Vol. 14, No. 1 (2025): 330 - 340 http://dx.doi.org/10.23960/jtep-l.v14i1.330-340

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Scientometric Analysis of Marine and Land Resources-Based Edible Coating for Extending Shelf Life of Banana

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Article History:

Received : 29 July 2024
Revised : 27 December 2024
Accepted : 13 January 2025

Keywords:

Banana,
Chitosan,
Edible coating,
Moringa oleifera,
Review.

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ABSTRACT

The shelf life of bananas is significantly limited due to rapid deterioration during marketing. To address this issue, edible coatings made from marine and land resources can be used in food packaging, improving consumer health, sustainability, and waste reduction in the food supply chain. Despite advancements in the field, research focusing on extending the shelf life of bananas through edible coatings remains limited. This research addresses the gap in extending banana shelf life by systematically evaluating the efficacy of edible coatings in reducing spoilage and improving preservation during marketing and storage. Employing a Systematic Literature Review (SLR) and meta-analysis with the SALSA framework, 164 scholarly journals were analyzed, highlighting 11 research clusters and 40 articles specifically discussing shelf life. Among the findings, the combination of Moringa oleifera (MO) and chitosan nanoparticles (CN) emerged as a superior combination and the most effective, extending banana shelf life by up to 30 days. This combination offers notable advantages, including strong antimicrobial properties, accessibility, cost-effectiveness, and eco-friendliness, positioning it as a practical, scalable, and sustainable approach to food preservation and waste reduction. These findings highlight the potential of innovative edible coatings to reduce food waste, support sustainability, and enhance banana supply chains.

1. INTRODUCTION

Bananas play a vital role in modern dietary habits due to their rich nutritional content and convenience as a portable snack (Sznajder-Katarzyńska *et al*., 2018). However, their perishability presents a significant challenge, limiting their shelf life and increasing food waste (Lamberty & Kreyenschmidt, 2022). This issue affects both consumers and suppliers, necessitating effective preservation methods. Edible coatings have emerged as an innovative and eco-friendly solution, forming a protective barrier on the fruit's surface that reduces exposure to external factors such as moisture, gases, and microbes (Chavan *et al*., 2023; Zhang *et al*., 2024). These coatings help slow down nutrient degradation and extend freshness (Pham *et al*., 2023; Massoud *et al*., 2023).

The demand for sustainable food packaging solutions has driven the development of edible coatings derived from marine and land-based biopolymers. These include lipids, proteins, polysaccharides, and cellulose, each offering unique film-forming properties that help reduce water loss, slow respiration rates, and delay fruit senescence (Jing *et al*., 2024; Zhang *et al*., 2022). Notable biopolymers currently utilized for fruit preservation include chitosan (Darmawati & Shacrudin, 2023; Zhang *et al*., 2020), alginate (Khan *et al*., 2023), gelatin (Khorram *et al*., 2017), carrageenan (Maulidiyah *et al*., 2024; Muñoz-Tebar *et al*., 2023; Pamungkas *et al*., 2023), and starch and cellulose (Thakur *et al*., 2019; Wardak *et al*., 2024).

The integration of edible coatings in food packaging represents a strategic approach that merges technological advancements with sustainability efforts. Despite progress in this field, research on extending banana shelf life remains insufficient. Key considerations include the effectiveness, scalability, cost, availability, and logistical feasibility of edible coatings in real-world applications. To address these challenges, a scientometric analysis was conducted using bibliometric and manual research methods across various data sources. This methodology, which ensures transparency and reproducibility, is gaining popularity for literature reviews (Haghani, 2023). While previous studies have focused on the chemical, structural, and mechanical properties of coatings, they often overlook scalability and economic implications, limiting their practical application.

This research bridges this gap by systematically evaluating edible coatings' effectiveness in reducing spoilage and preserving bananas under real marketing and storage conditions. The findings provide valuable insights for stakeholders in the food industry, supporting cost-effective and scalable preservation solutions. By promoting sustainable and practical coatings, this study contributes to minimizing food waste, enhancing fruit quality, and increasing the economic value of bananas in global markets. Ultimately, this research advances post-harvest technology and food security initiatives.

