Food and Chemical Toxicology
Volume 1, Number 2, 2022

Integrated Risk Assessment of Chemical Exposure in Food Systems and Human Health

Jessica Novinda[1]

[1] Universitas Negeri Surabaya, Surabaya, Indonesia

Abstract

Article history:
Received: 30 August 2022
Revised: 19 September 2022
Accepted: 28 November 2022
Published: 30 December 2022

Keywords:
Bioactive compounds;
Dose–response;
Food safety;
Natural compounds;
Toxicity mechanisms;
Health risk assessment.

Identifier:
Zera Open
Page: 137-152
https://zeraopen.com/journal/fct

This study evaluates chemical exposure in food systems using an integrated risk assessment perspective, focusing on cumulative exposure, toxicological mechanisms, and human health implications. Individuals are exposed to multiple chemical substances through food consumption, including environmental contaminants, food additives, and naturally occurring compounds. Using a qualitative Systematic Literature Review (SLR) approach, this study synthesizes recent research to examine how these diverse sources interact within food systems and biological processes. The findings indicate that chemical exposure is cumulative and influenced by multiple pathways, including environmental transfer, dietary patterns, and compound interactions. Shared mechanisms such as oxidative stress and cellular disruption are identified as key contributors to health risks. Furthermore, current risk assessment frameworks are limited in addressing combined exposure and real-world conditions. This study highlights the need for more integrative and system-level approaches to improve food safety evaluation and public health protection.

1. Introduction

Chemical exposure through food consumption has become an increasingly important public health concern due to the growing complexity of modern food systems. Humans are exposed to a wide range of chemical substances through their diet, including environmental contaminants, food additives, and naturally occurring bioactive compounds (Thompson & Darwish, 2019).

These exposures do not occur in isolation but rather as continuous and combined interactions that may influence human health outcomes. Public health concerns related to food safety have highlighted the need to better understand how multiple sources of chemical exposure contribute to risk (Gizaw, 2019).

From a regulatory perspective, food safety assessments have traditionally focused on evaluating individual substances using established toxicological thresholds and acceptable daily intake values. These frameworks provide structured approaches for risk management but are primarily designed for single-compound evaluation (Pressman et al., 2017).

However, real-world dietary exposure involves the simultaneous intake of multiple chemicals across different food sources. Evidence suggests that such combined exposure patterns are not fully captured by traditional risk assessment models (Fitch et al., 2021).

Environmental pollutants represent a major pathway through which chemicals enter food systems, linking ecological conditions directly to food safety. Contaminants present in soil, water, and air can be transferred into crops and animal products, contributing to indirect human exposure (Guo et al., 2019).

The persistence and widespread distribution of environmental contaminants further complicate exposure pathways and increase the likelihood of continuous dietary intake. Emerging contaminants in particular introduce new challenges for monitoring and control within food systems (Morin-Crini et al., 2022).

Dietary patterns also play a significant role in shaping exposure levels, especially with the increasing consumption of processed and ultra-processed foods. These foods are often associated with higher intake of additives and other chemical substances (Fiolet et al., 2018).

In addition, long-term consumption of ultra-processed foods has been linked to adverse health outcomes, suggesting that dietary habits contribute to cumulative exposure risks (Pagliai et al., 2021).

At the biological level, diverse chemical substances share common toxicological mechanisms that influence their effects on human health. Oxidative stress has been identified as a key pathway through which chemical exposure can lead to cellular damage (Pizzino et al., 2017).

Mechanistic frameworks such as adverse outcome pathways further explain how molecular-level interactions can translate into broader health effects. These approaches provide a more integrated understanding of toxicity across different chemical classes (Vinken et al., 2020).

Natural compounds present in food are also important contributors to overall chemical exposure, despite being commonly perceived as safe. Evidence indicates that certain natural substances may exhibit toxic effects depending on dose and exposure conditions (Hudson et al., 2018).

