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Emerging Environmental Contaminants in Food Systems and Human Health Risks

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Abstract

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This study evaluates the presence and health risks of emerging environmental contaminants in food systems, with a focus on microplastics, PFAS, and their transfer through the food chain. Using a qualitative Systematic Literature Review (SLR) approach, this study synthesizes recent research to examine how these contaminants enter environmental media and are subsequently incorporated into food systems. The findings indicate that microplastics and PFAS are widely distributed and persist in soil, water, and biological organisms, enabling their transfer across trophic levels and leading to human exposure through dietary intake. Key processes such as bioaccumulation and biomagnification contribute to increased contaminant concentrations within food chains. At the biological level, these substances are associated with mechanisms including oxidative stress, inflammation, and endocrine disruption, which may result in long-term health risks. This study highlights the need for integrated risk assessment approaches that consider environmental pathways and cumulative exposure.

1. Introduction

The presence of environmental contaminants in food systems has become an increasing concern due to their potential impact on human health. In recent years, attention has shifted from traditional pollutants to emerging contaminants such as microplastics and per- and polyfluoroalkyl substances (PFAS), which are now recognized as significant contributors to modern exposure pathways (Bayabil et al., 2022).

Microplastics, defined as plastic particles smaller than 5 mm, have been widely detected in various environmental compartments, including water, soil, and air. As reported by Eze et al. (2024), these particles can enter the food chain through multiple routes, ultimately leading to human exposure via dietary intake.

The widespread distribution of microplastics in ecosystems has raised concerns about their accumulation in food-producing organisms, including fish, livestock, and agricultural products. Studies suggest that these particles can be transferred across trophic levels, thereby increasing the likelihood of human ingestion through contaminated food sources (Prata & Dias-Pereira, 2023).

In addition to microplastics, PFAS represent another group of emerging contaminants that have gained significant attention due to their persistence and bioaccumulative properties. De Silva et al. (2021) highlight that PFAS are widely distributed in the environment and can enter food systems through contaminated water, soil, and agricultural inputs.

The persistence of PFAS in environmental media contributes to their long-term presence in food chains, making them a continuous source of exposure for human populations. These substances are resistant to degradation, which further complicates efforts to control their spread and mitigate associated risks (DeLuca et al., 2022). Environmental contaminants are not confined to isolated ecosystems but are transferred through interconnected pathways that link soil, water, plants, and animals. This transfer process enables contaminants to move across different levels of the food chain, ultimately reaching humans through dietary consumption (Sarker et al., 2022).

A key process underlying this transfer is bioaccumulation, where contaminants are absorbed and retained within organisms over time. As described by Ali and Khan (2019), bioaccumulation is often accompanied by biomagnification, resulting in increased concentrations of contaminants at higher trophic levels. Beyond their presence in food systems, emerging contaminants may exert adverse health effects through various biological mechanisms. Microplastics have been associated with oxidative stress and inflammatory responses, which may contribute to cellular and systemic toxicity (Campanale et al., 2020).

Similarly, PFAS exposure has been linked to disruptions in metabolic and endocrine functions, highlighting their potential to affect multiple organ systems. These effects are particularly concerning given the long-term and cumulative nature of exposure (Yang et al., 2023). Despite the growing body of research, existing studies often focus on individual contaminants without integrating multiple exposure pathways and biological mechanisms. This fragmented approach limits the understanding of how different contaminants interact within food systems and affect human health.

Therefore, there is a need for a comprehensive analysis that integrates emerging contaminants, environmental transfer processes, and toxicological mechanisms within a unified framework. Such an approach is essential for capturing the complexity of exposure in modern food systems. This study aims to evaluate the presence and health risks of emerging environmental contaminants in food systems by synthesizing recent literature on microplastics, PFAS, food chain transfer, and associated biological effects. Using a qualitative Systematic Literature Review (SLR) approach, this study seeks to provide an updated and integrated perspective on environmental contamination and its implications for human health.

2. Literature Review

2.1. Emerging Contaminants in Food Systems

Emerging environmental contaminants such as microplastics and PFAS have gained increasing attention due to their widespread occurrence and persistence in ecosystems. Unlike traditional pollutants, these contaminants are characterized by their ability to remain in the environment for extended periods and enter food systems through multiple pathways. Recent reviews emphasize that microplastics are now commonly detected in water, soil, and food products, indicating their pervasive presence in modern environments (Eze et al., 2024).

