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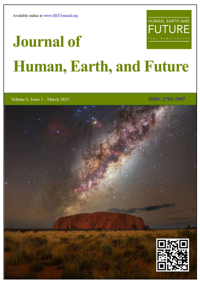

Review Article

Global Trends in Agricultural Waste-Based Bioplastic Research: A Scientometric Review

Erdiwansyah [1, 2], Salfauqi Nurman [3, 4], Masyudi [5], Saudah [6], Irhamni [7, 8*], Diana [3], Fadlan Hidayat [3]

[1] *Department of Natural Resources and Environmental Management, Universitas Serambi Mekkah, Banda Aceh 23245, Indonesia.*

[2] *Centre for Automotive Engineering, Universiti Malaysia Pahang Al-Sultan Abdullah, Pekan 26600, Malaysia.*

[3] *Department of Agricultural Industrial Engineering, Faculty of Agricultural Technology, Universitas Serambi Mekkah, Banda Aceh 23245, Indonesia.*

[4] *Department of Ship Engineering, Politeknik Pelayaran Malahayati, Aceh Besar 23381, Indonesia.*

[5] *Department of Public Health, Faculty of Public Health, Universitas Serambi Mekkah, Banda Aceh 23245, Indonesia.*

[6] *Master of Biology Education, Universitas Serambi Mekkah, Banda Aceh 23245, Indonesia.*

[7] *Department of Environmental Engineering, Faculty of Infrastructure and Regional Technology, Institut Teknologi Sumatera, Lampung Selatan, 35365, Indonesia.*

[8] *Department of Environmental Engineering, Faculty of Engineering, Universitas Serambi Mekkah, Banda Aceh 23245, Indonesia.*

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Abstract

The research of utilizing agricultural waste has been established for over 6 decades, yet problems regarding plastic waste remain the biggest challenge in environmental issues. The aim of this study was to capture the publication, thematic, and collaborative trends in agricultural waste-based bioplastic research through bibliometric or scientometric analysis. Metadata of relevant research was downloaded from the Scopus database as of November 9, 2024, utilizing a pre-determined combination of keywords. We included records from original research and English-written documents, which were further manually screened for relevance. Scienntometric analysis was analyzed using both bibliometrix and VOSviewer. We found 1,451 records being relevant to the scientometric studies, where the publication peaked at 2024 (n = 170). The most relevant source title was the Science of The Total Environment (n=40), followed by polymer and agricultural-related titles. The words “plastic,” “film,” and “mechanical strength” were the most commonly used, with occurrences reaching 3532, 1471, and 1008 times in the abstract. The thematic analysis revealed that the “bioplastic for food packaging” and “starch” are motor and declining themes, respectively. The VOSviewer visualization of keywords co-occurrence revealed “starch” and “bioplastic” as the dominant keywords with total link strengths (TLSs) of 12 and 13, respectively. An Indonesian university, Universitas Sumatera Utara, was the most productive (n=45). However, the country is in 18th position (n=329) with the least average citations per document (5.5). China and the United States were the most productive countries (n=194 and 99, respectively) that received a total of 3523 and 3345 citations, respectively. Collaboration between China and the United States was established with a TLS of 14, with other observed collaborations such as India, the United Kingdom, Canada, Germany, and Brazil. In conclusion, the research is growing rapidly each year, with China-based institutions leading the field, while countries like Indonesia are beginning to gain recognition. The main focus of innovation in this research is on producing bioplastics for food packaging, which is the most reported area. Additionally, there is a trend toward exploring alternative raw materials, indicating a reduced utilization of starch. Future research should aim to optimize bioplastic production by exploring diverse approaches and fostering international collaboration.

Keywords: Agriculture; Bibliometric; Bioplastic; Circular Economy; Plastic.

* Corresponding author: irhamni@serambimekkah.ac.id

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1. Introduction

Plastic pollution has become a major global threat due to its non-biodegradable nature and the toxic chemicals it releases into the environment [1]. Substances such as Bisphenol A, phthalates, and microplastics pose serious health and ecological risks, contaminating air, water, and soil [2]. According to previous studies, Bisphenol A and phthalates are endocrine disruptors, capable of interfering with hormonal systems and affecting reproductive health in both humans and wildlife [2-4]. Other published reports highlight the significant role of microplastics in bioaccumulation, where small plastic particles enter food chains, leading to toxic effects in marine and terrestrial ecosystems [5, 6]. A meta-analysis estimated that the burden of microplastic bioaccumulation in *Thalassia testudinum* could reach as much as 4.56 microplastics per individual [7]. Plastics are extensively used in various applications, with food packaging being one of the most common forms, often in the form of film. According to a previous report, single-use plastic films used for food packaging are one of the largest contributors to plastic waste, owing to their short lifespan and limited recyclability [8]. A review article specifically highlights that flexible packaging plastic waste from food packaging is a major contributor to the formation of microplastics and nanoplastics [9]. This type of waste dominates packaging markets, accounting for over 40% of plastic usage in regions like the United States, Japan, and South Korea [9].