2. MATERIALS AND METHODS

The research utilized the Scientometric Analysis which includes Systematic Literature Review (SLR) methodology, incorporating meta-analysis for data analysis from January until June 2024. A systematic literature review (SLR) endeavors to ensure that the research outcomes are characterized by qualities such as qualitative nature, systematic approach, and explicitness. This approach described by del Amo (2018) which summarized in Figure 1, enables the identification, evaluation, and synthesis of scholarly journals. The SALSA framework, which stands for Search, Appraisal, Synthesis, and Analysis, provides a shared foundation for several strategies used in literature reviews (Taskin, 2019).

2.1. Search (S)

The initial stage in acquiring data involves searching. A focused search approach strategically locates the appropriate document inside a given database (del Amo *et al*., 2018). This study used Web of Science and Scopus, two reputable academic databases. Although this approach ensures the exclusion of gray literature and less reliable sources, relying solely on these two platforms may overlook relevant studies available in other databases, potentially limiting the global representation of research on banana edible coatings. Table 1 presents the search terms "edible coating" and "banana." The search results are refined by applying filters that prioritize the inclusion of the latest journal publications. This analysis classifies articles published from 2010 onwards as the most contemporary journals.

Table 1. The searching words used and the total number of publications

Database	Searching String	Keywords	Number of papers	Acquisition date
Web of science	Main searching terms-using doc title, abstract, and keywords	Edible coating banana	163	20/09/2023
Scopus	Main searching terms-using doc title, abstract, and keywords	Edible coating banana	106	20/09/2023

2.2. Appraisal (AL)

The evaluation process involves the selection of journals that align with the stated objectives by employing a filter guided by predetermined criteria (Mengist *et al*., 2020). The selection criteria for the journal are established according to the specifications outlined in Table 2. The process of selecting journals is depicted in Figure 1. At the outset of the search, 269 journals were identified from the Web of Science and Scopus databases. The initial screening process involved filtering out duplicate sources, including journals, books, language, and grey literature. As a result, 164 journals were chosen for further analysis, specifically focusing on the content related to "edible coating banana." The election results are utilized in this study.

Table 2. SLR study selection of literature using inclusion and exclusion criteria

Criteria	Decision
Predefined search terms are typically present either in their entirety or, at the very least, within the title of the papers, keywords, or abstract section.	Inclusion
The manuscript should be written in English.	Inclusion
When discussing the edible coating of bananas, the articles examine various aspects	Inclusion
The manuscript was published in a scholarly, peer-reviewed scientific publication.	Exclusion
The occurrence of duplicate manuscripts inside the search materials.	Exclusion
Research manuscripts that do not fall within accessible review manuscripts and meta-data	Exclusion
Manuscripts that do not provide primary or original research	Exclusion
The manuscripts do not describe the application of edible coatings to bananas	Exclusion
Manuscripts that were published prior to the year 2010	Exclusion

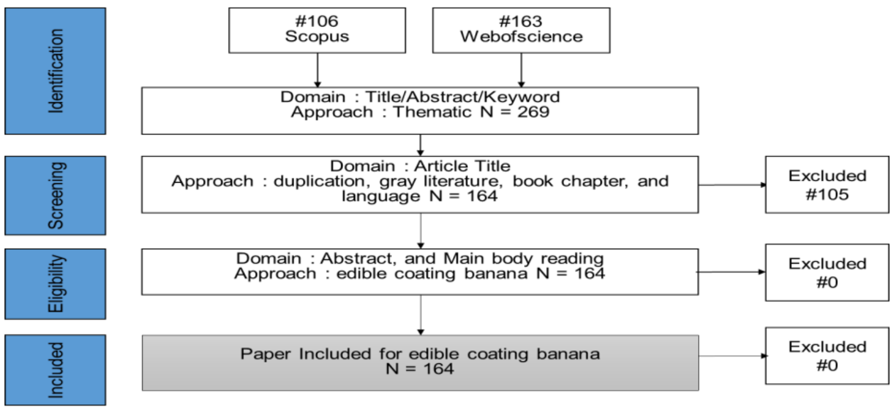

Figure 1. The flow diagram of database searching for systematic review publications. Source (Mengist *et al*., 2020)

2.3. Systhesis (S)

The synthesis phase integrates information from 164 carefully selected academic journals, adhering to pre-established objectivity criteria (Mengist *et al*., 2020). Table 3 presents the level of objectivity maintained in the systematic literature review (SLR). To facilitate analysis, the collected data has been systematically organized into tables and figures. The synthesis process was designed to enhance analytical efficiency. During the meta-analysis, effect sizes from relevant studies were statistically combined using a random-effects model to account for variability across different research settings. Additionally, funnel plots and sensitivity tests were conducted to evaluate potential publication bias and assess the robustness of the meta-analysis findings, ensuring a transparent and replicable synthesis process.

