



Emerging Contaminants in Food Systems and Their Impact on Human Health

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Abstract

Article history:

Received: July 29, 2025

Revised: October 25, 2025

Accepted: November 14, 2025

Published: December 30, 2025

Keywords:

combined exposure,
emerging contaminants,
food safety,
microplastics,
PFAS,
risk assessment.

Identifier:

Zera Open

Page: 111-127

<https://zeraopen.com/journal/fct>

Emerging contaminants in food systems, including microplastics and per- and polyfluoroalkyl substances (PFAS), have become a growing concern due to their persistence, widespread distribution, and potential health impacts. This study evaluates their presence and implications for human health by synthesizing recent evidence on contamination sources, food chain transfer, toxicological mechanisms, and combined exposure risks. A qualitative Systematic Literature Review (SLR) approach was applied to analyze peer-reviewed studies published between 2020 and 2025. The findings indicate that these contaminants enter food systems through environmental pathways and accumulate through bioaccumulation and trophic transfer, leading to continuous dietary exposure. Toxicological effects are associated with oxidative stress, inflammation, and metabolic disruption, with potential additive or synergistic interactions. The study highlights limitations in traditional risk assessment approaches and emphasizes the need for integrative frameworks that account for mixture effects and exposure variability to improve food safety evaluation.

1. Introduction

Emerging contaminants in food systems have gained increasing attention due to their persistence, widespread distribution, and potential risks to human health. These contaminants include microplastics, per- and polyfluoroalkyl substances (PFAS), and other synthetic chemicals that are not traditionally monitored but are now recognized as significant food safety concerns (Liu et al., 2025; Chen et al., 2025). Unlike conventional contaminants, emerging substances often originate from modern industrial processes and consumer products, leading to continuous environmental release and accumulation. Their presence in food systems is facilitated by complex pathways involving soil, water, and food production processes. As a result, these contaminants are increasingly detected in various food categories, raising concerns about long-term exposure. This evolving landscape highlights the need to better understand their distribution and implications for human health.

The growing concern surrounding emerging contaminants is closely linked to their ability to enter and persist within the food chain. These substances can be transferred from environmental media into crops, aquatic organisms, and animal products, leading to indirect human exposure through dietary intake (Ben Seghir et al., 2023). In particular, microplastics have been identified in a wide range of food items, including seafood, salt, and drinking water, suggesting that exposure is widespread and continuous. Similarly, PFAS are known for their persistence and resistance to degradation, allowing them to accumulate in biological systems over time. Shetty et al. (2025) emphasize that food chain processes such as

bioaccumulation and trophic transfer play a critical role in amplifying exposure levels. These characteristics make emerging contaminants particularly challenging to manage within food safety frameworks. Understanding how these substances move through food systems is therefore essential for evaluating exposure risks.

In addition to their presence in food systems, emerging contaminants exhibit diverse toxicological properties that can affect human health. Microplastics, for example, may act as carriers for other toxic substances and have been associated with inflammation, oxidative stress, and potential tissue damage. PFAS exposure has been linked to immune dysfunction, endocrine disruption, and other chronic health effects due to their bioaccumulative nature. These health impacts are influenced by factors such as exposure pathways, concentration levels, and duration of exposure. Furthermore, recent studies suggest that exposure often involves multiple contaminants simultaneously rather than isolated substances. This introduces the possibility of additive or synergistic effects, which are not fully captured by traditional toxicological assessments. Such complexity underscores the need for more comprehensive approaches to evaluating health risks.

Despite growing research on individual contaminants, current risk assessment approaches remain limited in addressing the combined effects of multiple substances. Traditional frameworks typically evaluate contaminants independently, which may underestimate the risks associated with real-world exposure scenarios. Cattaneo et al. (2023) highlight that combined exposure to multiple chemicals represents a major challenge in modern food safety assessment. In addition, Mukherjee et al. (2022) emphasize that interactions between contaminants can

influence toxicity in ways that are not predictable based on single-substance studies. These limitations suggest that existing models may not fully reflect the complexity of exposure in modern food systems. As new contaminants continue to emerge, there is an increasing need to adapt risk assessment methodologies accordingly. This requires integrating knowledge from environmental science, toxicology, and food safety disciplines.

This study aims to evaluate emerging contaminants in food systems and their impact on human health by synthesizing recent evidence on contamination sources, food chain transfer, toxicological mechanisms, and risk assessment challenges. Using a qualitative Systematic Literature Review (SLR) approach, the study provides an integrated perspective on how multiple contaminants interact within food systems and influence human exposure. The analysis emphasizes the importance of considering combined exposure, environmental dynamics, and evolving consumption patterns. By addressing these aspects, this study contributes to advancing current understanding and supports the development of more comprehensive food safety strategies.