Microplastics are particularly concerning because of their small size and ability to carry other chemical substances, including additives and environmental pollutants. Campanale et al. (2020) note that these particles can act as vectors for toxic compounds, thereby increasing their potential impact on human health. In addition, the detection of microplastics in terrestrial animals suggests that exposure is not limited to marine ecosystems but extends across food production systems (Prata & Dias-Pereira, 2023).

PFAS represent another important class of emerging contaminants due to their chemical stability and resistance to degradation. These substances are widely used in industrial and consumer applications, leading to their widespread distribution in environmental media. According to De Silva et al. (2021), PFAS contamination has been detected in water sources and agricultural systems, facilitating their entry into food chains.

2.2. Environmental Pathways and Food Chain Transfer

The movement of contaminants from environmental sources into food systems occurs through interconnected pathways involving soil, water, and biological organisms. Contaminants present in environmental media can be taken up by plants or ingested by animals, thereby entering the food chain and ultimately reaching humans through dietary exposure (Sarker et al., 2022). This transfer process is influenced by environmental conditions such as soil composition, water quality, and agricultural practices. Bayabil et al. (2022) highlight that emerging contaminants can persist in both soil and water systems, increasing their likelihood of being incorporated into food production processes.

In aquatic environments, contaminants such as microplastics and heavy metals can be ingested by marine organisms, leading to their accumulation in edible species. Yang et al. (2023) emphasize that different exposure routes, including ingestion and inhalation, contribute to the overall burden of contaminants in the human body.

2.3. Bioaccumulation and Biomagnification Processes

A critical factor in understanding the impact of environmental contaminants is their ability to accumulate within biological systems. Bioaccumulation refers to the gradual uptake and retention of contaminants within organisms over time, leading to increased internal concentrations (Ali & Khan, 2019). Biomagnification further amplifies this process by increasing contaminant concentrations at higher trophic levels in the food chain. This phenomenon is particularly relevant for human exposure, as individuals often consume organisms that occupy higher positions in the food chain, such as fish and livestock (Sarker et al., 2022).

The combined effects of bioaccumulation and biomagnification contribute to the persistence of contaminants within food systems and increase the potential for long-term exposure. These processes highlight the importance of considering ecological interactions when assessing human health risks.

2.4. Toxicological Mechanisms and Health Effects

Emerging contaminants exert their effects through a range of biological mechanisms that can impact cellular and systemic functions. Microplastics have been associated with oxidative stress and inflammatory responses, which may disrupt cellular integrity and contribute to disease development (Campanale et al., 2020). In addition to microplastics, PFAS exposure has been linked to metabolic and endocrine disruptions, indicating their potential to affect multiple physiological systems. DeLuca et al. (2022) report that these substances can enter the human body through various exposure routes, including dietary intake and environmental contact.

The complexity of these mechanisms is further increased by the interaction of multiple contaminants within biological systems. Kannan and Vimalkumar (2021) suggest that microplastics may act as carriers for other toxic substances, thereby enhancing their combined effects on human health.

2.5. Challenges in Risk Assessment of Emerging Contaminants

Despite growing evidence on the presence and effects of emerging contaminants, current risk assessment approaches face several limitations. Traditional frameworks are primarily designed to evaluate individual substances under controlled conditions, which may not accurately reflect real-world exposure scenarios involving multiple contaminants (De Silva et al., 2021). The dynamic nature of environmental contamination, combined with the complexity of food systems, further complicates the assessment of health risks. Studies indicate that exposure patterns are influenced by a range of factors, including environmental variability, dietary habits, and interactions between contaminants (Bayabil et al., 2022).

Overall, the literature highlights the need for more comprehensive and integrative approaches that consider cumulative exposure, environmental pathways, and biological mechanisms. Such approaches are essential for improving the assessment of risks associated with emerging contaminants in food systems.

