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A Bibliometric Analysis of Research Trends in Bacterial Degradation of Plastics: Emerging Themes and Future Directions

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ABSTRACT

Plastic pollution poses a critical environmental challenge due to the durability and stability of plastic materials, necessitating urgent global attention for effective management strategies. This study conducted a comprehensive bibliometric analysis of publications related to bacterial plastic degradation from 1977 to 2024 using data collected from Scopus. It was analyzed through Rstudio and VOSviewer to understand research trends and identify emerging themes. The analysis revealed a steady annual growth rate of 6.21% in research output, with significant contributions from India (94 publications) and China (88 publications), particularly evident in the exponential growth observed from 2015 onwards. Examining citation networks and keyword co-occurrence identified key research themes, including marine ecosystem impacts, degradation pathways, and microplastics, with particular emphasis on common pollutants such as polyethylene, polypropylene, and polystyrene. The Journal of Hazardous Materials emerged as the most frequently cited journal, while publications by Restrepo-Flórez (2014) and Hadad (2005) received the highest individual citation counts of 481 and 447, respectively. The study underscores the growing academic focus on microbial and enzymatic processes for plastic degradation, highlighting the potential of bacterial degradation as a promising solution for plastic waste management. However, continued research and international collaboration are essential for developing more efficient biological processes and implementing effective strategies to combat plastic pollution and protect environmental health.

Keywords – Bacterial degradation, Plastics, Pollution, Environmental health, Bibliometric

Introduction

Plastic pollution presents a significant threat to the environment's health and the well-being of animals, plants, and humans, making it a pressing and widespread global concern [1,2] with far-reaching consequences for ecosystems, human well-being, and the Earth's climate. The durability and stability of this material tend to worsen environmental challenges.[3,4] Plastic production, consumption, and improper disposal have contributed to a pervasive pollution problem, particularly severely affecting marine environments. Plastic with varieties such as microplastics is a significant component of waste that pollutes the marine and terrestrial environment is plastics. Thus, the build-up of plastic waste reduces the soil's fertility, hinders water penetration in plant systems, and is hazardous to animal life.[5] Poor management of post-consumer waste plastic worsens the impacts, including soil and water resource pollution.[3]

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Without proper disposal methods, these plastics often enter aquatic ecosystems. In 2016, estimates indicated that between 19 and 23 million of metric tons plastic waste polluted water bodies.[6]

The increasing presence of plastic waste, particularly in aquatic ecosystems, represents a growing environmental challenge due to its persistent nature and potential adverse effects on both animal species and human health. Among the numerous forms of plastic contaminants, polyethylene (PE) and polypropylene (PP) are widely distributed across various environments, including rivers, oceans, and sediment layers. Furthermore, polystyrene (PS) is another extensively used plastic that frequently becomes waste, particularly in microplastics and nanoplastics (particles between 1 and 1000 nanometers).[7,8,9]. Polyvinyl chloride, polypropylene, polyethylene, polystyrene, and polyurethane are commonly utilized polymers that typically become plastic debris in nature. The majority of plastics produced internationally possess polymer frameworks composed of carbon-carbon bonds, leading to an extensive accumulation of plastic refuse in dumping sites and natural locations. The ubiquitous occurrence of plastic debris causes significant environmental complications due to its robust durability and resistance to natural degradation processes, resulting in prolonged persistence in environmental matrices.[10,11] Both oceanic and freshwater sediment samples reflect a broad spectrum of polymer varieties, with polyethylene (PE), polypropylene (PP), and polystyrene (PS) being the most frequently encountered. The breakdown of these plastics results in the emission of harmful volatile organic compounds (VOCs), causing further ecological hazards,[12] consequently, these substances permeate throughout society, with the general populace experiencing persistent

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exposure via dietary intake, respiratory pathways, and dermal contact.[13] Plastic refuse typically incorporates additive substances such as ultraviolet stabilizers and antioxidants, which possess the potential to leach out and further contaminate the environment.[13,14] The transport and accumulation of plastic particles depend on their density, surface dimensions, and scale, whereby polymers with low density exhibit a heightened propensity to be conveyed by water currents. At the same time, larger debris tends to accumulate in sediments or on beaches.[7]

The primary aim of this review is to conduct a comprehensive bibliometric analysis of research trends in bacterial degradation of plastics, with a particular focus on emerging themes and future directions. This study is novel as it represents the first bibliometric analysis specifically examining bacterial plastic degradation research's evolution and current state. Through systematic evaluation of publication patterns, citation networks, and keyword analysis, we seek to identify key research themes, influential contributors, and gaps in current knowledge. This approach is particularly relevant given the increasing global focus on sustainable plastic waste management solutions and the potential of bacterial degradation as an environmentally friendly treatment method.