Table 3. The criteria used for the extraction of information from the selected articles

Criteria	Categories considered	Justification
Year of Publication	After 2010	Those studies before 2010 discarded
Study site	Name of the continental	Geographic site

2.4. Analysis (A)

CiteSpace software was used to visualize global research trends, highlighting areas of high activity and knowledge dissemination (Wei *et al*., 2022). Graph networks were analyzed based on node characteristics, connections, density, and centrality, identifying key research focal points. Bibliometric networks—such as word co-occurrence, document co-citation, and journal co-citation—were constructed to deepen understanding of edible banana coatings. To ensure accuracy, an alias list was created to merge search term variations, and exclusions were applied to mitigate biases from overlapping keywords. The Minimum Spanning Tree (MST) technique was avoided to preserve essential nodes and links, ensuring accurate network representation (Luo *et al*., 2022).

Time-slicing within CiteSpace segmented the co-citation network into distinct clusters, each representing specialized research areas. These clusters provided insights into evolving trends and highlighted gaps for future exploration in the field of edible coatings for bananas.

3. RESULTS AND DISCUSSION

3.1. Analysis of Published Articles Related to Edible Coating for Bananas

This study found a noticeable increase in scholarly investigations pertaining to the development of edible banana peels since 2010. Between the years 2019 and 2021, a substantial surge in research initiatives was observed. However, subsequent to this period, a decline in the quantity of scholarly publications being published was noted. Figure 2 exhibits a conspicuous surge in research productivity, as evidenced by the substantial growth in the quantity of scholarly papers, resulting in a cumulative count of 28. The graph illustrates the fluctuating trends in research pertaining to the coatings used on bananas intended for human consumption. There has been a substantial surge in research activity from 2019 to 2021, indicating a notable rise in interest in this specific issue. This platform serves as an effective means for researchers and professionals in the industry to be informed about the most recent advancements in banana coating technology. This trend emphasizes the need for ongoing studies to sustain progress in edible coating innovations.