2. Literature Review

2.1. Sources and Types of Emerging Contaminants in Food Systems

Emerging contaminants in food systems originate from a wide range of modern industrial, agricultural, and consumer-related activities that contribute to their widespread environmental distribution. These contaminants include microplastics, PFAS, and other synthetic chemicals that are increasingly detected in

soil, water, and food products (Chen et al., 2025). Unlike traditional contaminants, emerging substances are often not fully regulated, allowing them to persist and accumulate in the environment. Mukherjee et al. (2022) note that mixed contaminants frequently coexist in environmental systems, creating complex contamination scenarios that extend into food production. In addition, the diversity of these substances makes classification and monitoring more challenging. These characteristics indicate that emerging contaminants represent a dynamic and evolving category within food safety research. Understanding their sources is essential for identifying entry points into food systems.

2.2. Food Chain Transfer and Exposure Pathways

The transfer of emerging contaminants through food systems occurs via multiple pathways that link environmental contamination to human exposure. Contaminants present in soil and water are absorbed by plants or ingested by aquatic organisms, initiating their movement through the food chain. Ben Seghir et al. (2023) emphasize that food chain processes such as bioaccumulation and trophic transfer significantly influence contaminant distribution. These processes can lead to higher concentrations of contaminants at higher trophic levels, increasing potential exposure in humans. In addition, indirect exposure pathways, such as ingestion of contaminated water or food packaging interactions, may contribute to overall intake. The complexity of these pathways makes it difficult to accurately quantify exposure levels across populations. As a result, understanding food chain dynamics is critical for evaluating real-world exposure scenarios.

2.3. Microplastics and Human Health Implications

Microplastics have emerged as a major concern due to their widespread presence in food systems and their potential to affect human health. These particles originate from the degradation of larger plastic materials and can enter food systems through environmental contamination. Lane et al. (2025) highlight that human exposure to microplastics occurs through ingestion, inhalation, and dermal contact, with dietary intake being a significant pathway. Nouri et al. (2025) report that microplastics have been detected in various human tissues, raising concerns about their accumulation and long-term effects. In addition, microplastics may act as carriers for other toxic substances, increasing their potential health impact (Campanale et al., 2020). Abbas et al. (2025) further indicate that exposure may be associated with inflammation and disruption of biological systems. These findings suggest that microplastics represent a complex and emerging risk in food safety.

2.4. PFAS Exposure and Toxicological Concerns

PFAS are a group of persistent synthetic chemicals widely used in industrial applications and consumer products, which have become a significant concern in food safety. Their chemical stability and resistance to degradation allow them to accumulate in the environment and enter food systems through contaminated water and soil. Schoeters et al. (2025) emphasize that dietary intake is a major route of PFAS exposure, particularly through contaminated food products. Melnyk et al. (2025) further identify multiple pathways of dietary exposure, including bioaccumulation in animal-based foods. De Silva et al. (2021) note that PFAS are associated with a range of health effects, including immune system disruption and

metabolic disorders. The persistence of these chemicals makes them particularly challenging to manage within existing regulatory frameworks. These characteristics highlight the importance of monitoring and controlling PFAS exposure in food systems.

2.5. Combined Exposure and Risk Assessment Challenges

One of the most significant challenges in evaluating emerging contaminants is understanding the effects of combined exposure to multiple substances. In real-world conditions, individuals are exposed to mixtures of contaminants rather than isolated compounds. Cattaneo et al. (2023) highlight that combined exposure can lead to additive or synergistic effects, complicating risk assessment. Mukherjee et al. (2022) further emphasize that interactions between contaminants may alter toxicity and influence health outcomes. Traditional risk assessment approaches, which focus on single substances, may therefore underestimate actual risks. Liu et al. (2025) suggest that emerging contaminants require more integrative assessment frameworks that consider multiple exposure pathways and interactions. These challenges indicate that advancing risk assessment methodologies is essential for addressing modern food safety issues.