On the other hand, agricultural solid waste presents a pressing challenge, contributing to environmental degradation if not managed properly [10-12]. According to previous studies, improper disposal of agricultural waste can lead to increased greenhouse gas emissions and the contamination of soil and water resources [13]. However, this biomass holds great potential for recycling or upcycling into valuable materials, such as biodegradable plastics [14-16]. Early research focused on utilizing starch derived from agricultural waste due to its natural biodegradability and availability [14]. As an overview, agricultural waste-based bioplastics are polymeric materials made of starch-rich and lignocellulosic residues. Examples of starch-rich residues include corn, yam, and potato peels, which are valued for their renewable and cost-effective nature [17-19]. Nonetheless, those feedstocks often suffer from poor mechanical properties and water sensitivity [20, 21]. More recently, innovative approaches have emerged, incorporating advanced materials and processing techniques to enhance the properties and applications of bioplastics [22, 23]. Additionally, lignocellulosic materials such as rice husks, sugarcane bagasse, and wheat straw are gaining attention for their potential to enhance the durability and thermal stability of bioplastics [24, 25]. Previous research has highlighted the successful reinforcement of sugar palm-based nanocellulose into starch-based bioplastics, significantly improving their strength and durability [26]. A review article highlights that the heterogeneous chemical composition of agricultural waste feedstock could offer opportunities, though the conversion of biomasses into value-added materials requires innovative fractionation strategies [27]. Recent reviews have covered the sustainability, commercial feasibility, and production aspects of agricultural waste-derived bioplastics [28-32]. However, a literature review using a scientometric approach that could inform the research trend comprehensively has been underreported.

To support advancements in this field, it is essential to identify research trends that provide valuable insights for researchers to produce impactful studies. According to previous studies, bibliometric analysis has proven to be an effective method for examining large datasets, enabling researchers to track publication trends and identify influential works in a field [33, 34]. Bibliometric analysis is a powerful tool for this purpose, as it can handle large volumes of publication records and uncover patterns and collaborations in research, unlike systematic reviews that must focus on specific topics [35]. Using tools such as VOSviewer and bibliometrix, bibliometric analysis allows researchers to map thematic networks, analyze keyword co-occurrences, and evaluate collaborative trends. VOSviewer visualizations in this study highlight collaboration networks by mapping co-authorship patterns between institutions and countries, revealing key contributors and global partnerships. According to previous studies, the use of co-occurrence networks and thematic mapping has been instrumental in identifying key research clusters and emerging topics, particularly in rapidly evolving fields [36, 37]. A scientometric or bibliometric review allows for an understanding of emerging themes and research gaps, international collaborations, and their impact on scientific advancements. Some research groups have even utilized a similar approach to observe the shift of research interest and trends as the results from the global phenomenon such as the coronavirus disease 2019 pandemic [38, 39]. This scientometric review consists of the methods section describing the bibliometric approach used to analyze publication trends, thematic evolution, and collaboration patterns. The results and discussion sections present key findings, including the most relevant keywords, thematic clusters, and future research trajectories, followed by a conclusion.

2. Methods

2.1. Database and Records Identification Strategies

The scientometric review followed the recommendation from a published guideline [40]. The search was performed on the Scopus database for records indexed as of November 9, 2024. The keywords combination was established using Boolean operators (i.e., OR, AND) to identify records relevant to agricultural waste-based bioplastics. The following keywords were applied on the Scopus search engine: (TITLE(bioplastic OR plastic) AND

TITLE-ABS-KEY(agriculture OR fruit OR rind OR leaf OR leaves OR seed* OR peel OR husk OR pod OR starch)). The identification and screening of the records involved several sequential steps, where the illustration is presented in Figure 1. Manual screening criteria focused on retaining records that explicitly addressed agricultural waste-based bioplastics in the title, abstract, or keywords. Articles were excluded if they lacked relevance to the topic, such as studies focusing solely on synthetic plastics, theoretical modeling without agricultural waste-based inputs, or unrelated material properties. The search criteria included original research articles written in English, with metadata such as titles, abstracts, keywords, and citation information exported for analysis. Challenges encountered during the process included ambiguity in some abstracts that required further full-text examination and differences in interpretation between reviewers, which were resolved through discussion to ensure consistency. Duplicate records and irrelevant publications were removed through manual screening by two independent reviewers, where any discrepancies were resolved through discussion. The cleaned dataset in comma-separated values (.csv) format was then imported into analysis tools, namely Bibliometrix and VOSviewer.