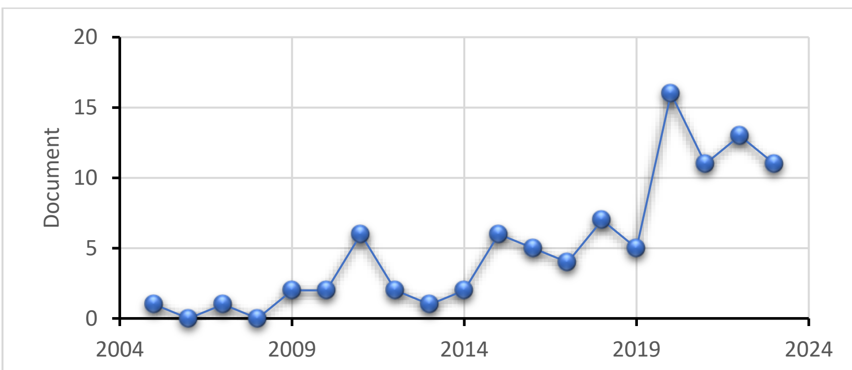

Figure 2. Number of journal papers on green construction between 2010 and 2023

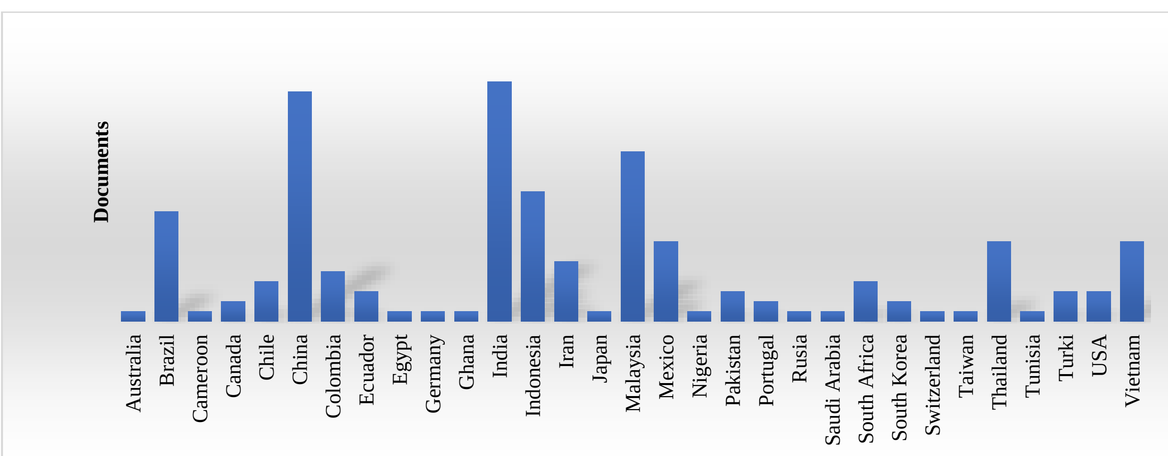

Figure 3. Countries Most Involved in Edible Coating Banana Research

Figure 3 shows that China and India emerge as the leading nations in doing research on edible coverings for bananas. The majority of research in the field of banana cultivation is conducted by scholars and scientists based in nations renowned for their banana production, such as Brazil, Indonesia, and Malaysia. China and India are at the forefront of research in the field of edible coverings for bananas. It is unsurprising that nations such as Brazil, Indonesia, and Malaysia, which are major banana producers, are diligently endeavoring to discover methods for rendering banana peels edible for human consumption. These nations possess a rationale for enhancing post-harvest technologies related to bananas and exploring sealing alternatives to mitigate spoilage, extend their shelf life, and potentially expand their presence in international export markets. The selection of these countries for the study is justified due to their proximity to major banana production hubs and their comprehensive knowledge of local banana cultivars and associated challenges. These findings underline the importance of geographic and agricultural contexts in driving research priorities and highlight opportunities for collaboration across global research networks.

3.2. Major Cluster in Edible Coating Banana

Figure 4 presents a timeline and clusters related to research on edible coverings for bananas, revealing 11 distinct clusters through CiteSpace analysis. The first cluster, consisting of 43 members, centers on research by Andrade *et al*. (2014) investigating the effects of gelatin, glycerol, and cellulose nanofibers on the adhesive properties of gelatin-based coatings for bananas and eggplants. This study employs surface-free energy analysis using Zisman and Van Oss, Chaudhury, and Good (vOCG) techniques. Findings indicate improved surface wettability with increased amounts of gelatin, glycerol, or cellulose nanofibers.