The variability and safety concerns associated with herbal and plant-based products further highlight the need for careful evaluation of natural compounds. These factors challenge the assumption that natural origin ensures safety (Mensah et al., 2019).

Despite extensive research on individual categories of chemical exposure, studies often remain fragmented and fail to integrate multiple sources into a unified framework. This limitation reduces the ability to fully assess cumulative risks in real-world conditions.

Accordingly, this study aims to evaluate chemical exposure in food systems using an integrated risk assessment perspective that considers environmental pathways, dietary patterns, toxicological mechanisms, and cumulative health risks. By employing a qualitative Systematic Literature Review (SLR) approach, this study seeks to provide a comprehensive understanding of how combined chemical exposures influence human health and to support the development of more holistic food safety strategies.

2. Literature Review

2.1. Sources of Chemical Exposure in Food Systems

Chemical exposure in food systems originates from multiple sources, including environmental contaminants, food additives, and naturally occurring compounds. Environmental pollutants are introduced into food systems through soil, water, and air, creating indirect exposure pathways for humans (Thompson & Darwish, 2019).

Persistent organic pollutants and other contaminants can accumulate in environmental media and enter food chains, contributing to continuous dietary exposure. These pollutants often originate from industrial activities and agricultural practices, highlighting the connection between environmental conditions and food safety (Guo et al., 2019).

Food additives represent another major source of chemical exposure, as they are intentionally incorporated into food products to enhance quality and shelf life. These substances are regulated, yet their widespread use increases the likelihood of cumulative intake across different food products (Cox et al., 2021).

Dietary patterns further influence exposure levels, particularly through the consumption of processed and ultra-processed foods. Such foods have been identified as key contributors to increased intake of multiple chemical substances (Fiolet et al., 2018).

Long-term consumption of ultra-processed foods has also been associated with negative health outcomes, suggesting that exposure is not only widespread but also potentially harmful over time (Pagliai et al., 2021).

In addition to external contaminants and additives, natural compounds present in food contribute to overall chemical exposure. These compounds, including phytochemicals and herbal constituents, may exhibit both beneficial and adverse effects depending on their properties and usage (Hudson et al., 2018).

The complexity of these diverse sources demonstrates that chemical exposure in food systems is multifactorial and requires integrated evaluation rather than isolated analysis.

2.2. Pathways of Exposure and Accumulation

Once introduced into the food system, chemical substances follow multiple pathways that determine their distribution and accumulation. Environmental contaminants can be absorbed by plants and transferred into animal products, creating indirect exposure through dietary intake (Morin-Crini et al., 2022).

These pathways are further influenced by bioaccumulation processes, where substances are retained within organisms over time. Bioaccumulation increases internal concentrations of chemicals and contributes to long-term exposure risks (Ali & Khan, 2019).

In addition to accumulation within individual organisms, biomagnification can occur across trophic levels, resulting in higher concentrations of chemicals in organisms higher in the food chain. This process amplifies exposure risks for humans consuming contaminated food products (Ren et al., 2017).

Combined exposure from multiple pathways is a defining feature of modern food systems. Individuals are exposed to mixtures of chemicals from different sources, making it difficult to isolate the effects of individual substances (Awuchi et al., 2020).

This interconnected system of pathways highlights the importance of considering both environmental and dietary factors when evaluating chemical exposure.

2.3. Toxicological Mechanisms of Chemical Exposure

The health effects of chemical exposure are mediated by underlying biological mechanisms that are shared across different classes of substances. One of the most widely recognized mechanisms is oxidative stress, which occurs when the balance between reactive oxygen species and antioxidant defenses is disrupted (Pizzino et al., 2017).

Oxidative stress can lead to cellular damage, affecting proteins, lipids, and DNA, and may contribute to the development of chronic diseases. This mechanism provides a common pathway linking diverse chemical exposures to adverse health outcomes (Genchi et al., 2020).