Plastic waste degradation in the environment is one of many strategies designed to benefit ecosystems and human health, with negative repercussions for both. Plastic degrades into microplastics (<5 mm), posing ecological and health threats.[15,16] Various microorganisms and enzymes can degrade synthetic plastics, such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), polyurethane (PUR), and polyethylene terephthalate (PET), that biodegradation rates depend on factors like chemical structure, molecular weight and crystallinity of polymers.[17,2] Invertebrates, such as insects, can also contribute to the degradation of plastic waste, highlighting a potential biological approach to handling plastic pollution.[16] Chemical recycling and upcycling, which includes depolymerization and conversion into fuels or chemical feedstocks, provide potential solutions for plastic waste management, although these processes are often prohibitive.[18,19] Catalytic degradation, mainly using photocatalysts like titanium dioxide (TiO_2), can accelerate the breakdown of plastics into environmentally benign products.[20] Plastic waste in landfills is subjected to both biological and abiotic degradation processes, with evidence of microbial activity contributing to its breakdown, while long-term exposure can result in changes in its physical/chemical properties, such as crystallinity or surface oxidation.[21,22,23]

Microbial degradation of plastics offers an attractive solution by employing microorganisms and enzymes to break down synthetic polymers.(18) Numerous microorganisms, including bacteria and fungi, have been identified as proficiently degrading synthetic plastics.(25) Specific bacterial species such as *Pseudomonas sp.*, *Ideonella sakaiensis*, and fungal species such as *Aspergillus flavus* and *Penicillium raperi* have shown significant capabilities to degrade plastic materials.[25,26,27] Microbial consortia, a cluster of different microorganisms working together, have been found to enhance the degradation of plastics, especially PET, by breaking them down more efficiently than using individual strains.[24,28] The degradation process typically involves adhering enzymes to plastic surfaces and hydrolyzing polymer bonds to break them down further, eventually yielding smaller monomers, which microorganisms can then digest for further metabolization.[2,29] Utilizing bacteria in plastic degradation offers a hopeful approach to tackling the escalating environmental problem of plastic waste. Some factors that affect their effectiveness depend on the environment and may be enhanced through bioengineering approaches. Continuous research and developments in this field significantly maximize microbial degradation for green plastic waste management's productivity and implementation. Hence, investigating the current landscape of this sector is essential. Bibliometry is a quantitative method that employs statistical and mathematical analyses to examine academic patterns and trends within a specific research field, systematically evaluating publications, citations, and bibliographic data to assess the development and impact of a research topic.[30,31] There are currently no bibliometric analysis reports on bacterial degradation of plastic, this review aims to evaluate published articles in the field, creating a concise database for researchers to identify research trends and gaps.

Materials and Methods

This study employed a Systematic review approach to analyze research trends in bacterial degradation of plastics. The bibliometric analysis was conducted following these systematic steps. Data Collection, the systematic search for relevant peer-reviewed papers, was performed using the Scopus database, chosen for its comprehensive coverage of scientific literature. The following search string was used to ensure comprehensive coverage.

Scopus: TITLE-ABS-KEY ("bacteria" OR "enzymatic" OR "microbial") AND ("biodegradation" OR "Decomposition" OR "Deterioration" OR "decay") AND ("plastics" OR "LDPE" OR "polyethylene" OR "polystyrene" OR "PVC")

Data Analysis Tools the collected bibliometric data were analyzed using three complementary software tools: RStudio (version 4.3.1) for statistical analysis and data processing, VOSviewer (version 1.6.20) for network visualization and mapping, Tableau (version 2024.1) for data visualization and graphic representation. Analysis Procedure, the systematic analysis followed a structured workflow (Figure 1), consisting of data extraction from the Scopus database, data cleaning and standardization, upload of processed data to biblioshiny in RStudio, network analysis using VOSviewer, visualization of results using Tableau. Parameters Analyzed, the bibliometric analysis examined several key parameters including annual publication trends, geographic distribution of research, citation patterns and impact, keyword co-occurrence networks, author collaboration networks and journal impact analysis.

This systematic approach enabled the comprehensive mapping of research trends and identification of emerging themes in bacterial plastic degradation. The methodology aligns with recent bibliometric studies in environmental science.[31,32] and ensures reproducibility of results.

