Research Paper

Microplastics in Food and Their Toxicological Effects: A Two-Decade Bibliometric Study (2000–2025)

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ABSTRACT

Background: Microplastics (MPs) have emerged as pervasive contaminants in the global food supply chain, raising growing concerns about their potential toxicological effects on ecosystems and human health.

Methods: The present study is a cross-sectional bibliometric and science-mapping study of Scopus-indexed publications from 2000 to 2025. Using VOSviewer and Bibliometrix (RStudio), we mapped the scientific landscape of this field, highlighting a marked increase in research output and identifying the leading contributors by authorship, country, and collaboration patterns.

Results: Keyword co-occurrence analysis identifies seven dominant research themes spanning marine pollution pathways, toxicological mechanisms, human exposure risks, environmental fate, polymer-specific impacts, interactions with co-contaminants, and ecological effects on the early life stages of aquatic organisms.

Conclusion: Temporal evolution analysis highlights a shift from environmental distribution studies toward mechanistic toxicology and human health risk assessment. Despite rapid advances, critical research gaps remain in standardized analytical protocols, long-term exposure effects, and combined-contaminant toxicity. This integrative study offers a strategic overview of scientific progress, identifies knowledge frontiers, and provides guidance for future interdisciplinary research and evidence-based policy development to mitigate microplastic contamination in food systems.

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Introduction

Plastic pollution is one of the biggest environmental problems of this century. Every year, more than 390 million tons of plastic are produced worldwide [1]. Microplastics (MPs), which are particles smaller than 5 mm that result from plastic degradation, are now ubiquitous in the environment and enter the human food chain through food, air, and water [2, 3]. Their presence has been confirmed in a wide variety of foods, including drinking water, honey, seafood, dairy products, salt, sugar, meat, fruits, and vegetables [4-6].

Human exposure to MPs is therefore inevitable and potentially chronic, with estimates reaching hundreds of thousands of particles ingested annually [7, 8]. MPs can carry chemical pollutants (such as heavy metals, persistent organic pollutants, and additives) and pathogens, which makes them more toxic [9, 10]. Toxicological studies, primarily conducted using cellular models or animal subjects, demonstrate that MP exposure may lead to metabolic problems, alterations in the gut microbiota, oxidative stress, immune dysfunction, and reproductive consequences [7, 11, 12].

Nevertheless, most available research focuses on acute exposures at elevated concentrations, whereas the consequences of chronic low-dose exposure are inadequately understood [5, 13]. Moreover, the lack of standardized methodologies for microplastic analysis in food matrices hinders data comparability and the evaluation of genuine human health hazards [4, 14]. Given these uncertainties, it is imperative to continue research on the quantification, characterization, and toxicity of microplastics in food, while concurrently developing bibliometric methodologies to chart the progression of knowledge and ascertain scientific and regulatory priorities [1, 14].

To address the growing scientific concern about microplastics (MPs) in food, we conducted a cross-sectional bibliometric and science mapping study. Bibliometric analysis is a quantitative, systematic approach for evaluating scientific literature to identify publication patterns, research trends, collaboration structures, and scholarly impact within a defined field [15–17]. Accordingly, our objective was to map the research landscape on MPs in food and their toxicological implications and to provide a strategic overview that can guide future research directions and support regulatory prioritization.

Materials and Methods

This study adopted a cross-sectional bibliometric and science-mapping design based on Scopus records retrieved on 13 July 2025. The query was designed to cover a broad spectrum of research on MPs in food and their toxicological effects by searching titles, abstracts, and keywords, using the following search string: ("microplastic*" OR "microplastic particle*") AND ("food" OR "food product*" OR "seafood" OR "fish*" OR "meat" OR "vegetable*" OR "drinking water") AND ("toxicity" OR "toxic* effect" OR "toxic*" OR "health risk" OR "ingestion" OR "cytotoxicity" OR "genotoxicity" OR "bioaccumulation" OR "oxidative stress" OR "health risk*" OR "endocrine disruption").