3. Methods

This study employs a qualitative Systematic Literature Review (SLR) approach to examine the presence and health risks of emerging environmental contaminants in food systems, with a focus on microplastics, PFAS, and related exposure pathways. The SLR method is used to systematically synthesize existing scientific evidence across interdisciplinary fields, including environmental science, food safety, toxicology, and public health, without generating new experimental data. The literature search was conducted using major academic databases and publisher platforms. The search strategy utilized combinations of keywords such as "microplastics," "PFAS," "emerging contaminants," "food chain," "bioaccumulation," and "human health risk" to identify relevant studies addressing contamination sources, environmental transfer, and toxicological effects. The inclusion criteria were limited to peer-reviewed articles published between 2019 and 2024 to ensure relevance to recent developments in environmental contamination and food systems.

Studies were selected based on their relevance to emerging contaminants in food systems, including those examining environmental pathways, food chain transfer, bioaccumulation processes, and health-related outcomes. Studies focusing exclusively on non-food exposure pathways without clear relevance to dietary intake were excluded. The selected literature was analyzed using qualitative thematic synthesis, which involved identifying recurring patterns, conceptual relationships, and convergent findings across studies.

The analysis was structured around key thematic areas, including emerging contaminants, environmental pathways, bioaccumulation and biomagnification, toxicological mechanisms, and challenges in risk assessment. Rather than applying quantitative meta-analysis, this study emphasizes conceptual integration to provide a comprehensive understanding of how emerging environmental contaminants influence human health through food systems.

4. Results

This section presents the synthesized findings on emerging environmental contaminants in food systems, focusing on their sources, environmental pathways, food chain transfer, and associated health risks. The results indicate that contaminants such as microplastics and PFAS are widely distributed across environmental media and enter food systems through interconnected pathways, leading to complex exposure patterns in humans.

4.1. Sources and Environmental Pathways of Emerging Contaminants

The findings show that emerging contaminants originate from multiple sources, including industrial activities, consumer products, and environmental degradation processes. These contaminants are released into environmental media such as soil, water, and air, where they persist and accumulate over time. Studies have demonstrated that microplastics are now widely present across ecosystems and can enter food systems through contamination of water and agricultural environments (Eze et al., 2024).

PFAS contamination follows similar pathways, with these substances entering food systems through polluted water sources, soil contamination, and agricultural inputs. Their chemical stability allows them to persist in environmental media and facilitates their transfer into food-producing systems (De Silva et al., 2021). Environmental conditions play a significant role in determining the movement and distribution of contaminants. Factors such as water flow, soil composition, and agricultural practices influence how contaminants are transported and incorporated into food systems (Bayabil et al., 2022).

Table 1. Sources and Environmental Pathways of Emerging Contaminants in Food Systems

Source Category	Contaminant Type	Environmental Medium	Pathway to Food System
Industrial emissions	PFAS	Water, soil	Contamination of crops and livestock
Plastic degradation	Microplastics	Water, soil, air	Uptake by aquatic and terrestrial organisms
Agricultural inputs	Mixed contaminants	Soil and water	Absorption by plants and entry into food chain
Environmental persistence	PFAS and microplastics	Multiple media	Long-term accumulation in ecosystems

4.2. Food Chain Transfer and Human Exposure

The results indicate that contaminants are transferred through the food chain via processes such as ingestion, absorption, and trophic interactions. Contaminants present in environmental media are taken up by plants and animals, which then serve as vectors for human exposure through dietary consumption (Sarker et al., 2022).

Microplastics have been detected in a variety of food sources, including seafood and agricultural products, indicating widespread exposure across different dietary pathways. Research suggests that these particles can be ingested directly or indirectly through contaminated food items, contributing to overall human exposure (Prata & Dias-Pereira, 2023). PFAS exposure also occurs through dietary intake, particularly through contaminated water and food products derived from affected environments. Studies highlight that multiple exposure routes contribute to the accumulation of these substances in the human body (DeLuca et al., 2022).

Bioaccumulation plays a central role in increasing contaminant levels within organisms, leading to higher internal concentrations over time. Ali and Khan (2019) emphasize that this process is critical in understanding how contaminants persist within food systems.