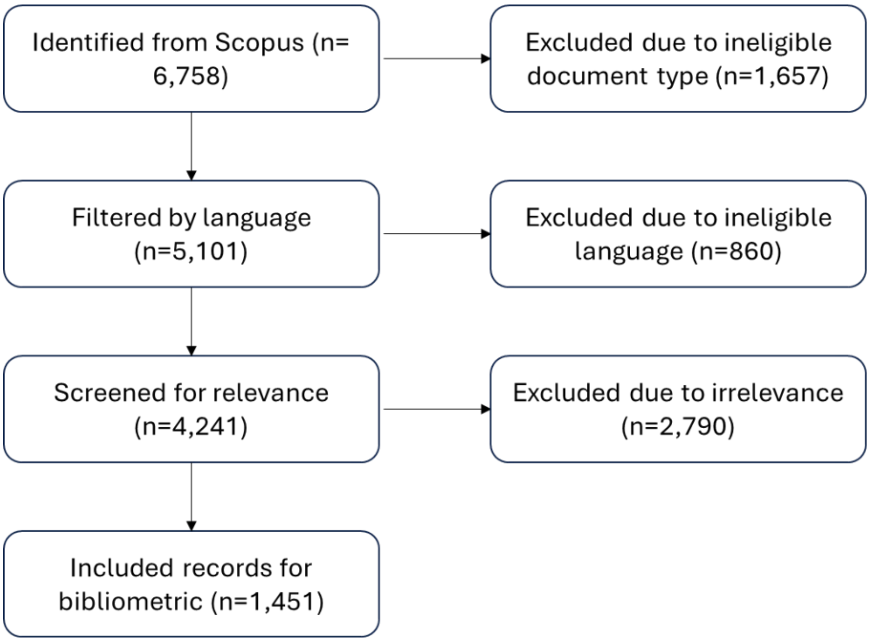


Figure 1. Flow-chart diagram on the selection of Scopus-indexed records relevant to agricultural waste-based bioplastics.

2.2. Bibliometric Analysis on Bibliometrix

The bibliometric analysis was conducted using the Bibliometrix package in RStudio version 2024.04.2 following the guideline published previously [41]. The analysis included mapping publication trends, the most relevant keywords, institutions, and countries. Collaboration patterns were assessed by analyzing co-authorship networks, providing insights into the strength of international partnerships and the extent of multi-country collaborations. A detailed evaluation of keywords was performed, focusing on terms extracted from abstracts, to identify recurring themes and trends in the research field. Thematic evolution since the study was first published was analyzed by classifying the research themes into niche, emerging or declining, basic, and motor categories. Moreover, the citation analysis was also carried out to determine the most cited publications per country of the corresponding author.

2.3. Bibliometric Analysis on VOSviewer

The VOSviewer software (version 1.6.20) was used to perform network analyses following the published guideline [42]. Herein, the software was employed to construct the network visualizations for co-occurrence of authors' keywords and affiliation countries. The tool's clustering algorithm grouped related keywords into clusters based on association strength using the full counting method. Each connection in the network was assigned a Total Link Strength (TLS) value, which quantifies the strength of the relationship between keywords or affiliated countries.

3. Results and Discussion

3.1. Publication Trend

The screening process resulted in a total of 1,451 records from relevant original research articles being analyzed in the bibliometric review. A graph illustrating the publication trends as observed by the annual number of publications is presented in Figure 2a. The publication began to gradually increase in the 1990s, with publications reaching double digits consistently. Notably, the period from 2000 to 2010 marked steady growth, with annual publications increasing from 12 in 2000 to 34 in 2011. Around 2011, an exponential growth phase began, as evident from sharper annual increases in publications. This trend became particularly pronounced after 2020, when the number of publications rose sharply from 82 in 2020 to 170 in 2024. This transition suggests a rapid acceleration in research activity in recent years, underscoring the growing importance of the field. A similar publication trend is observed in other research themes, such as those in polymeric material research or medical research [43-46]. However, for bioplastic research from specific feedstock material such as nanocellulose and chitosan nanofibers, the declining publication terms are reported [47-49]. Agriculture waste-based bioplastic is, therefore, a promising field, as indicated by the increase in research interest throughout the years.