Only research articles that were published in English between 2000 and 2025 were considered for inclusion. Also, the subject area was limited to: Environmental Science; Agricultural and Biological Sciences; Pharmacology, Toxicology and Pharmaceutics; Medicine; Chemistry; Biochemistry, Genetics and Molecular Biology; Immunology and Microbiology; Neuroscience, and Veterinary Science. The extracted data were exported in CSV and BibTeX formats. The bibliometric analysis and network visualization were performed using the VOSviewer software (version 1.6.20) and Bibliometix (R Studio version 2025.05.1+513) (Figure 1).

Scopus was chosen because it offers broad multidisciplinary coverage spanning environmental sciences, food-related research, and toxicology, and provides standardized bibliographic metadata and citation information that can be exported and analyzed reliably using VOSviewer and Bibliometrix. Furthermore, the period 2000–2025 was selected to capture the historical evolution of research on microplastics in food over two decades and to map the field's recent expansion.

Ethical approval was not required for this bibliometric study because it used publicly available bibliographic metadata and did not involve human participants, animal experiments, or identifiable personal data.

Results and Discussion

The bibliometric analysis of publications on the topic reveals 3,424 documents across 515 sources, with a remarkable annual growth rate of 44.66%. A total of 11 917 authors contributed to this body of work, with an average of 6.47 co-authors per article and an international collaboration rate of 31.31%. Only 32

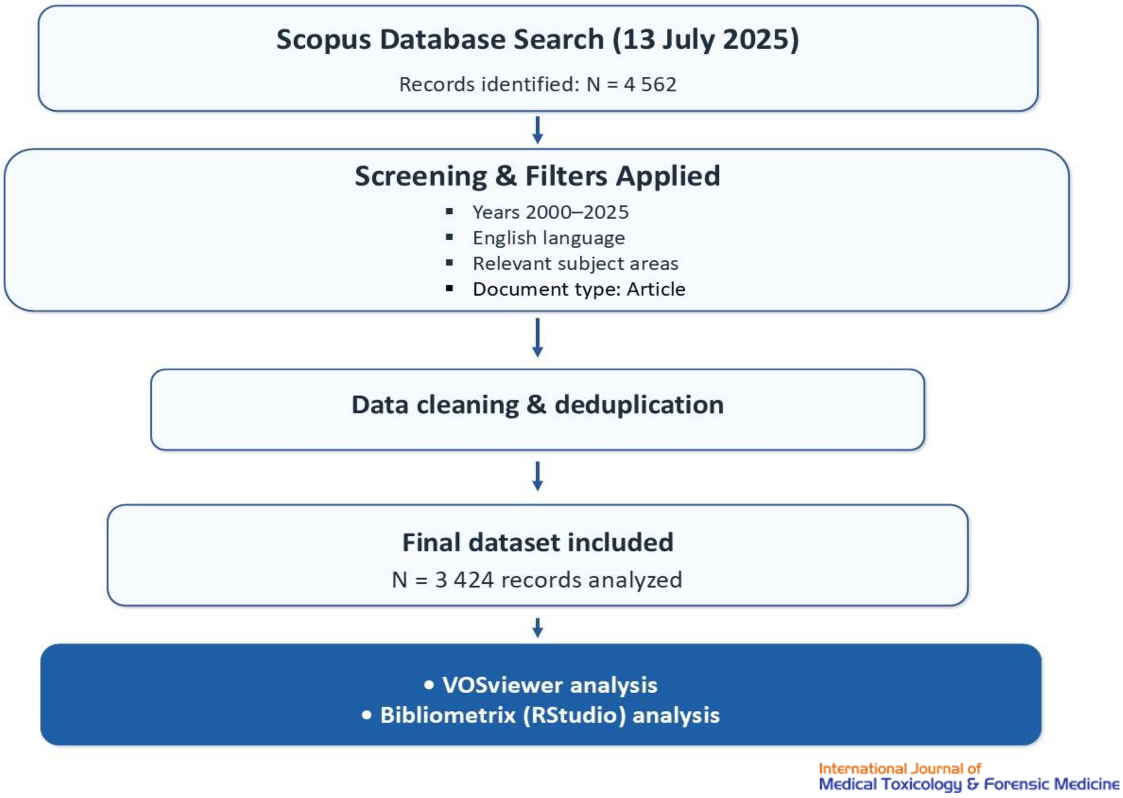

Figure 1. Methodological workflow of the bibliometric study and record selection process.

documents were single-authored, highlighting a strong collaborative dynamic within the field. The dataset includes 6,957 author keywords, with an average of 58.28 citations per document and a mean publication age of 2.66 years, reflecting a rapidly growing, relatively recent research domain.

