 83 |
| Documents | 119 |
| Annual growth rate % | 8.91 |
| Average document age | 4.63 |
| Average citations per document | 15.25 |
| References | 5438 |

The application of these criteria ensured that the bibliometric review focused on the most relevant and useful information available on the topic of interest. In addition, as a complement to the quantitative analysis, a sentiment analysis applied to the abstracts of the documents collected was carried out. This qualitative approach made it possible to identify the predominant emotions expressed in the academic discourse on banana pseudostem as a biodegradable resource, revealing positive perceptions and a general tone of confidence in its scientific and industrial viability. This emotional perspective provides a broader view of the scientific community's attitudes towards this sustainable alternative.

## 2.3. Natural Language Processing (NLP)

Natural Language Processing (NLP) is a field of artificial intelligence that allows machines to understand, interpret and generate human language in a useful way (Chowdhary, 2020). This technology is especially valuable for analyzing large volumes of text in an automated, efficient, and accurate manner.

In this study, NLP was used to perform sentiment analysis on the abstracts of 119 scientific articles related to the use of banana pseudostem as a biodegradable material. The abstracts were extracted from a CSV file and subjected to a textual preprocessing process, which included: conversion of all text to lowercase, removal of punctuation marks, numbers and stopwords, and normalization of linguistic content. These cleaning steps are essential to reduce semantic noise and optimize the accuracy of the subsequent analysis.

Subsequently, the "syuzhet" package was applied in R, which uses emotion lexicons to classify words into eight basic emotional categories: joy, trust, fear, surprise, sadness, disgust, anger and anticipation, according to Plutchik's model. This methodology made it possible to quantify the emotional charge of the texts, yielding results that were represented graphically by means of a bar chart (Figure 2).

## 3. Research results

According to the data obtained through the Bibliometrix tool, a temporal analysis of scientific production from 2003 to 2024 was carried out. As shown in Figure 1, there is a sustained growth in the cumulative number of publications related to the defined search string.

The International JOURNAL OF BIOLOGICAL MACROMOLECULES stands out, which presents the highest cumulative number of publications in the area, followed by MATERIALS TODAY: PROCEEDINGS. Both journals have shown a constant growth trend, which reflects a continuous interest of the scientific community in their respective lines of research.

Also, the conference series "IOP CONFERENCE SERIES: MATERIALS SCIENCE AND ENGINEERING" and "JOURNAL OF PHYSICS: CONFERENCE SERIES" also show a significant increase in the cumulative count of publications, suggesting a growing interest in the thematic areas covered by these conferences. These data support the importance and relevance of publications related to materials, earth sciences, and the environment, as well as macromolecular biology within the scientific community. The analysis of these trends can provide valuable information on the development and evolution of research in these fields over time.

### 3.1. Advances in biodegradable materials

Figure 2 presents a bibliometric comparison of research focused on the main by-products derived from the banana pseudostem over the period from 2003 to 2024.

From Figure 2, it can be observed that biofilm is the most common by-product utilizing the banana pseudostem. Recent studies, such as the one by (Chavez-Guerrero et al., 2019), investigated the production of cellulose films with good transparency derived from the banana pseudostem. Similarly, Henry et al. (2011) worked on creating bioplastics from agricultural waste, demonstrating how these residues can be transformed into useful and environmentally friendly products. Additionally, the properties of biodegradable films based on polyvinyl alcohol and tropical fruit waste flour have been studied, highlighting their potential to replace conventional plastic materials (Ooi et al., 2018).