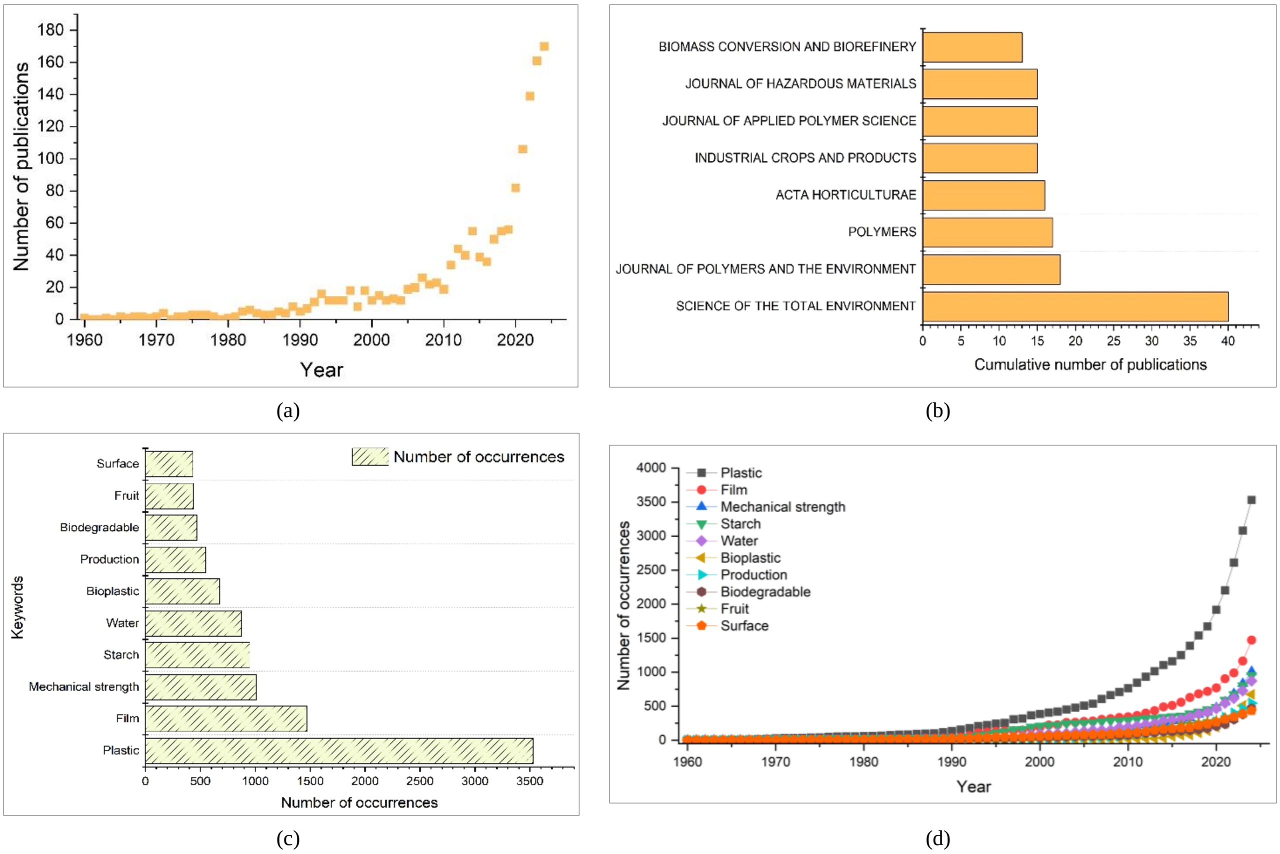


Figure 2. Number of publications according to (a) publication year and (b) journal titles. The most relevant (c) keywords presented accumulatively and (d) annually

The cumulative number of publications across journals reveals that *Science of the Total Environment* leads with 40 publications, underscoring its prominence in the field of agricultural waste-based bioplastic research (Figure 2b). This journal's consistent output highlights its role as a key platform for disseminating research focused on environmental sustainability and bioplastics. The *Journal of Polymers and the Environment* follows with 18 publications, reflecting its significant contributions to the exploration of environmentally friendly polymer technologies. Other journals, such as *Polymers* (17 publications), *Acta Horticulturae* (16 publications), and *Industrial Crops and Products* (15 publications), also exhibit notable contributions, showcasing a range of research platforms within the field. Similarly, the *Journal of Applied Polymer Science*, the *Journal of Hazardous Materials*, and *Biomass Conversion and Biorefinery* account for 15 or fewer publications, respectively (Figure 2b). These journals contribute to the advancement of specific aspects of bioplastic research, including polymer properties, waste valorization, and the integration of agricultural residues into sustainable materials. The strong presence of multidisciplinary journals highlights the diverse and cross-cutting nature of this research field, which spans environmental science, polymer chemistry, and agricultural applications. For some instances, the bioplastic research has been focused on the environmental impact [50], polymeric material manufacturing [23, 26], and its benefits to the agricultural sector [51]. Collectively, these results suggest that *Science of the Total Environment* serves as a primary platform for agricultural waste-based bioplastic research, while other journals also play critical roles in advancing specialized areas within the domain.

3.2. The Most Relevant Keywords

The most relevant keywords in agricultural waste-based bioplastic research were analyzed based on their cumulative and annual occurrences. "Plastic" emerged as the most dominant keyword with 3,532 occurrences, followed by "film" (n=1,471) and "mechanical strength" (n=1,008). "Starch," "water," and "bioplastic" were also prominent with 950, 872, and 674 occurrences, respectively. Keywords like "production," "biodegradable," "fruit," and "surface" appeared less frequently, with cumulative occurrences ranging from 433 to 546. Over time, "plastic" showed a sharp increase in usage beginning in the 1990s, with exponential growth after 2010, peaking in 2024. "Film" and "mechanical strength" followed similar trends, reflecting their importance in bioplastic development. This shows an increasing demand for sustainable materials to replace traditional plastics, especially for food packaging. Researchers have focused on improving mechanical properties like strength and flexibility to match the functionality of conventional plastics [52, 53]. Studies also suggest that bioplastics degrade more efficiently under composting conditions [54, 55].