Evolution of Scientific Production

Research on MPs in food and their toxicological effects has gained significant momentum since the first Scopus-indexed publication appeared in 2008. Since then, scientific interest in this field has grown rapidly and continuously, reflecting increasing global concern over the health and environmental implications of microplastic contamination (Figure 2). The research has experienced exponential growth, particularly after 2015, peaking in 2024 with nearly 800 published articles. This trend reflects a growing awareness of the health and environmental challenges associated with MPs, supported by methodological advancements and increased research funding. The slight decline observed in 2025 may be attributed to the incomplete indexing of recent publications in the Scopus database [16].

Key Authors in the Field

Top Contributing Authors

The analysis of the most productive authors in the field of MPs in food and their toxicological effects, as visualized through Scopus data (Figure 3), reveals the top contributing researchers based on the number of publications. Among the most prolific authors, Shi, H. leads the field with 32 publications, followed closely by Wang, J. and Koelmans, A.A., with around 29 and 25 documents respectively. These authors have likely played a central role in advancing research on MP contamination pathways, toxicological assessments, and environmental modeling. Notably, Koelmans is widely recognized for his work on risk assessment and exposure modeling,

Author Citation Analysis

The author citation network provides a visual representation of the intellectual relationships within the field of MPs in food. Of the 15 364 authors identified in the corpus, only those with at least 10 publications were included, resulting in a final network of 53 authors grouped into six distinct clusters (Figure 4). This visualization offers a detailed understanding of the intellectual structure of the research domain, highlighting the most influential contributors and their interconnections based on citation patterns. The network reveals a well-defined thematic organization. The size of each node represents the citation impact of an author, while the thickness of the links indicates the strength of their citation relationship—that is, how often authors are co-cited or cite each other—reflecting shared research interests or intellectual alignment.

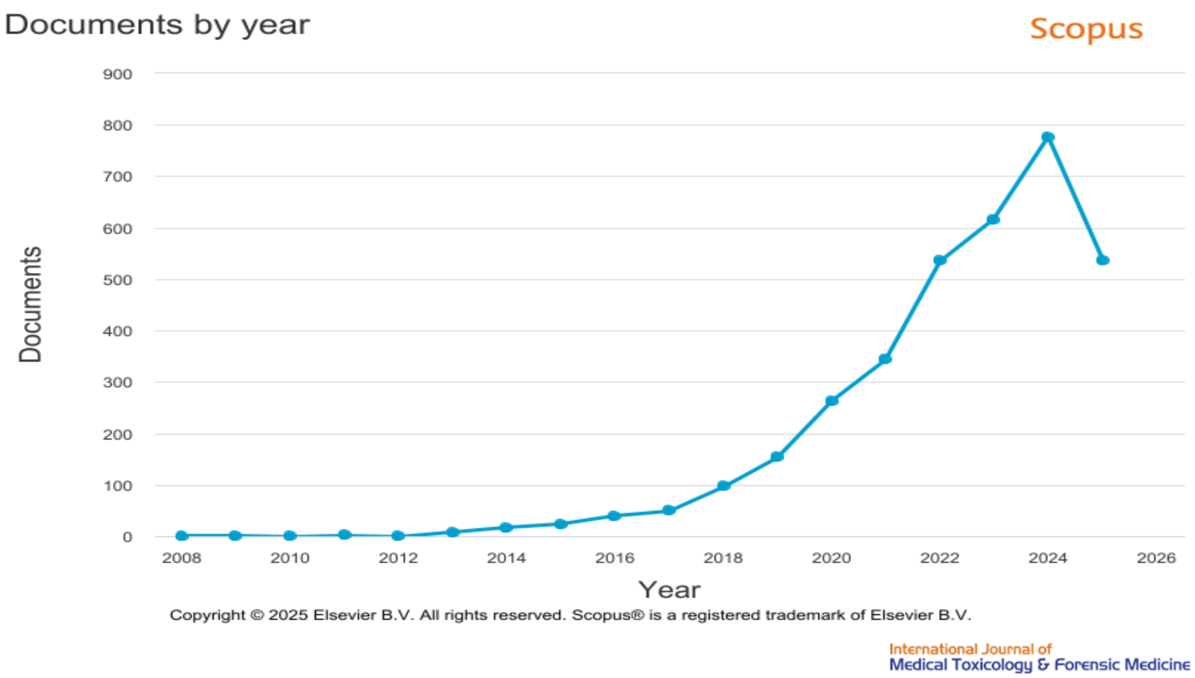

Figure 2. Growth of Annual Scientific Production From 2000 to 2025.