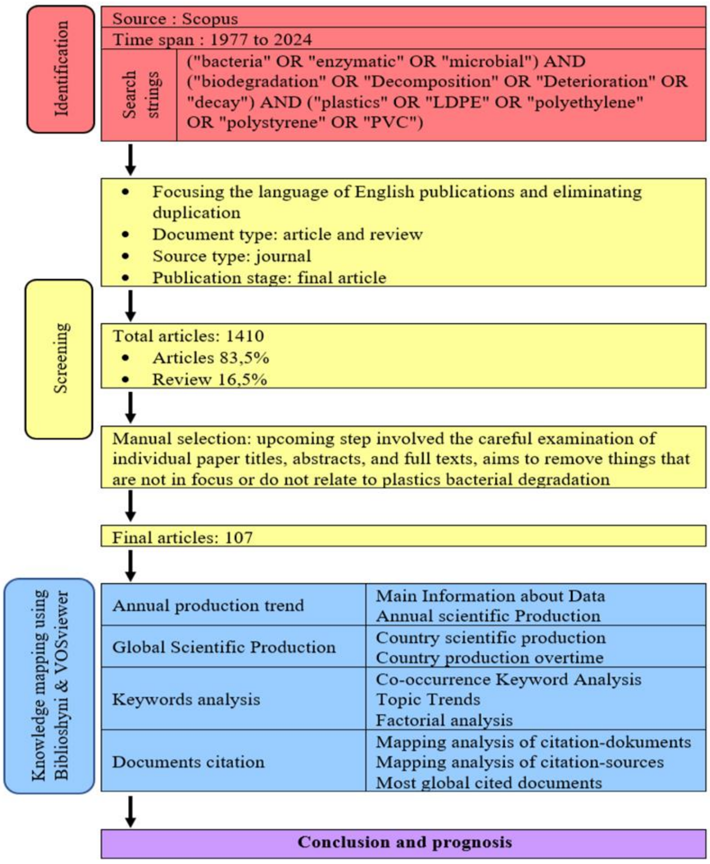

Figure 1: Diagram flow of the research on plastic bacterial degradation

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Results And Discussion

Main Information about Data

The bibliometric analysis revealed several significant findings regarding research trends in bacterial degradation of plastics. Table 1 presents the main data of bibliometric analysis of a research field or topic spanning from 1977 to 2024. The study covers 106 documents from 76 different sources, including journals and books. The field shows steady growth with an annual growth rate (AGR) of 6.21, notably higher than 4.8% AGR reported in similar environmental microbiology fields.[33] This accelerated growth reflects increasing global attention to microbial-based solutions for plastic pollution. AGR helps researchers understand if a field is expanding, stable, or declining regarding of research output. A high AGR might indicate an emerging or rapidly evolving field, while a low or negative AGR could suggest a mature or declining study area. The average document age was 6.69 years, and each received an average of 43.6 citations, 295 keywords and 486 author-provided keywords from 82 articles were identified during our analysis.

International co-authorship percentage refers to the proportion of publications with authors from different nations collaborating on one paper, often leading to higher-quality research, higher citation rates and greater global visibility through combining diverse expertise and resources into a single piece. This metric can be an indicator of high-quality work produced from international cooperation. In the given data, the international co-authorship rate is 17.92%, indicating a moderate level of cross-border collaboration. Nearly one in five papers have international co-authors and knowledge transfer across borders could result in a significant exchange of expertise. While this 17.92% rate demonstrates that international collaboration is an established practice in the bacterial degradation of plastics, it also implies potential room for growth. Most of the research is still conducted within single countries, but there is substantial international collaborative work. This percentage reflects a noteworthy level of global cooperation in the research area, further exploring opportunities for increased cross-border partnerships to boost global impact and research quality in this field.

Table 1: Major information on plastics bacterial degradation research from 1977 to 2024.

Description	Results
Timespan	1977:2024
Sources (Journals, Books, etc.)	76
Documents	107
Annual Growth Rate %	6.21
Document Average Age	6.69
Average citations per doc	43.6
References	0
DOCUMENT CONTENTS	
Keywords Plus (ID)	1249
Author's Keywords (DE)	259
AUTHORS	
Authors	486
Authors of single-authored docs	6
AUTHORS COLLABORATION	
Single-authored docs	6
Co-Authors per Doc	5.14.
International co-authorships %	17.92
DOCUMENT TYPES	
Article	83
Book chapter	4
Conference paper	3
Erratum	3
Note	1
Review	12

Annual Production Trends

By tracking annual production over time, researchers can identify trends in the growth or decline of research output in a particular field. Changes in publication volume within a specific area of research can indicate evolving trends in that field's development.[32] The literature screening identified 5078 studies related to Plastic degradation published in almost 5 decades. From this screening, 107 eligible articles on plastic bacterial degradation were retrieved for the bibliometric analysis covering the period from 1977 to 2024 (Fig. 2). Initially, publication rates remained consistently low, with years registering zero to one article annually from 1977 through the early 1990s. A discernible shift occurred in 1995, marked by a sudden increase to eight publications. Subsequently, the early 2000s to mid-2010s exhibited a relatively stable, albeit low, publication rate, typically ranging from one to three articles per annum. Approximately 57% of the articles were published up to 2021. However, the most striking feature of this dataset is the exponential growth observed from 2015 onwards. This period is characterized by a sharp upward trajectory, with publication numbers rising from five in 2018 to a peak of 18 in 2023. Despite some fluctuations, such as a decrease to 11 articles in 2022, the trend remains robustly positive, with a projected 17 publications for 2024. This dramatic surge in recent years suggests a significant intensification of research interest or activity in plastic bacterial degradation, potentially indicative of emerging trends, increased funding, or heightened academic focus on the subject matter. The pattern demonstrates a clear shift from sporadic publications in the late 20th century to a more consistent and voluminous output in the contemporary academic landscape.