The fiber of the banana pseudostem is primarily composed of cellulose (55–65%), hemicellulose (15–25%), lignin (10–15%), and pectin (3–5%) (Srivastava et al., 2019). Cellulose, being the predominant component, is essential for providing structural integrity to the fiber. Suchaiya and

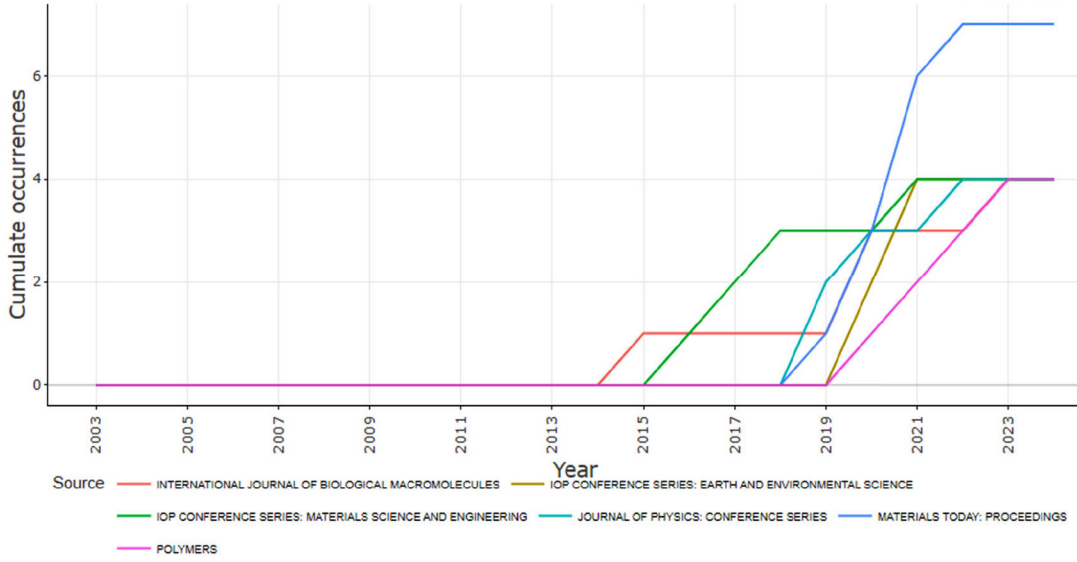


**Figure 1.** Scientific production over the years

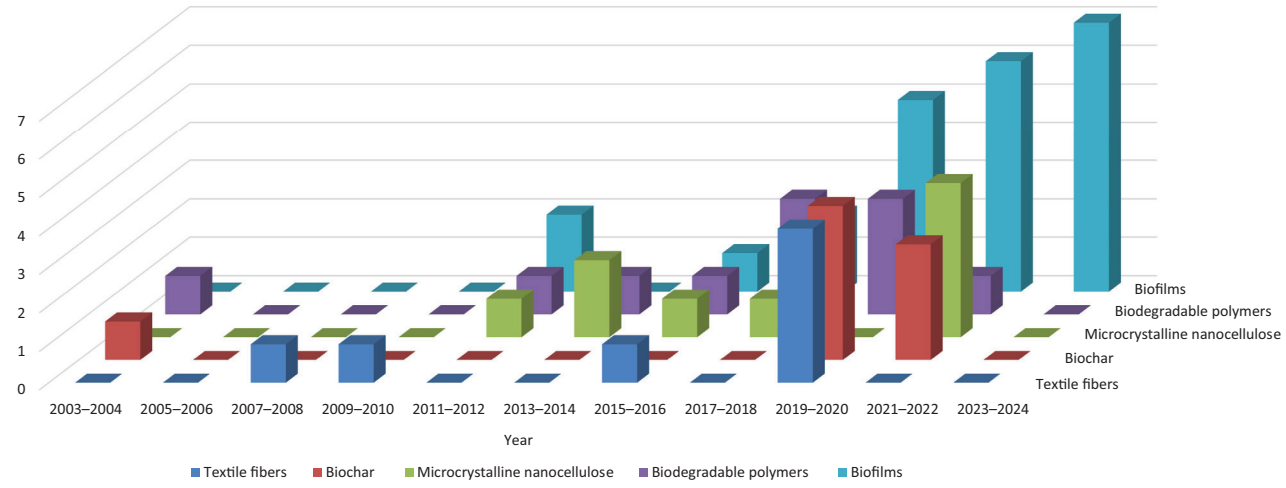


**Figure 2.** Bibliometric comparison of the main by-products derived from the banana pseudostem

Aht-Ong (2013) investigated the production of microcrystalline cellulose from banana pseudostems, cementing new opportunities to use organic waste in creating innovative materials.