Meanwhile, "starch" and "bioplastic" demonstrated steady growth, with a recent shift toward alternative raw materials, while the rise in "biodegradable" and "production" highlights a growing focus on sustainability and scalability. These patterns illustrate the dynamic evolution of research priorities in agricultural waste-based bioplastic development. Critically, the reliance on conventional terms like "starch" suggests a slower transition toward innovative raw materials. Starchy materials are widely preferred for bioplastic manufacturing due to their abundance, renewability, and cost-effectiveness [21, 56]. Chemically, starch consists of amylose and amylopectin, which have hydroxyl (-OH) groups that enable strong hydrogen bonding. This contributes to its ability to form films, making it versatile for various applications like packaging, including smart packaging [57]. Starch-based bioplastics can be infused with functional additives or nanoparticles, allowing them to detect or respond to environmental changes such as temperature, humidity, or microbial activity [57-59]. These properties make starch bioplastics suitable for intelligent food packaging to monitor spoilage or extend shelf life. However, the hydroxyl moieties in starch make it hydrophilic, reducing its resistance to water. As a result, native starch-based bioplastics are prone to swelling and degradation in humid environments [60]. To address this, researchers have modified starch chemically or blended it with hydrophobic polymers to enhance its water resistance and mechanical strength [61]. The trend for the “starch” appearance did not increase significantly as others probably did due to the shift of research interest to other feedstock materials such as pectin and nanocellulose [62-64].

Moreover, the emphasis on "film" and "mechanical strength" aligns with research trends exploring bioplastics for packaging applications, particularly in addressing durability and flexibility issues to meet industrial requirements. These properties are crucial for ensuring that bioplastic films can withstand mechanical stresses during transportation and storage. Advances in this area have included blending bioplastics with reinforcing agents such as nanocellulose or clay nanoparticles, which enhance tensile strength and barrier properties [21, 65]. Additionally, the development of multilayer bioplastic films has emerged as a promising approach to improving both durability and flexibility [66]. Lignocellulosic materials, abundant in agricultural waste, offer potential for creating bioplastics with enhanced mechanical and thermal properties while reducing reliance on food-based resources [67]. In previous studies, integrating fibers derived from lignocellulosic biomass into bioplastic matrices has been shown to significantly improve their performance [68, 69]. Moreover, research interest has also shifted to nanocellulose as filler to enhance the mechanical strength and the resistance of the film [70, 71].

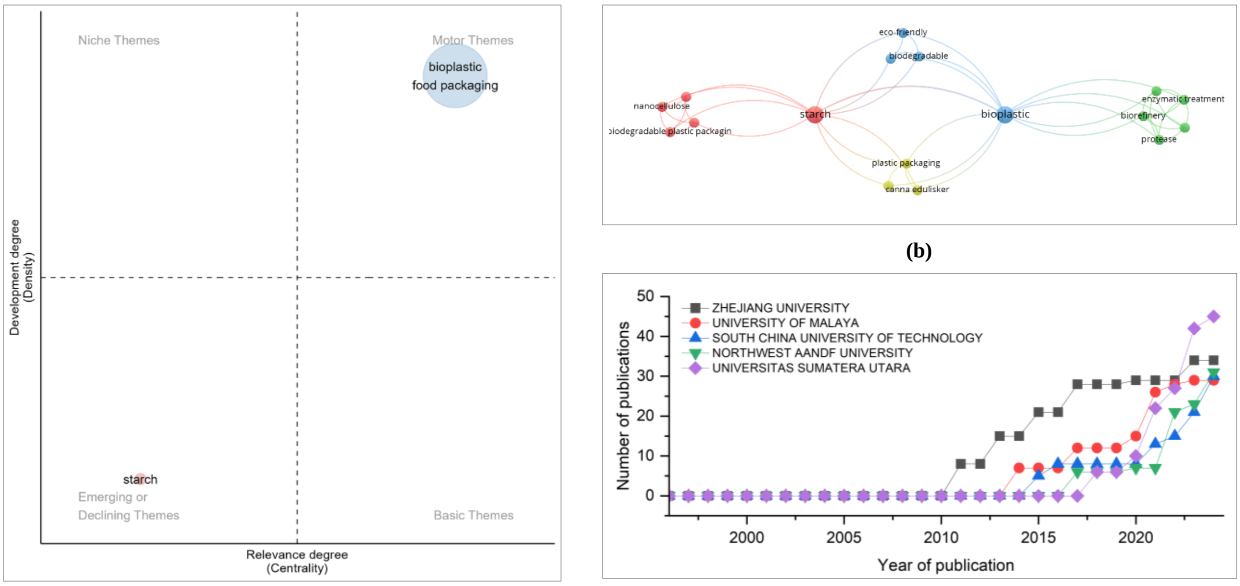
3.3. Keywords Co-Occurrence

The thematic map illustrating the research trend of the agricultural waste-based bioplastic theme is presented in Figure 3a. The illustration highlights the centrality and development degree of key research themes in agricultural waste-based bioplastic research. "Bioplastic food packaging" is positioned as a motor theme, indicating its high relevance and advanced development in the field. This theme demonstrates strong centrality and density, reflecting its critical role in driving innovations and applications in bioplastic research. Conversely, "starch" is categorized as an emerging or declining theme, showing lower centrality and density. This indicates that while it has historically been a focus, its current research significance and development are limited compared to other themes.