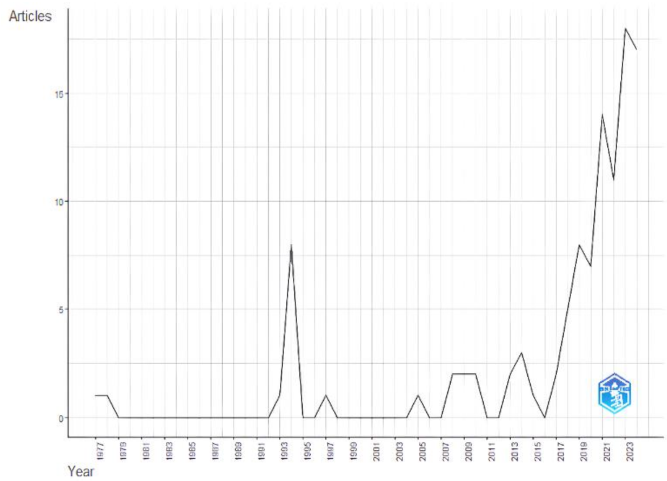


Figure 2: Annual number of publications on plastic bacterial degradation from 1976 to 2024 as well as the contributions by different countries in the world

Global Scientific Production: Country Comparisons and Temporal Perspectives

A visualization of comprehensive bibliometric analysis of scientific production across countries, focusing on cumulative output and temporal trends (Fig. 3). The analysis is divided into two main sections: Country Scientific Production and Countries Production over Time. The Country Scientific Production section provides an overview of the total scientific output per country, an indicator of a nation's research capacity and innovation potential, which varies widely across different countries, and was derived from data encompassing 37 countries, each with its respective publication frequency.

The geographical distribution of research output demonstrated interesting patterns, with India (94 publications) and China (88 publications) emerging as leading contributors. This dominance aligns with recent findings, noting that developing nations with significant plastic pollution challenges often show heightened research activity in environmental remediation.[34] Notably, these countries' research output has grown exponentially since 2015, coinciding with stricter environmental policies and increased research funding.[35] European nations, such as Germany (42 publications) and France (31), also made notable contributions, solidifying their established positions within international research communities. The United States, with 33 publications, occupies the fourth position, followed by Indonesia with 30 publications. Indonesia's participation among other developed nations demonstrates positive developments in its national research capacity. Other Asian countries such as Japan, Malaysia and South Korea also demonstrate significant contributions, with 22, 19 and 19 publications respectively demonstrating considerable contributions.

This distribution of scientific publications illustrates the global research landscape, with developed and developing countries contributing significant work. This pattern may be affected by factors including international collaborations, investments in higher education and national research priorities. Further research is needed to analyze the factors driving these differences in research productivity and their implications for global scientific advancement. Though these data offer an informative snapshot of scientific production by country, it should remember that its analysis only considers publication frequencies. Therefore, factors like population size, per capita research investment and citation impact are not considered.

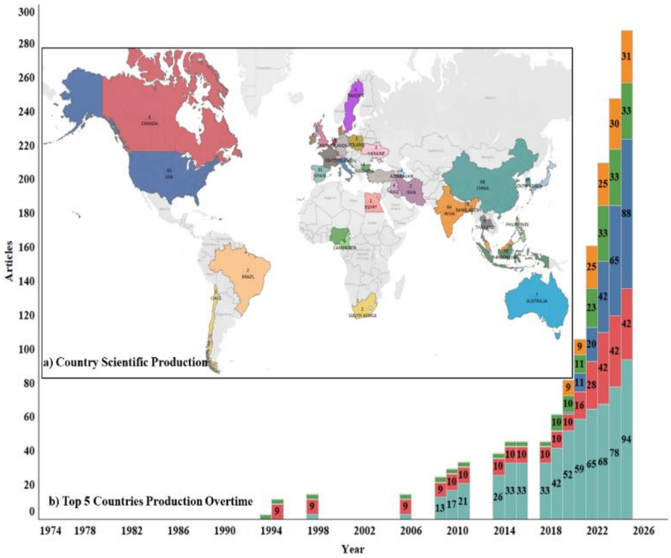


Figure 3: Country scientific production of plastics bacterial degradation from 1977-2024 (a), country and journal publication on bacterial degradation productive time (b)

The Countries Production over Time section examines the trends in scientific output among the top five contributing countries, China, France, Germany, India and the USA, from 1977 to 2024. This longitudinal data allows for a detailed examination of each nation's research trajectory, especially noteworthy is China and India's rapid ascension on the international research scene (China's production increased from 1 article produced annually until 2019 to an astonishing 88 articles by 2024). China experienced a remarkable surge during that period, compared to making only one article annually before. India demonstrates a more gradual but consistent growth, starting from 3 publications in 1997 and reaching 94 by 2024. Germany's output shows a stepwise increase, with notable jumps in 1994 and 2020. The USA and France exhibit more modest growth patterns, with significant increases observed from 2020 onwards.