Similarly, Tibolla et al. (2020) analyzed how process conditions, such as pH, temperature, and concentrations of enzymes and substrates, influence the properties of cellulose nanofibers (CNF). Their results showed that treatment with xylanase at a concentration of 70 U/g of banana peel, with a substrate concentration of 15%, a pH of 6.0, and a temperature between 35 and 55 °C, significantly favored enzymatic hydrolysis (Merais et al., 2022; Tibolla et al., 2017). Transmission electron microscopy (TEM) images confirmed that this treatment effectively isolated cellulose fibers at the nanoscale. Additionally, Fourier-transform infrared spectroscopy (FTIR) analysis revealed the removal of amorphous compounds, while X-ray diffraction showed a high crystallinity index (66.2%) in the CNF (Mittal et al., 2024; Tejada-Tovar et al., 2019).

Other uses of banana pseudostem include biochar (Mokkapati et al., 2016) for the removal of toxic contaminants from aqueous solutions (Tabassum et al., 2019) a crucial strategy for enhancing sustainability in wastewater treatment (Farias et al., 2023; Mussagy & Magri, 2022). In a study conducted by Xu et al. (2018), the potential of banana pseudostem-derived biosorbents for arsenic removal was demonstrated, achieving efficiencies of 100%, 100%, and 90% in groundwater samples contaminated with 5, 10, and 50 µg/L of As, and 50%, 90%, and 90% in solutions with concentrations of 10, 50, and 100 µg/L of As. This approach not only helps purify water but also utilizes agricultural waste, providing a doubly sustainable solution (Kumari et al., 2025).

Furthermore, Basak et al. (2015) have contributed to the development of special chemical finishes for sustainable luxury textiles, integrating nanotechnology and biopolymers to enhance the antimicrobial properties (Raturi et al., 2021) and UV protection of fabrics, demonstrating how material science can positively influence the high-end textile industry. The collaboration between these scientists highlights the importance of interdisciplinary and collective research in addressing global sustainability challenges (Maity et al., 2020; Joshi et al., 2024). Each study contributes to a better understanding of natural resource and waste management (Lobo-Ramos et al., 2023). In addition, they offer insights into the integration of biodegradable materials into everyday life (Díaz et al., 2022; Kapoor et al., 2024), promoting the replacement of unsustainable materials and the reduction of negative environmental impacts.

## 3.2. Sentiment analysis

To complement the bibliometric analysis, a sentiment analysis was performed following the method proposed by Wankhade et al. (2022). This technique identifies the predominant emotional tone in the articles, providing additional insight into the implicit attitudes of researchers regarding the topics addressed (see Figure 3). Since emotions can influence scientific communication and the perception of its results Taboada (2016), understanding these emotional aspects allows for a more comprehensive understanding of the dynamics in the field of study.

The results indicate a predominance of feelings such as “positivity” and “confidence,” which may reflect widespread optimism or high expectations within the scientific community regarding the topics discussed. On the other hand, emotions such as “joy” and “fear” were also detected, showing a variety of emotional attitudes toward advances and challenges in the field.