The identification of "bioplastic food packaging" as a motor theme aligns with the growing emphasis on sustainability in the food industry. The centrality of this theme suggests its widespread relevance across multiple research and application areas, particularly in addressing global environmental challenges related to single-use plastics. Its high density further reflects ongoing advancements, including the development of bioplastics with enhanced mechanical and barrier properties suitable for food packaging applications. The prioritization of this theme highlights the industrial and societal demand for eco-friendly materials that maintain food safety and quality [72]. In contrast, the placement of "starch" as an emerging or declining theme indicates a reduced focus on its use as a primary material in recent research. While starch has been a key raw material due to its biodegradability, availability, and cost-effectiveness, its hydrophilic nature and poor mechanical properties limit its broader applications. This declining trend suggests a shift toward exploring alternative materials or modifying starch to address its limitations.

These findings are consistent with the aforementioned keyword analysis, where "bioplastic" and "food packaging" emerged as prominent terms with significant growth in recent years. Their relevance in the thematic map as a motor theme underscores their importance in driving advancements in bioplastic applications. Similarly, "starch" showed steady but less prominent growth in the keyword analysis, which aligns with its categorization as an emerging or declining theme in the map. Both analyses point to a broader research shift toward prioritizing advanced materials and applications like food packaging while moving away from traditional materials such as starch due to their inherent limitations.

To further support the analysis, we performed a keyword co-occurrence network analysis, where the results are presented in Figure 3b. The co-occurrence network map highlights the interconnectedness of key terms in agricultural waste-based bioplastic research. "Starch" and "bioplastic" are the central nodes, indicating their prominent roles in the field. "Starch" is closely linked with terms like "biodegradable," "plastic packaging," and "nanocellulose," reflecting its relevance in the context of biodegradable materials and packaging applications. On the other hand, "bioplastic" is connected to terms such as "eco-friendly," "biodegradable," "biorefinery," and "enzymatic treatment," demonstrating its association with sustainability and innovative processing methods.



(a) (c)

Figure 3. Thematic analysis according to (a) bibliometrix and (b) research cluster according to VOSviewer. (c) The most relevant institutions in investigating agricultural waste-based bioplastics

The network reveals distinct thematic clusters that emphasize different aspects of bioplastic research. The connections between "starch" and "biodegradable" or "plastic packaging" underscore its historical significance as a raw material for biodegradable plastics, particularly in food packaging applications. The link with "nanocellulose" highlights efforts to enhance the mechanical and barrier properties of starch-based bioplastics through reinforcement. However, the limited number of links branching from "starch" compared to "bioplastic" suggests a narrower scope of applications and research focus for starch.

The term "bioplastic" demonstrates broader connectivity, reflecting its central role in driving innovation in sustainable materials. Its links to "eco-friendly" and "biodegradable" align with the growing demand for environmentally sustainable solutions, while its association with "biorefinery" and "enzymatic treatment" points to advancements in bioplastic production technologies. These findings are in line with the thematic map and keyword analysis, which identified "bioplastic food packaging" as a motor theme with significant relevance and "starch" as an emerging or declining theme. The decline in "starch" may be attributed to its inherent limitations, such as hydrophilicity and poor mechanical properties, which often necessitate chemical modifications or blending with other materials [73, 74]. Meanwhile, alternative feedstocks, including lignocellulosic biomass and nanocellulose, are gaining attention due to their superior durability, scalability, and alignment with circular economy principles, making them more efficient and sustainable options [75, 76]. The co-occurrence network provides further evidence of a shift in research focus from traditional starch-based materials to advanced bioplastic technologies, including by incorporating agricultural waste-derived nanotechnologies into biodegradable polymers [77, 78].

The network also reveals a growing trend toward exploring bioplastics within the framework of circular economy principles. Terms like "biorefinery" and "enzymatic treatment" suggest a focus on sustainable production methods, emphasizing the utilization of agricultural residues and waste streams. This reflects an increasing interest in optimizing the life cycle of bioplastic materials, reducing reliance on primary resources, and integrating innovative processes to improve scalability and cost-efficiency. Additionally, the connection between "bioplastic" and "plastic packaging" reinforces the focus on addressing industrial demands for packaging materials that meet both environmental and functional requirements. These trends highlight the dynamic evolution of the field, with a clear transition from starch-centric research to more versatile and innovative bioplastic manufacturing and applications that prioritize sustainability and advanced material properties.

3.4. Publication Trends Among Countries

The analysis of publication trends across institutions reveals that Universitas Sumatera Utara leads with 45 publications, followed by Zhejiang University (n=34), Northwest A&F University (n=31), South China University of Technology (n=30), and the University of Malaya (n=29) (Figure 3c). Universitas Sumatera Utara demonstrated rapid growth, especially after 2021, overtaking other institutions to secure the top position in 2024. In terms of countries, China leads with 194 publications, with a significant number of single-country publications (n=155) (Figure 4). Meanwhile, the USA follows with 99 publications, with 80 single-country contributions. India (n=88), Italy (n=65), and Indonesia (n=60) also show strong publication activity, with Indonesia contributing predominantly through single-country publications (n=53). The total citation analysis highlights China as the most cited country with 3,523 citations, followed by the USA (n=3,345) and Spain (n=2,197). The highest average citation per document is observed in Hungary (112), followed by Ireland (85.2) and the Netherlands (79.5), reflecting high-impact contributions from these regions. Conversely, Indonesia, despite its increasing publication volume, shows a lower average citation per document (5.5), indicating potential challenges in achieving global recognition or targeting high-impact journals (Figure 4).