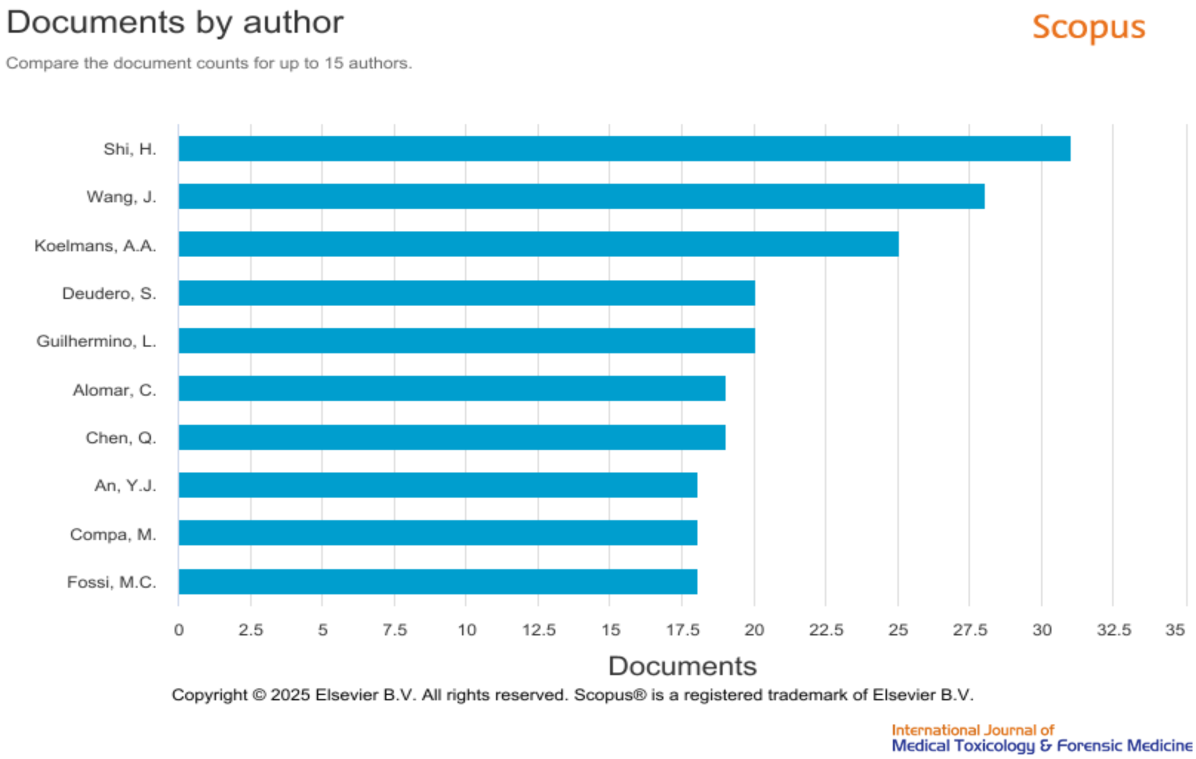

Figure 3. Top 10 Most Productive Authors in MPs in Food and their Toxicological Effects: A Scopus-Based Analysis.

The red cluster comprises 13 authors working on exposure modeling, ecological risk assessment, and MP-pollutant interactions. It emerges as the most prominent group, dominated by figures such as Koelmans, A., Rochman, C.M., and Galloway, T.S. This cluster represents a leading school of thought in the global environmental assessment of microplastics, particularly in marine and freshwater ecosystems.