3. Methods

This study employs a qualitative Systematic Literature Review (SLR) approach to analyze emerging contaminants in food systems and their impact on human health. The SLR method allows for a structured synthesis of existing scientific literature across multiple disciplines, including environmental science, toxicology,

and food safety, without generating new experimental data. Relevant studies were identified through academic databases such as Google Scholar, Scopus-indexed journals, and major publisher platforms including Elsevier, Springer, and MDPI to ensure comprehensive and reliable coverage. The search strategy utilized combinations of keywords such as “emerging contaminants,” “microplastics,” “PFAS,” “food chain,” “combined exposure,” and “human health risk” to capture studies addressing contamination sources, exposure pathways, and toxicological effects. The inclusion criteria were limited to peer-reviewed articles published between 2020 and 2025, focusing on research relevant to food systems and human exposure. Selected studies were analyzed using thematic synthesis to identify key patterns, relationships, and research gaps related to emerging contaminants and their health implications.

4. Results

This section presents the synthesized findings on emerging contaminants in food systems, focusing on their sources, food chain transfer, toxicological mechanisms, and implications for human health. The results indicate that emerging contaminants are widely distributed across environmental and food systems due to continuous release from industrial, agricultural, and consumer activities. These contaminants include microplastics, PFAS, and other synthetic compounds that persist in environmental media and enter food systems through multiple pathways. The analysis shows that exposure is not limited to individual contaminants but often involves complex mixtures that vary across regions and dietary patterns.

This variability highlights the difficulty of assessing exposure using conventional single-contaminant approaches. In addition, the findings emphasize that emerging contaminants are dynamic in nature, influenced by environmental conditions and human activities. Overall, the results demonstrate the need for integrated frameworks to evaluate exposure and risk.

4.1. Sources and Distribution of Emerging Contaminants

The findings show that emerging contaminants originate from diverse sources, including industrial production, agricultural practices, and degradation of consumer materials. Chen et al. (2025) note that contaminants such as microplastics and PFAS are increasingly detected in soil, water, and food products due to their widespread use and environmental persistence. These substances enter food systems through pathways such as irrigation, environmental deposition, and contamination during processing. Mukherjee et al. (2022) highlight that mixed contaminants frequently coexist, creating complex exposure scenarios. In addition, contaminants can vary in concentration depending on geographic location and environmental conditions. This variability makes it difficult to establish uniform exposure levels across populations. These findings indicate that contamination is a continuous and multifactorial process.

Table 1. Sources and Distribution of Emerging Contaminants in Food Systems

Contaminant Type	Source	Environmental Medium	Pathway to Food
Microplastics	Plastic degradation	Soil, water	Uptake by organisms
PFAS	Industrial chemicals	Water, soil	Bioaccumulation in food

Contaminant Type	Source	Environmental Medium	Pathway to Food
Mixed contaminants	Industrial/agricultural	Soil, water	Combined exposure pathways
Synthetic compounds	Consumer products	Air, water	Deposition and ingestion

4.2. Food Chain Transfer and Exposure Pathways

The results indicate that emerging contaminants are transferred through food systems via complex pathways involving environmental uptake and biological accumulation. Contaminants present in soil and water are absorbed by plants or ingested by aquatic organisms, initiating their movement through the food chain. Ben Seghir et al. (2023) emphasize that bioaccumulation and trophic transfer significantly influence contaminant distribution and exposure levels. These processes can result in higher concentrations of contaminants at higher trophic levels, increasing human exposure. In addition, indirect pathways such as ingestion of contaminated water and interaction with food packaging contribute to overall exposure. The variability of these pathways complicates efforts to quantify exposure accurately. These findings highlight the importance of considering multiple exposure routes in risk assessment.

4.3. Toxicological Mechanisms and Biological Effects

The findings show that emerging contaminants affect biological systems through a range of mechanisms that can lead to adverse health outcomes. Microplastics have been associated with physical and chemical interactions in tissues, including inflammation and oxidative stress (Nouri et al., 2025). Lane et al. (2025)

indicate that exposure routes such as ingestion and inhalation contribute to the accumulation of microplastics in the human body. In addition, microplastics can act as carriers for other toxic substances, enhancing their biological impact (Campanale et al., 2020). PFAS are known to interfere with metabolic and immune functions due to their persistence and bioaccumulative properties (Schoeters et al., 2025). These contaminants may also disrupt endocrine systems and contribute to chronic health conditions. The diversity of mechanisms reflects the complexity of evaluating health risks associated with emerging contaminants.