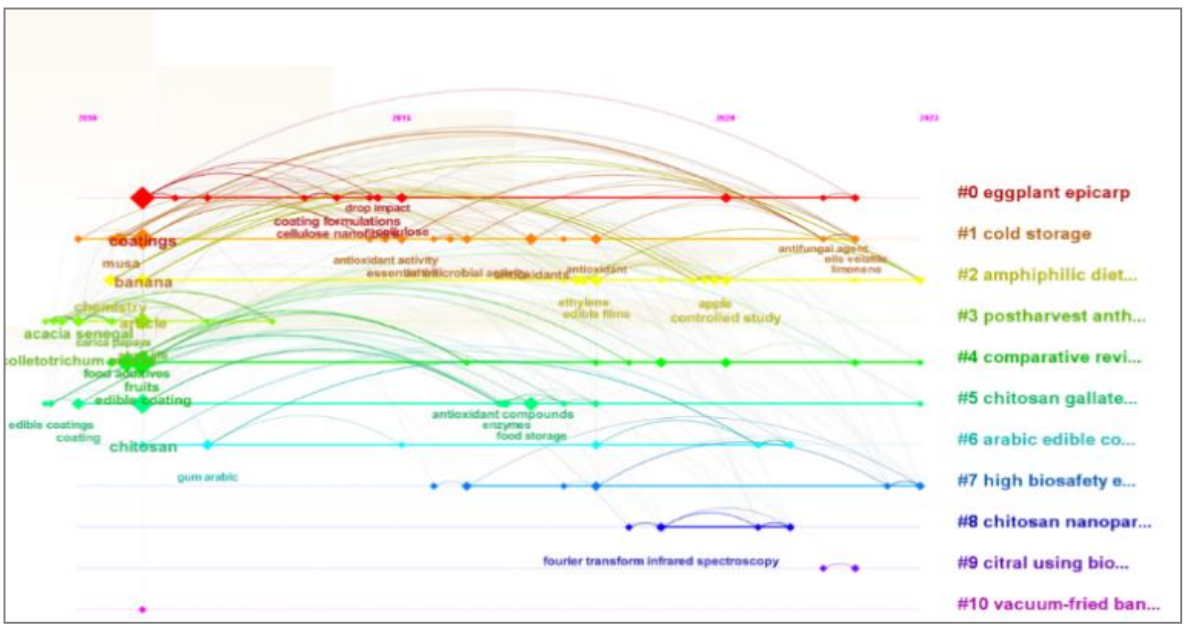

Figure 4. Timelines and the cluster size of edible coating banana journal

Key terms cited within this cluster include "coatings" (25 times), "cellulose" (5 times), and "strawberry" (4 times), reflecting the cluster's broader relevance. Beyond fruit surface wettability, the findings have implications for sustainable food preservation, innovative packaging solutions, and interdisciplinary collaborations across materials science, food science, and agriculture.

The second-largest cluster, comprising 35 members, is represented by Zhang *et al*. (2020). This study investigates the use of chitosan film enriched with banana peel extract, highlighting its enhanced antioxidant activity and improved physical and mechanical properties. This eco-friendly innovation aligns with global efforts to enhance food security, reduce waste, and develop sustainable packaging solutions.

The third-largest cluster, with 33 members, is centered on Cunha *et al*. (2020). This research explores the use of high molecular weight amphiphilic diethylaminoethyl chitosan as an edible film for preserving perishable fruits. Its superior antibacterial properties and pH resilience make it effective for extending shelf life. Key terms like "article" (8 citations), "chemistry" (6 citations), and "edible films" (5 citations) underline the significance of materials science and postharvest management in mitigating food waste and promoting sustainable agriculture.

The fourth cluster, consisting of 30 members, focuses on research by Maqbool *et al*. (2010), which examines the antifungal effects of Arabic gum (AG), chitosan (CH), and their mixtures in combating postharvest anthracnose in bananas. Core terms such as "shelf life," "*Colletotrichum Musae*," and "physicochemical property" emphasize the study's focus on postharvest disease management. This research offers strategic solutions for sustainable agriculture, including enhanced crop preservation and pest control using AG and CH-based coatings.

3.3. Citation Bursts in Edible Coating Banana Research

The outcomes of the "citation burst" from 2010 to 2023 are seen in Figure 5. This period of time enhances the durability of a product. The frequency of citations related to the concept of "shelf life" had an increase in the year 2022. The phenomenon of citation explosion exemplifies the rapid advancement of research into banana edible coatings. The use of the word "shelf life" is seeing a notable rise in prevalence in the year 2022, indicating a growing interest in the popularity of banana coatings. The heightened focus on food safety, sustainability, and banana preservation might perhaps be driving this increasing attention. Table 4 provides a comprehensive overview of the research conducted on the shelf life of bananas. Both the corporation and consumers benefit from academics conducting studies on procedures and materials aimed at prolonging the shelf life of packaged bananas.

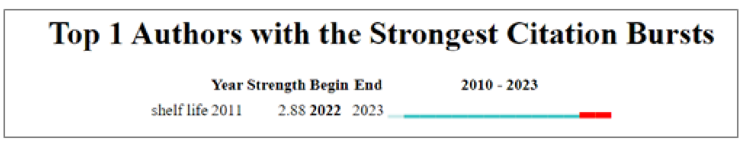

Figure. 5. Terms with the strongest citation bursts between 2010 and 2023

One of the most widely grown subgroups of bananas worldwide is the Cavendish subgroup (Lobo & Yahia, 2017). Cavendish banana also has high economic value, especially for export commodities (Widayatmo & Nindita, 2019). High export opportunities for Cavendish bananas need to be balanced with increased productivity and shelf life. Since bananas have a high-water content, preventing water loss during postharvest storage (by regulating temperature and humidity) is essential (Thakur *et al*., 2019). Ripening fruit undergoes physiological and biochemical changes, affecting soft flesh of the tissues desirable traits like increased membrane permeability, decreased flesh stiffness, increased sugar levels, color change, increased respiration rate, and decreased turgor (Jiang *et al*., 1999).

The distinctive skin color of ripe bananas serves as a crucial indicator of consumer acceptability. Within 1-3 days of becoming yellow, bananas lost their marketability to consumers (Ahmed & Palta, 2016). Most studies utilized mature-green bananas and marine and fisheries resources like carrageenan and chitosan as coating materials. Following starch and gelatin in terms of hydrocolloid concentration, carrageenan is a polysaccharide obtained from Rhodophyceae seaweed (Wullandari *et al*., 2021).