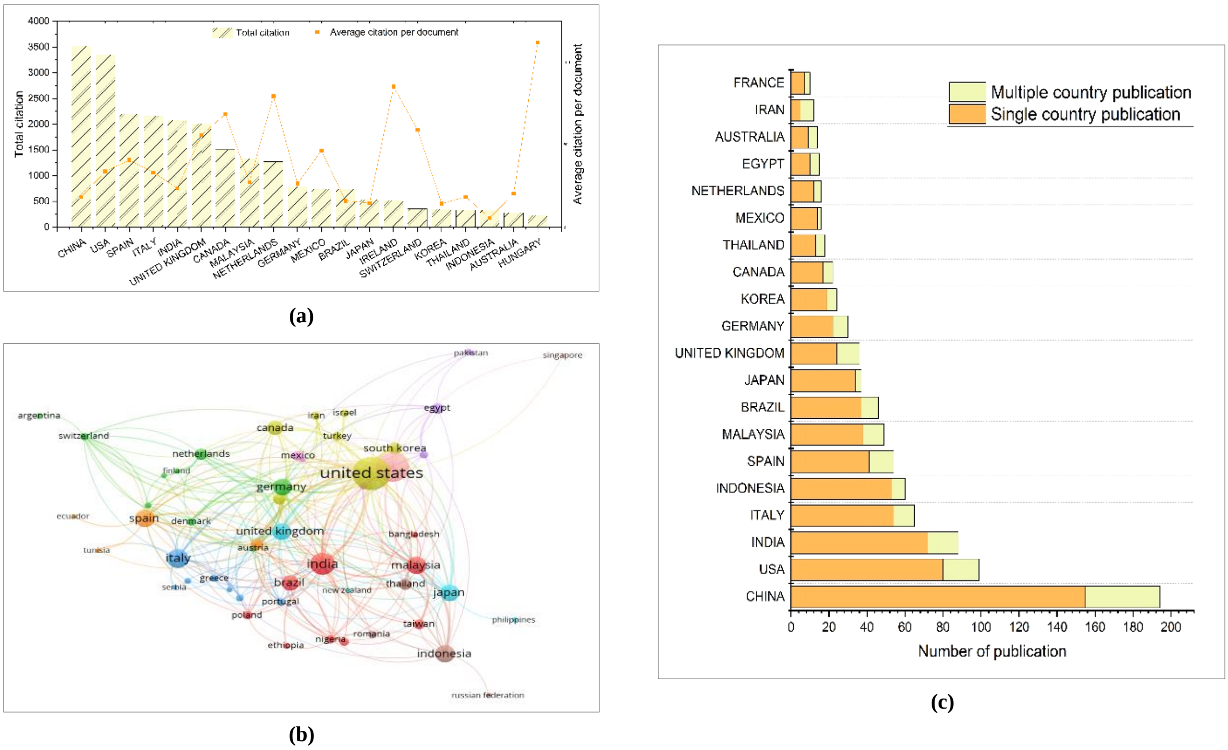


Figure 4. (a) Number of single and multiple countries publication. (b) Co-occurrence network of publishing countries. (c) Number of total citation and average citation per document in each publishing country

Universitas Sumatera Utara, as the leading institution, reflects the increasing recognition of Indonesia in agricultural waste-based bioplastic research. However, its low average citation per document suggests that the research may be regionally focused or not sufficiently aligned with global research priorities. In contrast, institutions like Zhejiang University and the University of Malaya have shown consistent growth, likely benefiting from strong international collaborations and targeting impactful journals. China's leadership in both publication volume and citation impact underscores its strategic investment in bioplastic research, supported by extensive infrastructure and global collaborations. The USA and European countries, while contributing fewer publications, achieve higher average citations, reflecting a focus on high-quality, impactful research. The prominence of Hungary, Ireland, and the Netherlands in citation averages suggests that smaller countries are producing specialized, high-impact contributions, often through international partnerships.

3.5. Collaboration Patterns

The co-authorship network highlights the global collaboration patterns in agricultural waste-based bioplastic research (Figure 4b). Central nodes, such as the United States, India, and China, represent countries with the highest levels of international collaboration. The United States shows strong connections with the United Kingdom, Germany, and Canada, while India and China demonstrate robust ties with developing nations such as Malaysia, Indonesia, and Brazil. European countries, including Spain, Germany, and the United Kingdom, form a dense intra-regional network, suggesting well-established partnerships within Europe. In comparison, Indonesia appears as a smaller node with fewer international links, reflecting its limited global collaboration despite its growing publication volume. The collaboration analysis shows that China and the United States dominate in both single-country and collaborative publications (Figure 4c). However, multiple-country collaborations are more prominent in countries like the United Kingdom, Germany, and Switzerland, where collaborative efforts significantly contribute to their publication output (Figure 4c). Universitas Sumatera Utara, despite being the most productive institution, reflects limited international collaboration, which may explain its lower citation impact.