In contrast, the green cluster, led by Wang Jun and Wang Lei, includes researchers primarily affiliated with East Asian institutions. This group is strongly focused on experimental studies in fish, histopathological analyses, and the biochemical effects of MPs. It is the most densely connected cluster in the network, indicating a high degree of regional and thematic collaboration.

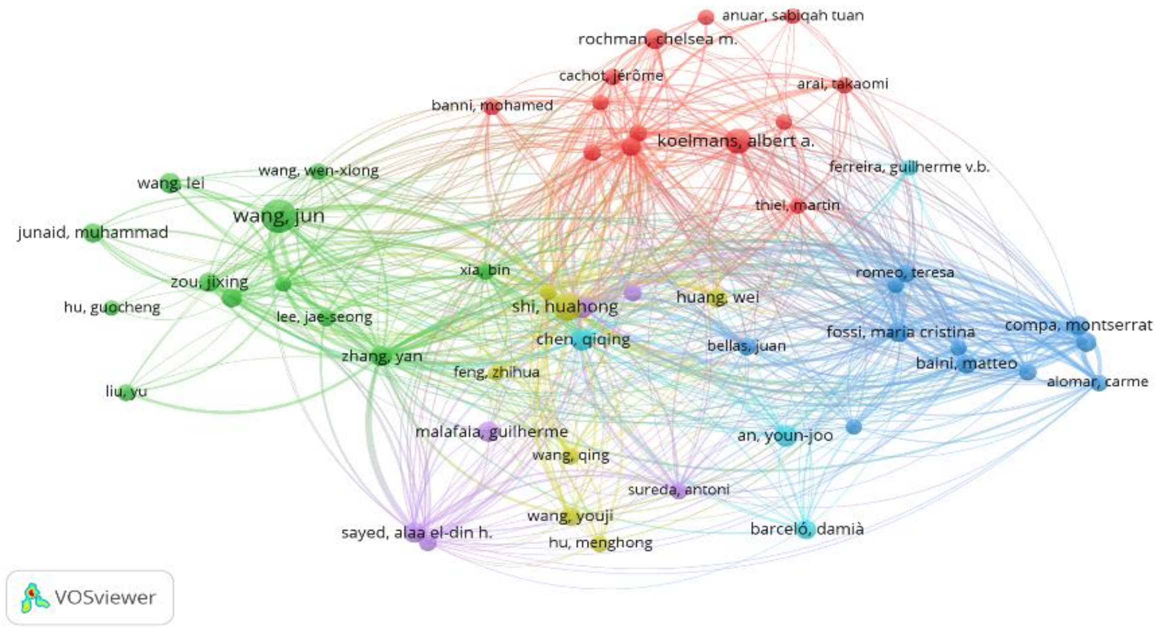

Figure 4. Citation Network of the Most Cited Authors (Minimum 10 Publications) Based on VOSviewer Mapping.

Geographical Distribution

The global research landscape in the explored domain, as depicted in Figure 5, encompasses contributions from 96 countries, of which 75 have published at least 5 documents between 2008 and 2025. The geographical distribution of scientific productivity (Figure 5a) reveals strong dominance by China, the leading contributor, followed by significant contributions from countries across North America, Europe, and Asia. This global participation reflects growing international concern about the health and environmental risks associated with MPs in the food supply chain.

Additionally, the analysis of the top 10 most productive countries (Figure 5b) further confirms China's leading position, with over 1 000 publications, far exceeding those of the United States and India, which rank second and third, respectively. Prominent European contributors include Spain, Italy, the United Kingdom, and Germany, while South Korea, Canada, and Portugal also demonstrate substantial involvement. This distribution not only highlights the presence of regional scientific hubs but also emphasizes the field's multidisciplinary and collaborative nature.