As the second-most significant polysaccharide in nature after cellulose, chitin, which is found in the exoskeletons of marine invertebrates, insects, fungi, algae, and yeast, is converted into chitosan (-(1,4)-2-amino-2-deoxy-D-glucose), a natural biopolymer. Chitosan, a natural fungicide and defense booster, has gained significant attention in recent years for its potential in forming semipermeable coatings on fruits and vegetables, extending their storage and preventing rot (Rohmah *et al*., 2022).

Table 4 states that the longest shelf life of banana is 28 and 30 days which was obtained with the addition of *Aloe vera* (AV) and Chitosan Nanoparticle (CN), also *Moringa oleifera* (MO) and Chitosan Nanoparticle (CN). The cavendish banana was subjected to the following treatments: *Aloe vera* 50% + chitosan nanoparticle 2% (AV+CN), and *Moringa oleifera* 10% + chitosan nanoparticle 2% (MO+CN). *Aloe vera* gel 50% (v/v) and moringa 10% (v/v) were combined with chitosan nanoparticle (CN)% (v/v) added to each solution and mixed to create chitosan nanoparticle coating solutions. To complete the volume, distilled water was added to the MO+CN and AV+CN mixtures, and all ingredients were homogenized to form smooth, uniform coating solutions. Each batch of bananas required approximately 8 L of coating solution. The emulsions were agitated at room temperature for two hours before banana fingers were dipped for one minute and air-dried for 15-20 minutes. After coating, the bananas were stored in a dark room at 18 ± 1°C with 35–45% relative humidity. Postharvest parameters such as color, weight loss, decay rate, soluble solids, and hardness were measured at 5-day intervals over a 30-day storage period (Odetayo *et al*., 2022). The coatings showed improved performance, with reduced decay and weight loss, demonstrating their potential for real-world applications.

3.4. Practical Implications and Differentiation from Existing Research

This scientometric analysis bridges fundamental research with practical applications, offering stakeholders in food production and supply chains cost-effective and scalable coating strategies for extending banana shelf life. Unlike prior studies focusing on individual coatings, this research emphasizes synergistic combinations, such as *Moringa oleifera* (MO) and chitosan nanoparticles (CN). These combinations not only enhance shelf life but also ensure ease of application and environmental benefits, making them suitable for real-world implementation.

A key distinction of this study lies in its meta-analytic synthesis, which uncovers broader patterns beyond isolated experiments. By contextualizing the economic and environmental advantages of MO- and CN-based coatings, the research aligns with global sustainability goals while advancing practical postharvest solutions.

3.5. Prospective Use of Coating Techniques Utilizing Chitosan Nanoparticles and *Moringa oleifera*

The use of CN and MO as banana coatings offers distinct advantages in availability, cost-effectiveness, safety, ease of application, and performance, making them superior to alternative materials.

- Availability and Cost-Effectiveness

Chitosan, derived from chitin found in shrimp, fungi, and insects, is widely accessible due to the global production of shrimp and other sources (Mutreja *et al*., 2020). Similarly, *Moringa oleifera* thrives in tropical and arid climates with minimal maintenance, making it an affordable, sustainable resource for edible coatings, especially in local farming contexts (Marhaeni, 2021; Horn *et al*., 2022). Both materials are cost-effective, with food-grade chitosan recognized as an economical biomaterial (Wang & Zhuang, 2022).

- Performance Advantages

CN coatings offer superior barrier properties, reducing oxygen and water vapor penetration to slow ripening and minimize weight loss (Wantat *et al*., 2022; Wardana *et al*., 2024). They also exhibit strong antifungal activity, outpacing traditional chitosan in preserving banana quality and extending shelf life (Wardana *et al*., 2024). Chitosan composites, such as chitosan-montmorillonite, effectively reduce peel discoloration and respiration rates (Kaeokanphai *et al*., 2024). MO coatings, including Moringa oil, provide antimicrobial benefits that reduce spoilage, minimize weight loss, and maintain firmness. They often outperform alternatives like Neem oil (Adetunji *et al*., 2013). Additionally, their biodegradability supports sustainable agricultural practices, enhancing their eco-friendly appeal (Adetunji *et al*., 2013).

- Safety and Ease of Application

Both CN and MO are food-grade materials, safe for human consumption. Their application is straightforward: bananas are dipped in the coating solution and air-dried. While careful management of storage conditions (e.g., temperature and humidity) is necessary, the process is practical for widespread use (Thakur *et al*., 2019).