In academia, a positive and, in many cases, non-linear relationship has been observed between productivity in terms of number of publications and the quality of those publications, which is measured by the number of citations they receive. This implies that authors who publish more frequently tend to obtain a greater number of citations, which can be interpreted as greater influence or impact of their work on the scientific community. Citation analysis, which studies the frequency and patterns of citations in articles and books, allows us to detect emerging trends

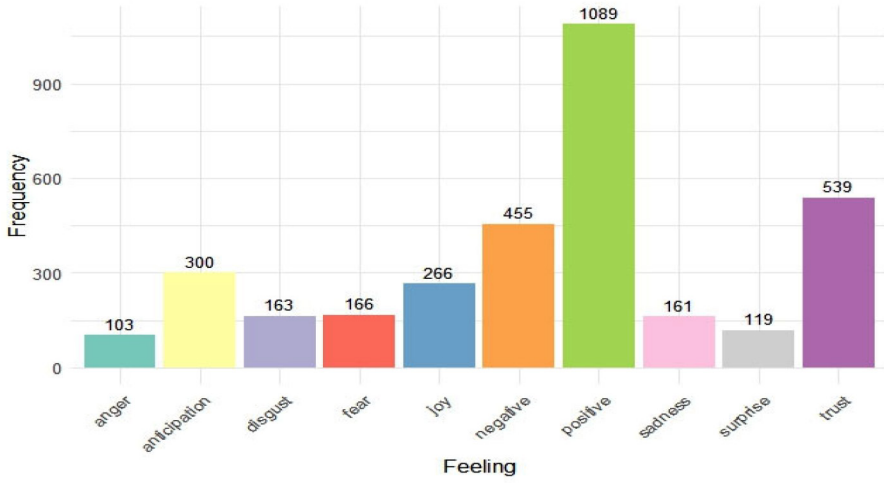


**Figure 3.** Sentiments in research abstracts

and thematic relationships between the work of different researchers over time. For example, an author may receive more citations in a specific period due to the relevance of their research at that time or the publication of a particularly influential article.

## 3.3. Characterization and mapping of research topics on banana pseudostem-derived products: thematic analysis

Figure 4 presents a Thematic Map that organizes the key research topics related to products derived from the banana pseudostem, using two fundamental dimensions: Relevance (Centrality) and Development (Density). These axes help identify which topics are more central and well-developed, in contrast to those that are emerging or in decline.

The most relevant and dense topics in the research on banana pseudostem as a biodegradable material (Figure 4) include biodegradation, biodegradable materials, cellulose, and the banana pseudostem itself. These topics are fundamental in the field and show a significant level of research and development. On the other hand, emerging or declining topics such as ionic polymer membranes and bioremediation are also observed. Although these topics may not be as prominent as the former, they show increasing or decreasing interest in research within these specific fields. Established topics such as fruit, biodegradable polymers, tensile strength, and scanning electron microscopy represent well-established areas of study that have contributed to the existing knowledge on the subject.

Among the most relevant and developed topics are biodegradation, biodegradable materials, cellulose and the banana pseudostem itself, which are fundamental pillars within the field of study. These topics have been the subject of numerous studies, reflecting their scientific maturity and their potential for technological application. On the other hand, topics such as ionic polymer membranes and bioremediation emerge, which although they present a lower research density, point to new directions of scientific exploration with possibilities for growth. Established topics such as fruit, biodegradable polymers, tensile strength and scanning electron microscopy also occupy an important place, contributing significantly to the body of accumulated knowledge on the use of pseudostems.