The nations with the most significant number of scientific publications about plastic biodegradation demonstrate a strong emphasis on public attention and government support for scientific research and plastic management technology, this correlation can be deemed significant.[33] Plastic waste management presents a significant environmental challenge in rapidly developing nations such as India.[34] and China. These countries face unique obstacles and opportunities in addressing this issue, driven by rapid industrialization, urbanization, and population growth. India grapples with both domestic generation and imports of plastic waste, while China's recent implementation of a ban on plastic waste imports has substantially altered global waste trade dynamics.[35]

India generates significant amounts of plastic waste annually, estimates range between 3.3 and 4 million tons a year despite efforts to address it, though only 60% is recycled through recycling processes.[34] The remaining plastic waste, often generated through incineration or landfill disposal, poses serious environmental and public health concerns, creating significant ecological and public health hazards. India faces multiple difficulties in effectively managing plastic waste, including inadequate waste collection and segregation systems and infrastructure gaps that hinder enforcement.[34,37,38] To mitigate these issues, India uses various avenues for improvement, including encouraging biodegradable materials and renewable raw materials to be utilized. Furthermore, the implementation of Extended Producer Responsibility (EPR) and the incentives provided to recycling businesses could contribute towards more effective management.[39] China's ban on plastic waste imports has significantly changed global waste trade.[35] Plastic waste has forced developed nations to find innovative solutions and highlighted the need for increased domestic recycling efforts.[40] While this has led to some environmental improvements in China, it has also caused problems as other Asian countries now receive more plastic waste.[41]

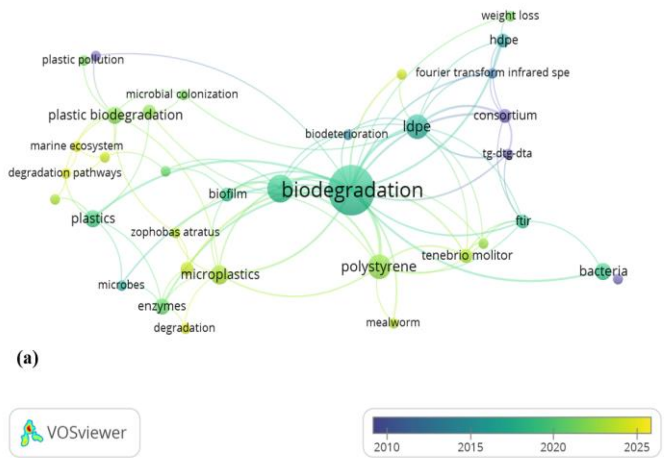
Co-occurrence Keywords Analysis

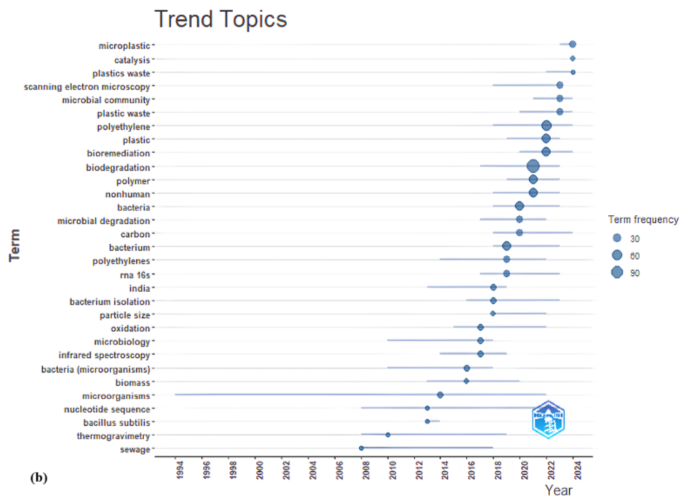
This comprehensive approach integrates Co-occurrence Keyword Analysis, Topic Trend Analysis, and Research Field Dynamics (thematic mapping) for an expansive view of scientific literature development (Fig. 4). Co-occurrence author keywords analysis in VOSviewer visually maps relationships between keywords in scientific literature, helping researchers find key themes, trends and connections within their field. This tool simplifies understanding complex research landscapes, spotting emerging topics, and guiding future research directions by presenting a clear, interactive visualization of how concepts are interlinked based on their frequency of appearing together in publications. The interconnected co-occurrence author keywords form five distinct clusters, each highlighted by a unique color in the visualization (Fig. 4a).