- Global Applicability and Sustainability

The wide availability, affordability, and sustainability of CN and MO make them ideal for global food preservation applications. By leveraging accessible, eco-friendly resources, these coatings offer cost-effective and innovative solutions for advancing edible coating technologies and promoting sustainable practices.

Table 4. Research on the extension of the shelf life of bananas through the application of edible coatings

Type of banana	Colour Index	Coating material	(Marine/ Land)	Coating method	Storage Temperature	Storage time (days)	Shelf life	References
Fresh banana (cavendish)	Mature green stage	rice starch, ι-carrageenan	Mixed	Spraying	20 ± 2 °C; RH 52 ± 3%	2, 4, 6, 8, 10, 12 and 14	14 days, extend to 4 days compared to control	(Thakur *et al*., 2019)
Fresh banana (cavendish)	Maturity stage A1	*Aloe vera* (AV), *Moringa oleifera* (MO), chitosan nanoparticle (CN)	Mixed	Dipping (1 minute)	18 ± 1 (room) 35-45% RH	0, 5, 10, 15, 20, 25, and 30	AV: 25 days MO: 26 days AV+CN: 28 days MO+CN: 30 days	(Odetayo *et al*., 2022)
Fresh banana	Matured	*Aloe vera* L.	Land	Immersing (5 minutes)	23±1 °C and 78% RH	0, 3, 6, 8, and 9	9 days, 6 days longer than control	(Jodhani & Nataraj, 2021)
Fresh banana	NA	chitosan/gum arabic	Mixed	Immersing (NA minutes)	35°C and 54% RH	0, 3, 6, 9, 13 and 17	Coated: 17 days Uncoated: 13 days	(La *et al*., 2021)
Fresh banana (Amritasagar)	Mature green stage	shrimp chitosan	Marine	Dipping (1 minutes)	26 (ambient)	0,1,2,3,4 ... 16, 17	Coated: 16.6 days Uncoated: 12.4 days	(Hossain & Iqbal, 2016)
Fresh banana	Mature green	chitosan, CaCl2, gibberellic acid (GA), glycerol, jojoba wax	Mixed	(NA) 10 minutes	34 ± 1°C and 70-75% RH	0, 5, and 10 days	Coated: 17.2 days Uncoated: 11.3 days	(Gol & Rao, 2011)
Fresh banana (cavendish)	Mature green	chitosan (CS) and chitosan nanoparticles (CN)	Marine	Dipping (2 minutes)	25 ± 1°C (ambient)	0, 1, 3, 5, 7, 9, and 11	Coated: 11 days Uncoated: 9 days	(Lustriane *et al*., 2018)
Fresh banana (cavendish)	Mature green	Carrageenan	Marine	Dipping (30 sec)	26 ± 1 (or 20)	0, 1, 3, 5, 7, 9, 11 and 13	Six days longer than control Coated: 13 days Uncoated: 7 days	(Dwivany *et al*., 2020)
Fresh banana (cavendish)	2 (green with trace of yellow)	Cellulose nanofibers (CNF) Cellulose nanocrystals (CNC)	Land	Brushing (using a paint brush width: 25 mm)	(20 ± 2°C and 50 ± 5% RH) ambient	0, 2, 4, 6, 8, and 10	Coated: 9 days Uncoated: 5 days	(Deng *et al*., 2017)
Fresh banana	Stage 1	Chitosan (CH), gum arabic (GA)	Mixed	Immersing (NA times)	25◦C and 70% (natural dried)	0, 3, 6, 9, 12, 15, 18 and 21	Coated: 21 days Uncoated: NA days	(Le *et al*., 2021)

4. CONCLUSION

The scientometric analysis of research on banana edible coatings emphasizes the critical need to prolong storage duration. CN and MO have emerged as effective solutions, offering unique antimicrobial and barrier properties. Their combination, as an edible coating, is highly practical due to extensive availability, cost-effectiveness, ease of application, and safety for consumption.

Future research should focus on scaling this coating formulation for industrial applications, particularly in high-volume banana production and export chains. Efforts to optimize application methods, such as automated or spray-based systems. This study highlights the unique contribution of CN and MO as a sustainable innovation in post-harvest technology, offering a significant step forward in reducing food waste and ensuring fruit quality during storage and transport.

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