Keyword Co-Occurrence and Temporal Evolution of Research Trends

The bibliometric analysis, based on a co-occurrence map of author keywords (Figure 6), reveals the dominant research themes and their interconnections in

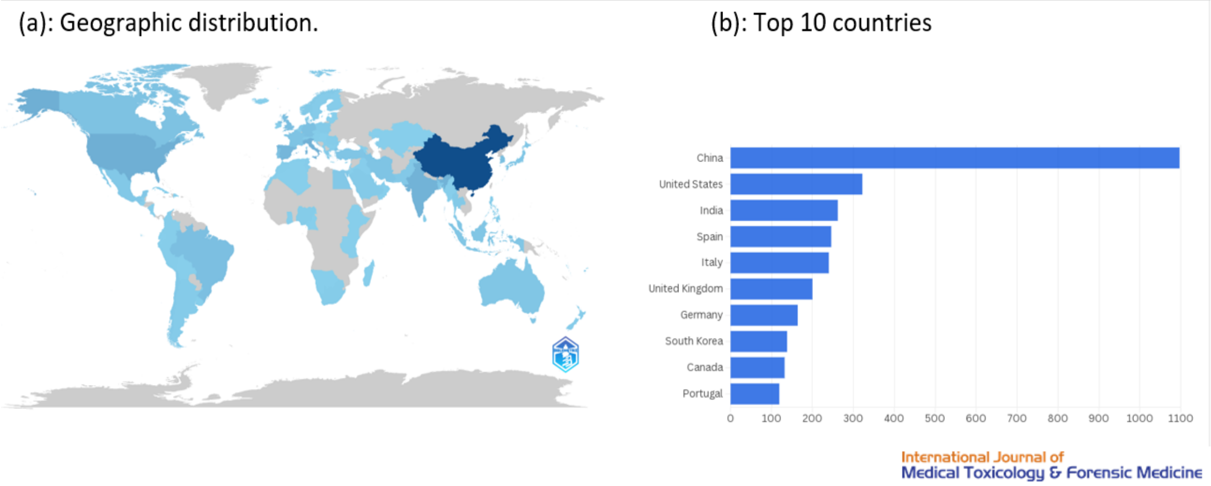

Figure 5. Global Distribution and Productivity of Scientific Research on Microplastics in Food (2008–2025). (a) Geographic distribution of scientific output. (b) Top 10 Countries by Publication Volume.

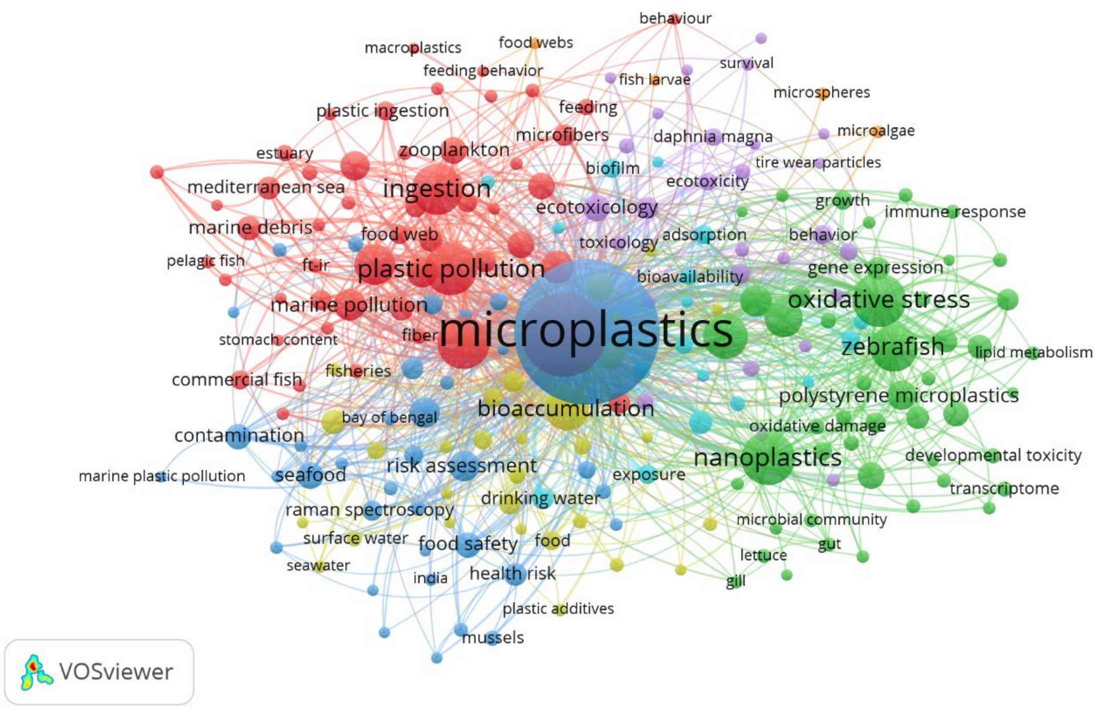

Figure 6. Keyword Co-occurrence Network Mapping the Main Research Themes on Microplastics (≥10 Occurrences).

the field under investigation. The size of the nodes on the map is proportional to the frequency of keyword occurrences, while the links represent co-occurrence strength between keywords. A total of 217 keywords met the inclusion threshold (≥10 occurrences), which were grouped into seven thematic clusters.