The collaboration patterns further emphasize the importance of international partnerships in enhancing research visibility and impact. Countries with higher proportions of multiple-country publications, such as the United Kingdom and Switzerland, tend to achieve higher average citations, highlighting the value of cross-border knowledge exchange. For Indonesia and Universitas Sumatera Utara, expanding collaborative networks could be key to enhancing the global impact and recognition of their research. These trends highlight the dual importance of increasing both publication volume and quality through strategic collaborations and targeting impactful research areas.

The affiliation network supports the findings from the collaboration pattern analysis by emphasizing the impact of international partnerships on research visibility and citation impact. Countries like the USA, China, and European nations, which are highly integrated into the global network, exhibit both higher citation counts and average citations per document. These well-established collaborations facilitate cross-border knowledge sharing and innovation, resulting in high-impact publications. China's leadership in this field is likely driven by its significant investments in research infrastructure, funding, and the establishment of robust international collaborations, while the USA benefits from interdisciplinary networks and partnerships with leading institutions worldwide. Conversely, Indonesia’s limited connections in the network align with its lower average citation per document, suggesting that a lack of international partnerships may hinder its global recognition. Expanding collaborations with established research hubs like the United States, China, and European countries could help Indonesia align its research with international priorities and achieve greater impact in agricultural waste-based bioplastic innovation.

4. Conclusion

This bibliometric analysis highlights the rapid growth and evolving trends in agricultural waste-based bioplastic research over the past six decades. The field has seen a substantial increase in global attention, with publications peaking in 2024 and *Science of The Total Environment* emerging as the most relevant journal. Thematic and keyword analyses identified "bioplastic food packaging" as the central innovation focus, driven by its critical role in addressing environmental challenges and industrial demands. The analysis further revealed a shift from traditional starch-based bioplastics toward alternative feedstocks, such as lignocellulosic biomass and nanocellulose, which offer enhanced mechanical properties, sustainability, and scalability. This transition underscores the dynamic nature of the field, as researchers strive to overcome the limitations of early bioplastic materials by exploring advanced feedstocks and innovative processing techniques. Collaboration patterns emphasize the leadership of China and the United States, supported by their extensive research infrastructure, funding, and strong international networks. These countries not only lead in productivity but also achieve higher citation impacts, reflecting their contributions to high-quality, impactful research. Meanwhile, Universitas Sumatera Utara has emerged as the most productive institution, reflecting Indonesia's growing recognition in the field. However, the lower average citation per document in Indonesia suggests potential challenges in aligning with global research priorities or establishing extensive international collaborations. Strengthening collaborative networks with established research hubs could significantly enhance the global visibility and impact of Indonesian research. Future research should focus on optimizing bioplastic production through diverse approaches, including leveraging underutilized agricultural residues, improving mechanical and thermal properties, and incorporating smart packaging technologies. Furthermore, the integration of circular economy principles, such as biorefinery and enzymatic treatment, offers promising pathways to enhance sustainability and scalability. By addressing these challenges and fostering international collaboration, agricultural waste-based bioplastic research can continue to advance toward innovative solutions that address pressing environmental and industrial needs.

4.1. Future Research Trajectories

The findings from this bibliometric analysis suggest that future research in agricultural waste-based bioplastic development should focus on optimizing applications such as "bioplastic food packaging," which has emerged as a motor theme. Advancing the mechanical and barrier properties of bioplastics, incorporating materials like nanocellulose and bio-based composites, and developing multilayer films could enhance durability and industrial applicability. Additionally, integrating smart packaging technologies, such as active or intelligent bioplastics, offers potential for innovations in food safety and spoilage detection. The declining prominence of starch as a raw material points to a growing shift toward alternative feedstocks, such as lignocellulosic biomass and agricultural residues. Future research should emphasize the use of renewable and underutilized materials while advancing enzymatic and biorefinery technologies to enable efficient, sustainable production. Collaboration patterns also highlight the need for regions with lower international connections, such as Indonesia, to strengthen global partnerships with leading research hubs (i.e., the United States, China, and Europe). Expanding international collaborations may warrant global alignment with the principles of sustainability and the circular economy in bioplastic production.

5. Declarations

5.1. Author Contributions

Conceptualization, E.E., S.N., M.M., S.S., and I.I.; methodology, I.I.; software, S.S.; validation, S.S., D.D., and F.H.; formal analysis, E.E. and I.I.; investigation, E.E., S.N., M.M., S.S., and I.I.; resources, I.I.; data curation, D.D.; writing—original draft preparation, E.E.; writing—review and editing, D.D., F.H., S.N., M.M., S.S., and I.I.; visualization, S.N.; supervision, F.H.; project administration, S.S.; funding acquisition, I.I. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

No new data were created or analyzed in this study. Data sharing is not applicable to this article.

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5.4. Institutional Review Board Statement

Not applicable.

5.5. Informed Consent Statement

Not applicable.

5.6. Declaration of Competing Interest

The authors declare that there are no conflicts of interest concerning the publication of this manuscript. Furthermore, all ethical considerations, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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