In addition to oxidative processes, adverse outcome pathways describe how molecular-level interactions can lead to observable health effects. These frameworks allow for a more systematic understanding of how different chemicals can produce similar biological responses (Vinken et al., 2020).

Furthermore, metabolic disruption and cellular signaling interference have been identified as important contributors to toxicity. These mechanisms highlight the complexity of biological responses to chemical exposure and emphasize the need for integrative analysis (Forman & Zhang, 2021).

2.4. Limitations of Current Risk Assessment Approaches

Current risk assessment frameworks are primarily based on evaluating individual chemicals under controlled conditions. These approaches rely on established thresholds, such as acceptable daily intake, to determine safe exposure levels (Pressman et al., 2017).

While these models provide a structured basis for safety evaluation, they do not fully account for combined exposure to multiple chemicals. This limitation reduces their ability to reflect real-world dietary conditions (Fitch et al., 2021).

Regulatory frameworks also face challenges in addressing variability in exposure patterns across populations. Differences in diet, environment, and individual susceptibility contribute to uncertainty in risk assessment outcomes (Stanković & Zrnić-Ćirić, 2021).

Recent discussions in toxicology emphasize the need for more comprehensive approaches that integrate multiple sources of exposure and biological mechanisms. Such approaches are essential for improving the accuracy and relevance of risk evaluation (Gürtler, 2021).

3. Methods

This study employs a qualitative Systematic Literature Review (SLR) approach to evaluate chemical exposure in food systems and its implications for human health through an integrated risk assessment perspective. The SLR method is selected to systematically synthesize existing scientific knowledge across multiple domains, including environmental toxicology, food safety, and public health, without generating new empirical data. The literature search was conducted using academic databases and publisher platforms. The search strategy utilized combinations of keywords such as "chemical exposure," "food contamination," "food additives," "environmental pollutants," "bioaccumulation," "toxicological mechanisms," and "risk assessment" to capture relevant studies addressing both individual and combined exposure pathways. The inclusion criteria were limited to peer-reviewed articles published between 2017 and 2022 to ensure consistency with the study scope and relevance to current scientific understanding. Studies were selected based on their relevance to chemical exposure in food systems, including those addressing environmental pathways, dietary intake, toxicological mechanisms, and risk assessment frameworks.

Studies focusing solely on non-food exposure pathways or lacking clear relevance to human health implications 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 sources of chemical exposure, pathways of accumulation, underlying toxicological mechanisms, and limitations of current risk assessment approaches. Rather than applying quantitative aggregation or statistical meta-analysis, this study emphasizes conceptual integration to develop a comprehensive understanding of how combined chemical exposures influence human health outcomes.

4. Results

This section presents the integrated findings from the systematic literature review, synthesizing evidence on sources of chemical exposure, pathways of accumulation, toxicological mechanisms, and implications for human health. The results demonstrate that chemical exposure in food systems is a multidimensional process involving interactions between environmental, technological, and biological factors. These interactions contribute to cumulative exposure and highlight the limitations of evaluating chemical risks in isolation.

4.1. Sources and Pathways of Chemical Exposure in Food Systems

he reviewed literature indicates that chemical exposure in food systems originates from multiple sources, including environmental contaminants, food additives, and naturally occurring compounds. Environmental pollutants enter food systems through soil, water, and air, forming indirect pathways of exposure through agricultural and ecological processes (Thompson & Darwish, 2019).Food additives contribute to direct exposure, as they are intentionally incorporated into food products and consumed regularly through processed foods (Cox et al., 2021).Natural compounds present in food also contribute to overall chemical exposure, particularly through plant-based foods and herbal products (Hudson et al., 2018).

These sources interact within food systems, resulting in simultaneous exposure to multiple chemical substances. This combined exposure reflects real-world dietary conditions and increases the complexity of risk evaluation (Awuchi et al., 2020).