- The first cluster (red), comprising 52 keywords, focuses on marine pollution and the ecological impacts of MPs

- The second cluster (green), with 48 keywords, centers on toxicological and physiological effects of MPs.

- The third cluster (blue), including 37 keywords, addresses human health risks and exposure assessment.

- The fourth cluster (yellow), containing 32 keywords, emphasizes bioaccumulation and environmental fate of MPs.

- The fifth cluster (purple), composed of 27 keywords, focuses on toxicological assessments and polymer-specific impacts of microplastics.

- The sixth cluster (light blue), comprising 17 keywords, highlights research on the interaction of microplastics with other environmental contaminants.

- The last cluster (orange), consisting of 4 keywords, highlights research on the early-life exposure and ecological interactions of microplastics.

Building on the structural mapping, the temporal evolution of author keywords from 2021 to 2023 provides further insight into the dynamic progression of research priorities within the field. The overlay visualization, using a color gradient from blue (earlier years) to yellow (more recent), reveals a chronological transition in thematic focus (Figure 7). Initial research efforts, predominantly from 2021 to early 2022, were centered on ecological and environmental concerns, as evidenced by darker-hued keywords such as marine debris, plastic pollution, ingestion, fish, and sediment. These terms highlight a foundational emphasis on the environmental distribution, accumulation, and trophic transfer of MPs, especially in marine systems.

As the field evolved into 2022 and 2023, the focus shifted noticeably toward health-related and toxicological investigations. Keywords rendered in lighter hues, including oxidative stress, inflammation, gut microbiota, apoptosis, and combined toxicity, signal an intensifying interest in the biological impacts and mechanistic pathways through which micro- and nanoplastics exert harm. The increasing prominence of nanoplastics, polystyrene MPs, and gene expression further underscores a shift toward molecular-level toxicology, interactions with emerging contaminants, and precise exposure models. Concurrently, the continued presence of keywords such as food safety, drinking water, and risk assessment indicates a sustained concern for human health and regulatory implications, bridging environmental science with public health discourse.