The size of each node (circle) represents the frequency of occurrence of that keyword in the dataset. Larger nodes indicate that the keyword appears more frequently in the literature, signifying its importance or popularity in plastic bacterial biodegradation research. The node "biodegradation" is the largest, suggesting that this keyword is the most commonly used among the papers analyzed. In comparison, the colors represent different clusters or periods. In this visualization, the color gradient (from blue to yellow) indicates the time frame of keyword occurrences, with blue representing older research and yellow representing more recent research. The marine ecosystem, degradation pathways, microplastics, and polystyrene represent several key terms that have gained significant traction in the scientific literature in recent years (Fig. 4a). The prominence of marine-related keywords reflects current concerns about oceanic plastic pollution, consistent with recent findings showing that 80% of plastic degradation studies focus on marine environments.[44] The frequent occurrence of these terms underscores the increasing research emphasis on understanding the fate of plastics in aquatic environments, their degradation mechanisms, and the resultant impact of microplastics on marine ecosystems, with specific attention to common pollutants such as polystyrene. The emergence of "microplastics" as a dominant keyword by 2023 represents a significant shift in research focus, as researchers increasingly recognize their pervasive environmental impact.[45]

Conventional and biodegradable plastics can induce significant changes in marine sediment and ecosystem structures, creating anoxic conditions within sediments, reducing primary productivity, and diminishing in faunal invertebrate populations. Furthermore, the top research topic for plastic bacterial degradation shifted to "microplastic" by 2023 due to the high frequency of the keyword "microplastic" in recent years (Fig. 4b). Microplastics are plastic particles in size less than 5mm produced by the degradation of plastic waste in urban and industrial areas.[42] Their microscopic size permits their consumption by soil inhabitants. The transformation of plastic debris and microplastics into nano-plastics (NPs, 1 nm-1000 nm) may result in grave environmental and human health hazards because plastic accumulation in the soil food chain can cause digestion issues.[43] Microplastic pollution has emerged as a pervasive issue across diverse marine ecosystems,[44] it can absorb and concentrate persistent organic pollutants (POPs), metals, and pathogens, exacerbating their toxicological effects on aquatic organisms.[45,46] Ingested microplastics can cause oxidative stress, immunological responses, and other physiological disruptions in marine life. These alterations can result in significant modifications to marine assemblages and the ecosystem services they provide.[47] Recent studies have demonstrated that these materials can unexpectedly influence biogeochemical cycles, stimulating the decomposition of marine-buried carbon while concurrently reducing the release of inorganic nitrogen.[48] This dual effect potentially impact carbon sequestration processes and climate change mitigation efforts.

Marine microorganisms emerge as key players in the biodegradation of plastic materials in aquatic ecosystems, possessing specific metabolic pathways that facilitate the breakdown of various polymers. However, the presence of plastic debris, including biodegradable types, may inadvertently serve as vectors for dispersal harmful pathogens, raising concerns regarding the potential impacts on marine organism health.[51,52] These findings demonstrate the complex and multifaceted interactions between plastic pollutants and marine ecosystems, including plastic debris. Their effects beyond physical presence alone influence biogeochemical cycles, ecosystem structures, and microbial dynamics. Furthermore, plastics contain various additives like stabilizers, plasticizers, and other chemicals that have the ability to alter marine ecology significantly.[51] These additives can leach into the surroundings leading to mammal teratogenicity and mutagenicity.





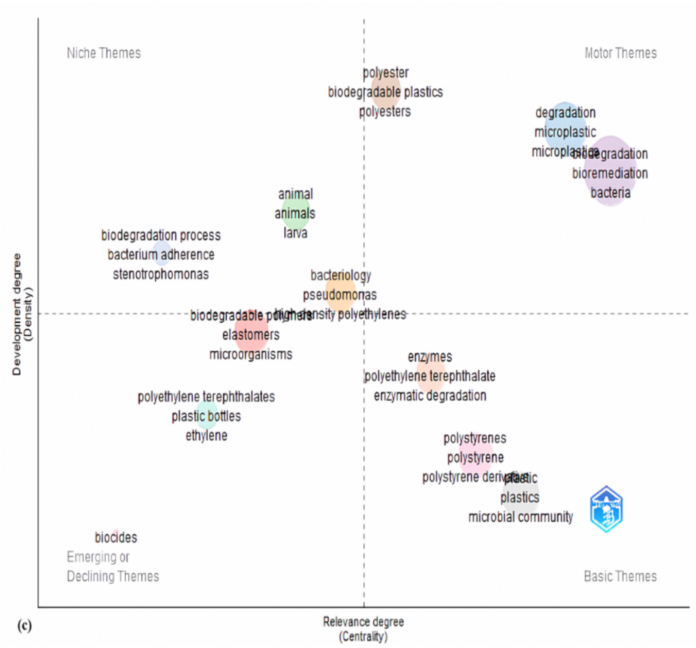


Figure 4: Co-Occurrence Author Keywords Analysis (a), Trend Topic (b), factorial analysis of trend topic on bacterial degradation of plastics (c)