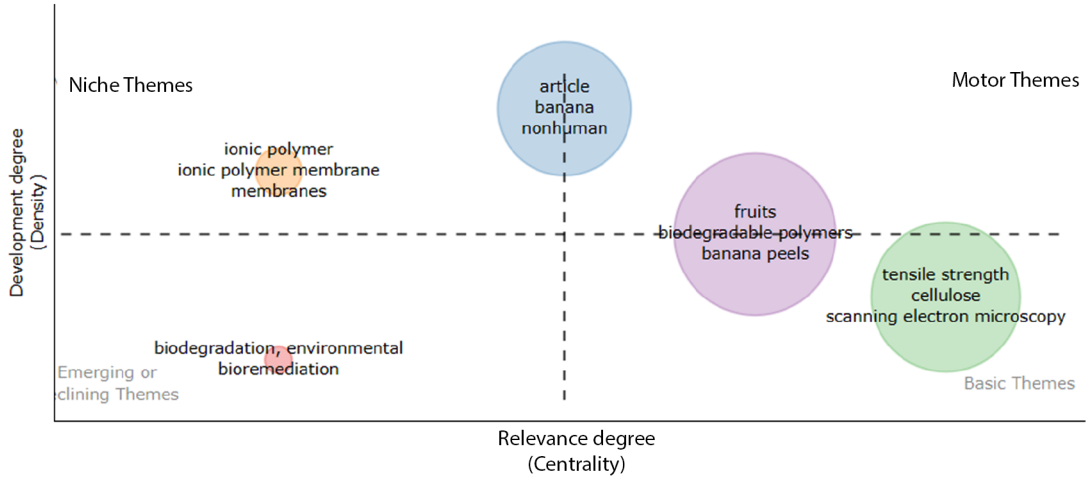


**Figure 4.** Thematic map

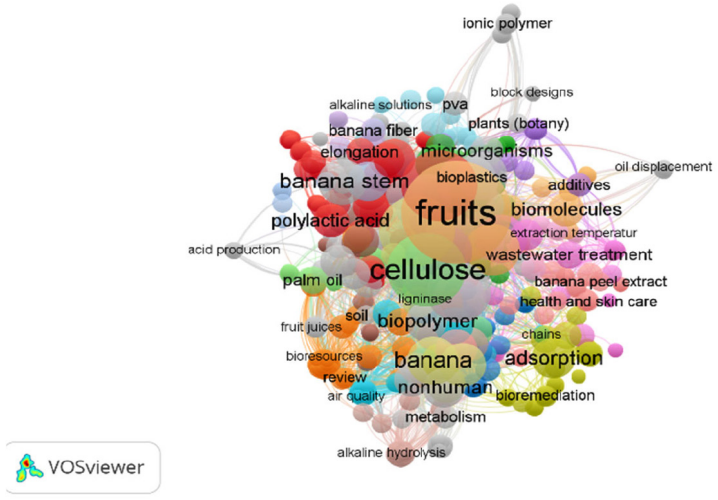


**Figure 5.** Word cloud

Complementarily, Figure 5 shows a word cloud that synthesizes the most frequent concepts in the literature analyzed. In this visualization, the size of the terms indicates their relevance and recurrence in the studies. The most prominent words include banana stem, fruits, cellulose, biopolymer and banana, which confirms the predominant focus on the use of pseudostem as a source of cellulose and other biodegradable compounds. In addition, terms associated with specific applications such as polylactic acid, bioplastics, adsorption, wastewater treatment, banana peel extract and health and skin care are identified, which shows a growing interest in its use in sectors such as environmental and cosmetics.

Terms linked to the extraction and structural modification processes also appear, such as extraction temperature, alkaline hydrolysis and elongation, indicating that diverse methodologies are being developed to optimize the obtaining and transformation of pseudostem components. Overall, this visualization provides a clear overview of the most active lines of research, as well as the potential applications of banana pseudostem as a raw material for the development of biodegradable materials and bioactive compounds.

## 4. Discussion

The sentiment analysis conducted on the analyzed scientific abstracts revealed a predominance of emotions such as positivity and confidence, which reflects a favorable perception by the research community regarding the use of banana pseudostem as a sustainable resource (Kampatzis et al., 2024). This optimism supports the increasing valorization of agricultural residues as viable alternatives to petroleum-derived materials, promoting more environmentally friendly and sustainable solutions. In turn, the confidence evidenced in the literature suggests an active willingness to invest resources in new technologies that enhance the adoption of pseudostems in various industrial applications.