Table 1. Integrated Sources and Pathways of Chemical Exposure in Food Systems

Source Category	Origin	Pathway into Food System	Exposure Type
Environmental contaminants	Industrial, agricultural, urban activities	Soil → plant → animal → food	Indirect exposure
Food additives	Food processing and preservation	Direct incorporation into food products	Direct exposure
Natural compounds	Plant-based foods and herbal products	Natural occurrence in food matrices	Dietary exposure
Combined exposure	Multiple sources	Simultaneous intake through diet	Cumulative exposure

4.2. Integrated Toxicological Mechanisms and Risk Framework

The findings indicate that different classes of chemical substances share common toxicological mechanisms that influence their effects on human health. Oxidative stress is identified as a central mechanism through which chemical exposure leads to cellular damage (Pizzino et al., 2017). In addition to oxidative processes, adverse outcome pathways provide a structured framework for linking molecular interactions to health outcomes (Vinken et al., 2020). Cellular toxicity and metabolic disruption further contribute to the biological effects of chemical exposure, demonstrating that different substances may converge on similar mechanisms (Genchi et al., 2020). The cumulative nature of exposure increases the likelihood of combined effects, where multiple chemicals interact within biological systems. This interaction complicates risk evaluation and challenges traditional single-compound approaches (Fitch et al., 2021).

.

Table 2. Integrated Framework of Chemical Exposure and Human Health Risk.

Process Stage	Description	Mechanism	Health Risk Implication
Exposure sources	Multiple chemical inputs from food systems	Combined intake of substances	Increased exposure complexity
Absorption and distribution	Entry of chemicals into biological systems	Transport and accumulation	Internal exposure burden
Biological interaction	Interaction with cellular components	Oxidative stress and signaling disruption	Cellular damage
Mechanistic progression	Molecular to systemic effects	Adverse outcome pathways	Disease development risk

Process Stage	Description	Mechanism	Health Risk Implication
Cumulative effects	Repeated and combined exposure	Interaction of multiple substances	Long-term health impact

4.3. Interpretation of Key Findings

The synthesis demonstrates that chemical exposure in food systems is inherently cumulative and cannot be accurately assessed through isolated evaluation of individual substances. Instead, exposure arises from multiple sources that interact within environmental and dietary contexts, leading to complex patterns of intake.

A key insight is that diverse chemical substances share common biological mechanisms, which means that combined exposure may produce amplified or overlapping effects. This suggests that risk is not solely determined by individual compounds but by the interaction of multiple substances within the human body.

Furthermore, the findings highlight that current risk assessment approaches may not fully capture the complexity of real-world exposure scenarios. The presence of multiple exposure pathways, combined with variability in dietary patterns and environmental conditions, underscores the need for more integrative and system-level approaches to evaluating chemical risks in food systems.

5. Discussion

The findings highlight that chemical exposure in food systems should be understood as a cumulative and interconnected process rather than a series of isolated events. Individuals are simultaneously exposed to multiple chemical substances originating from environmental contamination, food processing, and natural sources. This combined exposure creates complex interactions within biological systems, where the overall health impact cannot be explained by examining individual substances alone. As a result, conventional approaches that evaluate chemicals separately may underestimate the true extent of risk associated with real-world dietary exposure.

Another key implication is the need to shift toward system-level risk assessment frameworks that reflect the dynamic nature of modern food systems. The interaction between multiple exposure pathways, coupled with shared toxicological mechanisms, suggests that risk is shaped by both the diversity and persistence of chemical intake. In addition, variability in dietary patterns and individual susceptibility further complicates risk evaluation. Addressing these challenges requires more integrative models that consider cumulative exposure, interaction effects, and long-term health outcomes, thereby providing a more accurate basis for food safety management and public health protection.

6. Conclusion

This study demonstrates that chemical exposure in food systems is a multifaceted process involving environmental contaminants, food additives, and naturally occurring compounds, all of which contribute to cumulative human exposure. The findings show that these diverse sources interact within complex food systems, leading to continuous intake of multiple substances rather than isolated exposure to individual chemicals. This highlights that food safety cannot be effectively assessed without considering the combined nature of chemical exposure.