Thematic mapping analysis (Fig. 4c) demonstrates research landscapes by employing two key dimensions – development degree (Density) and relevance degree (Centrality). This approach comprehensively depicts how research themes develop over time in scientific disciplines. Thematic mapping revealed four distinct research categories, with "biodegradation" and "microplastic" emerging as motor themes. These areas show high density and centrality, indicating their crucial role in driving the field forward. This finding aligns with recent meta-analyses highlighting the increasing focus on enzymatic and microbial degradation processes.[54]

The analysis organizes themes into four quadrants, each providing valuable insight. Motor Themes in the upper right quadrant are distinguished by high density and centrality. These well-developed and highly relevant themes, such as "degradation", "microplastic" and "biodegradation" are central to driving the field forward, impactful research in these areas, indicating they are critical for advancing knowledge in the bacterial degradation of plastics research. Niche Themes in the upper left quadrant display high density but low centrality, representing highly developed but relatively isolated research areas such as "biodegradation process" or "bacterium adhesion". They represent specialized research areas with strong internal coherence but limited overall influence, it is not widely connected to other research themes. Basic Themes, positioned in the lower right quadrant, feature low density but high centrality, including "enzymatic degradation", "polystyrene" and "microbial community". These themes form the backbone of many other research themes but require further exploration and development. The lower left quadrant contains Emerging or Declining Themes, characterized by low density and low centrality. These could be nascent topics on the rise or areas losing relevance, such as "biocides" in this analysis suggesting either a potential new research avenue or an area becoming less relevant. This aligns with several studies indicating that research on the biodegradation of polystyrene has significantly increased,[52] mainly focusing on microbial degradation and identifying relevant enzymes.[53]

Citation Network: Visual representation of citation relationships between documents or sources

Comprehensive visual representation of the intellectual landscape within a field, identification of related document clusters based on citation patterns, detection of potential areas for cross-disciplinary collaboration, and illustration of the temporal evolution of research topics when combined with timeline analysis can be achieved through the application of citation-document mapping analysis in VOSviewer. This sophisticated bibliometric technique facilitates the elucidation of complex relationships within scientific literature, offering researchers a powerful tool for understanding the structure and dynamics of their field. An analysis of article titles can ascertain the extent to which the discussed topics are interrelated and demonstrate thematic coherence within their respective contexts.[54] We identified the most frequently cited journals (Fig. 5a) by applying specific filtration parameters. Criteria used to define our sources were as follows, minimum document count per source (1 per document) and citations count (20/source). Our methodology yielded 76 distinct sources that met or exceeded these 32 threshold criteria - representing the most impactful publications within our study parameters.

Citation network analysis revealed essential trends in knowledge dissemination. The Journal of Hazardous Materials emerged as the most influential publication venue, though individual high-impact papers often appeared in specialized journals. This pattern differs from earlier bibliometric studies in which environmental generalist journals dominated,[31] with suggesting a shift toward more specialized research dissemination channels. Publications play an essential role in knowledge dissemination, significantly influencing research trajectories across related disciplines. The network's edge thickness, representing the strength of inter-journal citations, reveals robust relationships, notably between the "Journal of Applied Microbiology" and "Journal of Polymers and the Environment", indicative of substantial interdisciplinary knowledge transfer. A chromatic gradient from blue to yellow introduces a temporal dimension to the analysis, with yellow nodes such as the "Journal of Hazardous Materials" and "Marine Pollution Bulletin" representing more recent, highly cited publications, thereby highlighting contemporary research trends. Nodes' spatial distribution and interconnectivity delineate distinct research clusters and thematic domains, with proximal journals often exhibiting thematic congruence or frequent cross-citations.

We employed specific filtration criteria to identify the most influential documents within the field (Fig. 5b). The selection process was based on a threshold of a minimum of 30 citations per document. This rigorous methodological approach resulted in identifying of 107 documents that surpassed the established threshold criteria of 36. These documents represent the core literature that has significantly shaped the discourse and direction of research in this domain. An analysis of the network visualization reveals two documents with the highest citation counts, represented by the most significat nodes. When correlated with Table 2, these documents are identified as follows: the work by Restrepo-Flórez J-M, published in 2014 in International Biodeterioration & Biodegradation, garnering 481 citations, and the publication by Hadad D. in the Journal of Applied Microbiology from 2005, accumulating 447 citations. Interestingly, despite their high citation counts, Figure 4b indicates that the journals hosting these highly cited papers are represented by nodes of relatively modest size. The publication volume elucidates this apparent discrepancy: International Biodeterioration & Biodegradation has only published three articles in this specific research domain, while the Journal of Applied Microbiology has contributed a single publication.