From a bibliometric perspective, a high thematic centrality of compounds such as cellulose and biopolymers was identified, evidencing their fundamental role in the development of biodegradable plastics. Particularly, the extraction of cellulose nanofibers (CNFs) has been consolidated as an effective technique, standing out for their morphological properties with diameters close to 3.7 nm and a high aspect ratio as well as for the stability of their suspensions (zeta value of –29.1 mV) (Wahab et al., 2023). These characteristics reinforce their usefulness as reinforcing agents in composite materials.

Additionally, it has been demonstrated that pseudostem residues can be used in the synthesis of biocomposites with functional properties, such as the production of ferulic acid, an antioxidant with anti-inflammatory effects and UV protection capacity (Mohd Sharif et al., 2020). These types of applications extend the potential of pseudostem beyond its structural use, positioning it also as a source of value-added bioactive compounds (Shrestha et al., 2021).

In addition, natural fiber composites are recognized as emerging materials with great potential for engineering applications (Cuebas et al., 2021). Various plant fibers including banana stalk, rice husk, sisal, jute or kenaf have demonstrated competitive advantages, such as low cost, availability, renewability and light weight (Jaramillo et al., 2024). These materials have been successfully used in sectors such as automotive, construction, shipbuilding, aerospace and furniture, partially replacing synthetic materials (Salit et al., 2015).

However, despite numerous advances in the characterization of properties and applications of pseudosteel-derived composites, limited availability of studies targeting industrial-scale manufacturing processes persists (Chugh & Kaur, in press). Therefore, an important opportunity is identified for future research focused on standardizing transformation and scalability processes, allowing their practical implementation in commercial contexts.

Overall, the results obtained through this study underline the high potential of banana pseudostem as a raw material for the elaboration of biodegradable materials. The continuity of this line of research could be oriented towards functional analysis and the technical and economic feasibility of its integration into industrial systems, strengthening its role as an ecological solution to current environmental challenges (Arquelau et al., 2019; Nik Yusuf et al., 2016; Yadav et al., 2013).

## 5. Limitations of the study

It is important to recognize that this bibliometric analysis was conducted exclusively using records indexed in the Scopus database. While Scopus is considered one of the most comprehensive and reliable scientific indexing platforms, it does not cover the entirety of global academic output. Therefore, publications not included in Scopus may have been omitted from the analysis, particularly those from emerging journals, regional databases, or alternative open-access platforms. This limitation may affect the overall representativeness and scope of the findings, especially with regard to identifying all relevant contributions related to the application of banana pseudostems as biodegradable materials. It is recommended that future studies expand the range of data sources and adopt multiplatform bibliometric strategies to achieve a more holistic and inclusive mapping of scientific discourse in this field.

## 6. Conclusions

The purpose of this article was to explore the banana pseudostem as an alternative resource with high potential for the production of biodegradable materials, through a combined approach of bibliometric, thematic and sentiment analysis. From this integrated approach, it was possible to identify the main lines of current research, as well as the most relevant emerging industrial applications.

The findings indicate that pseudostem derivatives, in particular cellulose and biopolymers, are being widely investigated as a basis for the manufacture of bioplastics, biocomposites, biosorbents and other functional materials. These applications extend to sectors such as packaging, water treatment, textiles and the development of biodegradable medical devices, with particular interest in their antimicrobial and UV protection properties.

There is also a sustained growth in the use of pseudostems in the manufacture of bioplastics that could replace conventional plastics, as well as in the production of materials applicable in environmentally friendly industries. The bibliometric review also revealed a remarkable enthusiasm and positive perception by the scientific community, suggesting a favorable openness towards the development of sustainable technologies based on agricultural residues. This study highlights the importance of continuing research on the processes of extraction, characterization, scalability and application of materials derived from banana pseudostems, promoting sustainable solutions that contribute to the development of a circular and environmentally friendly bioeconomy.

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## Conflicts of interest

The authors declare no conflicts of interest.

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