Table 2. Mechanisms and Health Effects of Emerging Contaminants

Contaminant	Mechanism	Biological Impact	Potential Health Outcome
Microplastics	Physical interaction, oxidative stress	Tissue irritation	Inflammation
PFAS	Bioaccumulation, endocrine disruption	Metabolic interference	Chronic disease
Mixed contaminants	Combined toxicity	Synergistic effects	Increased risk
Synthetic compounds	Cellular interaction	Functional disruption	Organ damage

4.4. Exposure Variability and Risk Implications

The results indicate that exposure to emerging contaminants varies significantly depending on environmental conditions, dietary patterns, and geographic location. Liu et al. (2025) highlight that the complexity of modern food systems contributes to diverse exposure scenarios across populations. Melnyk et al. (2025) identify dietary intake as a major pathway for PFAS exposure, particularly

through contaminated food products. In addition, the presence of microplastics in multiple food sources suggests that exposure is continuous and widespread. Differences in consumption habits further influence the level and frequency of exposure. These factors make it difficult to establish standardized risk assessments across populations. The findings emphasize the importance of considering variability in evaluating health risks.

4.5. Interpretation of Key Findings

The synthesis indicates that emerging contaminants represent a complex and evolving challenge in food safety. The interaction between different contaminants, environmental pathways, and biological mechanisms creates multidimensional exposure scenarios. A key insight is that exposure often involves mixtures of contaminants, which may produce combined or synergistic effects. Traditional approaches that focus on individual substances may therefore underestimate actual risks. The findings also highlight the importance of considering both environmental and dietary factors in evaluating exposure. In addition, the persistence of these contaminants contributes to long-term health concerns. These insights support the need for more integrative and adaptive risk assessment frameworks.

5. Discussion

The findings highlight that emerging contaminants represent a fundamentally different challenge compared to traditional food safety concerns, primarily due to their diversity, persistence, and complex pathways of exposure. Unlike single contaminants, these substances often occur simultaneously and interact within

environmental and biological systems, creating multidimensional exposure scenarios. This complexity makes it difficult to isolate individual effects and requires a broader perspective that considers interactions between contaminants. In addition, the continuous release of these substances into the environment contributes to their widespread presence in food systems. The role of modern industrial and consumer practices further amplifies their distribution and persistence. These factors indicate that emerging contaminants are not isolated issues but part of a larger systemic problem. Addressing them therefore requires integrated strategies that span environmental management and food safety regulation.

Another important implication is the limitation of current risk assessment approaches in capturing the real-world impact of emerging contaminants. Traditional frameworks often rely on evaluating individual substances and fixed exposure thresholds, which may not reflect combined and long-term exposure scenarios. The presence of shared mechanisms, such as oxidative stress and metabolic disruption, suggests that different contaminants may contribute to similar health outcomes. Furthermore, variability in dietary habits and environmental conditions introduces additional uncertainty in assessing risk. These challenges highlight the need for more adaptive and integrative assessment models that account for mixture effects and exposure variability. Advancing regulatory frameworks will require continuous incorporation of emerging scientific evidence and interdisciplinary collaboration. Such improvements are essential for ensuring effective protection of public health in increasingly complex food systems.

6. Conclusion

This study demonstrates that emerging contaminants in food systems represent a complex and evolving challenge for food safety and public health. The findings show that substances such as microplastics, PFAS, and other synthetic compounds are widely distributed across environmental and food systems, resulting in continuous human exposure. These contaminants enter food chains through multiple pathways and are influenced by environmental conditions, production practices, and consumption patterns. Their persistence and ability to accumulate in biological systems increase the potential for long-term health effects. This highlights that food safety must be evaluated beyond traditional contaminants and consider newer and less regulated substances. A broader and more integrated perspective is therefore necessary to address these challenges effectively.

From a toxicological perspective, the study emphasizes that emerging contaminants exhibit diverse mechanisms of action that can affect human health in multiple ways. Processes such as oxidative stress, inflammation, and metabolic disruption are commonly associated with exposure to these substances. In addition, the interaction between different contaminants may lead to additive or synergistic effects, increasing the complexity of health outcomes. The variability in exposure levels and individual susceptibility further complicates the assessment of risks. These findings indicate that evaluating health effects requires an understanding of both individual contaminants and their combined interactions. This integrated approach is essential for improving the accuracy of risk assessment models.

In practical terms, the findings highlight the need to advance current food safety and regulatory frameworks to address emerging contaminants more effectively. Traditional approaches that focus on single substances and fixed thresholds may not adequately reflect real-world exposure conditions. Future research should prioritize the development of integrative assessment frameworks that account for mixture effects and environmental variability. Strengthening monitoring systems and improving detection methods are also important for identifying contaminants in food systems. In addition, increased collaboration between scientific disciplines and regulatory bodies will support more effective risk management. These efforts are necessary to ensure that food safety strategies remain relevant in the face of evolving environmental and technological challenges.

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