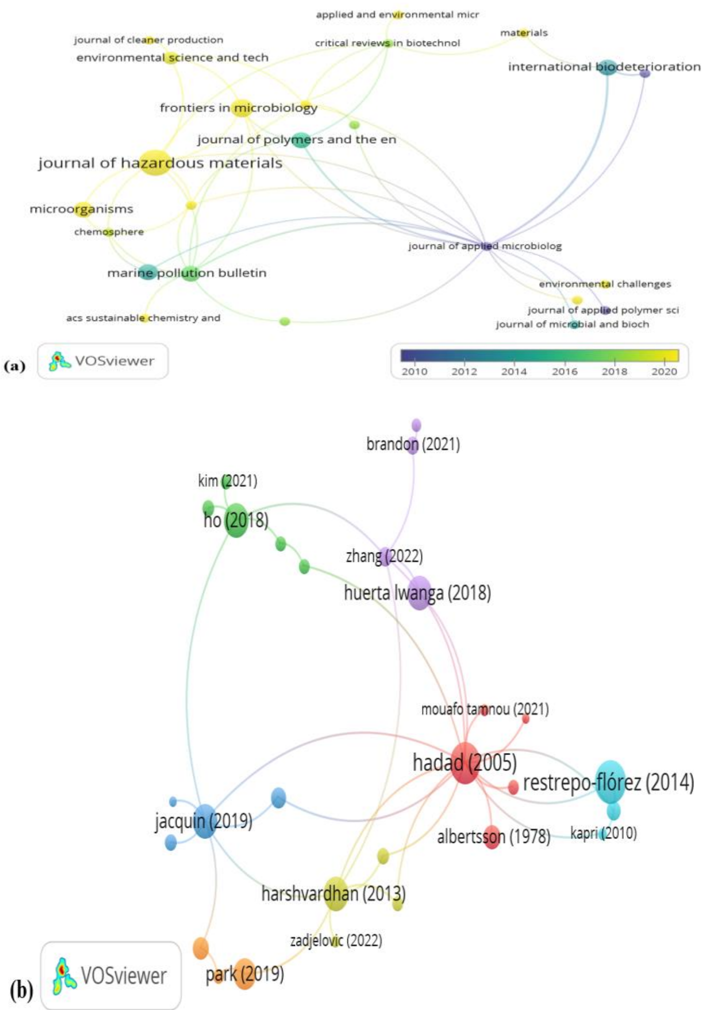


Figure 5: The most frequently cited journals on bacterial degradation of plastics (a), the most frequently cited documents on bacterial degradation of plastics (b).

Table 2: Top 10 The Most Cited Documents on Journal.

Paper	DOI	Total Citations
Restrepo-Flórez J-M, 2014, Int Biodeterior Biodegrad	10.1016/j.ibiod.2013.12.014	481
Hadad D, 2005, J Appl Microbiol	10.1111/j.1365-2672.2005.02553.x	447
Huerta Lwanga E, 2018, Sci Total Environ	10.1016/j.scitotenv.2017.12.144	309
Harshvardhan K, 2013, Mar Pollut Bull	10.1016/j.marpolbul.2013.10.025	306
Jacquin J, 2019, Front Microbiol	10.3389/fmicb.2019.00865	304
Ho Bt, 2018, Crit Rev Biotechnol	10.1080/07388551.2017.1355293	290
Park Sy, 2019, Chemosphere	10.1016/j.chemosphere.2019.01.159	247
Albertsson A-C, 1978, J Appl Polym Sci	10.1002/app.1978.070221207	140
Peixoto J, 2017, J Hazard Mater	10.1016/j.jhazmat.2016.11.037	132
Meyer-Cifuentes Ie, 2020, Nat Commun	10.1038/s41467-020-19583-2	126

Contrastingly, Figure 4a demonstrates that the Journal of Hazardous Materials, which emerges as the most frequently cited journal overall, does not house the individual documents with the highest citation counts. This observation underscores the distinction between journal-level and article-level impact within the field. The disparity highlights the complex relationship between a journal's overall citation frequency and the impact of individual articles published within it, suggesting that high journal citations do not necessarily correlate with the presence of the most cited individual papers in a specific research area. Several factors can influence the number of document citations, including the payment model and journal publication year.[31] Publications in the most recent year usually have fewer citations than publications in previous years.[54]

Conclusion

A comprehensive bibliometric analysis of plastic degradation research from 1977-2024 highlights increased research interest and collaboration globally in this area. The study identified several promising future research directions: (1) enhancement of bacterial strain through genetic engineering for improved degradation efficiency; (2) development of synergistic microbial consortia; (3) discovery of novel enzymatic pathways for recalcitrant plastics; and (4) optimization of biodegradation processes for industrial-scale applications. Critical areas requiring immediate attention include standardization of biodegradation assessment methods, understanding degradation product impacts, and integration with existing recycling technologies. The significant contributions from India and China highlight the shifting landscape of environmental research. This study concludes that continued international collaboration and research investment are essential for translating laboratory findings into practical solutions for plastic waste management, ultimately contributing to environmental protection through sustainable biodegradation approaches.

Conflict Of Interest

"The authors declare no conflict of interest"

Author Contribution

All authors contributed at every stage of the creation of this article and all authors approved the final version

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