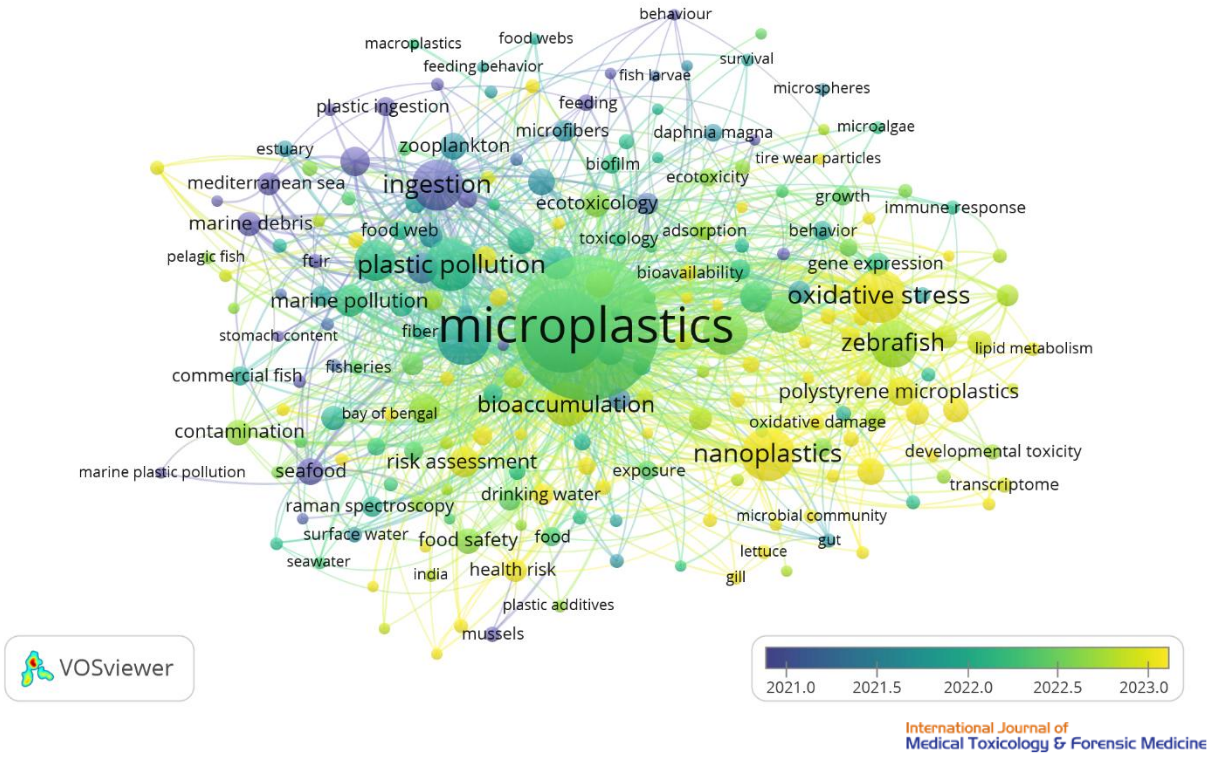

Figure 7. Temporal Evolution of Keyword Co-Occurrence Network in Microplastics Research.

Research Gaps

Despite the rapid increase in research on MPs in food and their toxicological effects, several gaps persist, hindering a comprehensive assessment of human health risks. Firstly, although numerous studies have demonstrated toxicological effects of MPs in *vitro* and in animal models, the precise mechanisms by which these particles induce biological disturbances often remain poorly understood. It is crucial to elucidate the absorption, distribution, metabolism, and excretion pathways of MPs in mammals, including humans, as well as specific interactions with cellular and molecular systems. Furthermore, direct epidemiological data on the long-term effects of MP exposure in humans are almost non-existent, representing a major gap for establishing causal links and relevant exposure thresholds.

The variability in polymer types, sizes, shapes, and concentrations of MPs in food makes standardizing sampling, extraction, and analysis methods extremely complex, limiting the comparability of results across studies and the robustness of exposure assessments. In addition, while significant advances have been made in detection techniques, there is a continuous need to develop more sensitive, faster, less costly, and more environmentally friendly methods capable of precisely characterizing MPs in complex food matrices. Finally, current research tends to focus on the effects of MPs in isolation, often neglecting their combined effects with other chemical contaminants (such as plastic additives, adsorbed pollutants like heavy metals, or persistent organic compounds) that can act synergistically or antagonistically, potentially underestimating the overall toxicological risk to consumers. These gaps highlight the need for multidisciplinary, collaborative research to fill knowledge gaps and inform public health policies.

Conclusion

This bibliometric review has revealed exponential growth and increasing complexity in research on MPs in food and their toxicological effects. Beyond simply quantifying scientific output, this analysis highlights crucial implications for public health and the environment and outlines essential research avenues for the future.

The observed trends in scientific production, with a notable acceleration since 2018 and a concentration of research efforts in China and the United States, underscore the urgency of a globally coordinated scientific response.

Moving forward, several research directions are imperative. Firstly, it is crucial to develop more standardized and sensitive detection and characterization methods capable of identifying MPs in complex food matrices, including the smallest fractions that may pose the highest toxicological risks. Secondly, a deeper understanding of precise toxicological mechanisms, particularly at the molecular and cellular levels, is necessary to establish clear cause-and-effect relationships between microplastic exposure and human health effects. This includes studying long-term effects, interactions with the microbiota, and impacts on vulnerable populations. Thirdly, research should focus on assessing the real risks to human health, considering multiple exposure pathways and combined effects with other contaminants present in food. Finally, it is critical to translate this scientific knowledge into effective risk management strategies, consumer recommendations, and robust regulatory policies to reduce microplastic contamination at the source.

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Conflicts of Interest

The authors report there are no competing interests to declare.

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