4.3. Toxicological Mechanisms and Health Risk Implications

The findings show that emerging contaminants exert their effects through various biological mechanisms that influence cellular and systemic functions. Microplastics have been associated with oxidative stress and inflammatory responses, which may disrupt cellular integrity and contribute to disease development (Campanale et al., 2020).

PFAS exposure has been linked to metabolic and endocrine disruptions, indicating their potential to affect multiple organ systems and contribute to chronic health conditions. These effects are particularly concerning due to the persistent and bioaccumulative nature of these substances (Yang et al., 2023). The interaction of multiple contaminants within biological systems further increases the complexity of health risks. Kannan and Vimalkumar (2021) suggest that microplastics may act as carriers for other toxic substances, enhancing their combined effects and amplifying overall toxicity.

Table 2. Integrated Framework of Emerging Contaminants and Health Risks

Process Stage	Description	Mechanism	Health Risk Implication
Environmental contamination	Release of contaminants into ecosystems	Persistence and accumulation	Initial exposure risk
Food chain transfer	Movement through plants and animals	Trophic interactions	Increased dietary exposure
Bioaccumulation	Retention within organisms	Tissue accumulation	Elevated internal concentration
Biological interaction	Cellular and systemic effects	Oxidative stress and endocrine disruption	Functional impairment
Cumulative exposure	Long-term intake of multiple contaminants	Interaction effects	Chronic health risks

4.4. Interpretation of Key Findings

The synthesis demonstrates that emerging environmental contaminants are integrated into food systems through complex and interconnected pathways that link environmental pollution with human dietary exposure. These pathways are influenced by environmental conditions, biological processes, and consumption patterns, resulting in variable exposure levels across populations. A key insight is that emerging contaminants differ from traditional pollutants in their persistence, diversity, and ability to interact within biological systems. Microplastics and PFAS, in particular, represent a new category of contaminants that require updated approaches to monitoring and risk assessment.

Furthermore, the findings highlight that human exposure is shaped not only by individual contaminants but also by cumulative and interactive effects within food systems. This underscores the need for more comprehensive frameworks that integrate environmental, biological, and dietary factors in assessing health risks.

5. Discussion

The findings indicate that emerging environmental contaminants such as microplastics and PFAS are not confined to isolated environmental compartments but are integrated into food systems through interconnected pathways. This integration reflects a shift in contamination patterns, where exposure is driven by complex interactions between environmental processes, food production systems, and dietary behaviors. Unlike traditional contaminants, these substances are characterized by persistence and mobility, enabling their continuous circulation within ecosystems and increasing the likelihood of human exposure through multiple routes.

Another important implication is the role of cumulative exposure and interaction effects in shaping health risks. The presence of multiple contaminants within food systems suggests that biological responses may result from combined rather than individual effects, adding complexity to risk evaluation. In addition, mechanisms such as oxidative stress, inflammation, and endocrine disruption highlight the potential for long-term health impacts associated with chronic exposure. These findings emphasize the need for more integrative and adaptive risk assessment approaches that consider environmental dynamics, food chain interactions, and cumulative exposure in evaluating the safety of modern food systems.

6. Conclusion

This study highlights that emerging environmental contaminants, particularly microplastics and PFAS, have become integral components of modern food systems due to their persistence and widespread distribution in environmental media. The findings demonstrate that these contaminants are transferred through interconnected pathways involving soil, water, plants, and animals, ultimately leading to human exposure through dietary intake. This underscores the importance of viewing food safety within a broader environmental context.

From an analytical perspective, the study integrates evidence on environmental pathways, food chain transfer, bioaccumulation processes, and toxicological mechanisms to provide a comprehensive understanding of associated health risks. The results indicate that contaminants exert their effects through mechanisms such as oxidative stress, inflammation, and endocrine disruption, which contribute to potential long-term health outcomes. This integrated framework emphasizes that exposure is shaped not only by individual contaminants but also by cumulative and interactive effects within biological systems.

In practical terms, the findings emphasize the need to advance current risk assessment approaches to better reflect real-world exposure scenarios. Future research should focus on improving methodologies for evaluating cumulative exposure, expanding monitoring of emerging contaminants in food systems, and integrating environmental and dietary perspectives in safety assessment. Strengthening these approaches is essential for enhancing food safety management and protecting human health in the context of evolving environmental challenges.

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