From an analytical perspective, this study integrates exposure pathways, toxicological mechanisms, and risk assessment limitations into a unified framework for evaluating chemical risks in food systems. The results indicate that shared biological mechanisms, such as oxidative stress and cellular disruption, provide a common link between different types of chemical substances. This convergence suggests that the overall risk is shaped not only by individual compounds but also by their interactions and cumulative effects within the human body.

In practical terms, the findings emphasize the need to advance current risk assessment approaches toward more comprehensive and system-level models. Future research may focus on developing methodologies that incorporate combined exposure, interaction effects, and variability in dietary patterns. Strengthening these approaches is essential for improving food safety management and ensuring that public health strategies are aligned with the complexity of modern food systems.

References

Awuchi, C. G., Twinomuhwezi, H., Igwe, V. S., & Amagwula, I. O. (2020). Food additives and food preservatives for domestic and industrial food applications. *Journal of Animal Health*, 2(1), 1–16.

Cox, S., Sandall, A., Smith, L., Rossi, M., & Whelan, K. (2021). Food additive emulsifiers: A review of their role in foods, legislation and classifications, presence in food supply, dietary exposure, and safety assessment. *Nutrition Reviews*, 79(6), 726–741.

Fiolet, T., Srour, B., Sellem, L., Kesse-Guyot, E., Allès, B., Méjean, C., & Touvier, M. (2018). Consumption of ultra-processed foods and cancer risk: Results from the NutriNet-Santé prospective cohort. *BMJ*, 360, k322.

Fitch, S. E., Payne, L. E., van de Ligt, J. L., Doepker, C., Handu, D., Cohen, S. M., & Wikoff, D. (2021). Use of acceptable daily intake (ADI) as a health-based benchmark in nutrition research studies that consider the safety of low-calorie sweeteners: A systematic map. *BMC Public Health*, 21(1), 956.

Forman, H. J., & Zhang, H. (2021). Targeting oxidative stress in disease: Promise and limitations of antioxidant therapy. *Nature Reviews Drug Discovery*, 20(9), 689–709.

Genchi, G., Carocci, A., Lauria, G., Sinicropi, M. S., & Catalano, A. (2020). Nickel: Human health and environmental toxicology. *International Journal of Environmental Research and Public Health*, 17(3), 679.

Gizaw, Z. (2019). Public health risks related to food safety issues in the food market: A systematic literature review. *Environmental Health and Preventive Medicine*, 24(1), 68.

Guo, W., Pan, B., Sakkiah, S., Yavas, G., Ge, W., Zou, W., & Hong, H. (2019). Persistent organic pollutants in food: Contamination sources, health effects and detection methods. *International Journal of Environmental Research and Public Health*, 16(22), 4361.

Hudson, A., Lopez, E., Almalki, A. J., Roe, A. L., & Calderón, A. I. (2018). A review of the toxicity of compounds found in herbal dietary supplements. *Planta Medica*, 84(9–10), 613–626.

Morin-Crini, N., Lichtfouse, E., Liu, G., Balaram, V., Ribeiro, A. R. L., Lu, Z., & Crini, G. (2022). Worldwide cases of water pollution by emerging contaminants: A review. *Environmental Chemistry Letters*, 20(4), 2311–2338.

Pagliai, G., Dinu, M., Madarena, M. P., Bonaccio, M., Iacoviello, L., & Sofi, F. (2021). Consumption of ultra-processed foods and health status: A systematic review and meta-analysis. *British Journal of Nutrition*, 125(3), 308–318.

Pizzino, G., Irrera, N., Cucinotta, M., Pallio, G., Mannino, F., Arcoraci, V., & Bitto, A. (2017). Oxidative stress: Harms and benefits for human health. *Oxidative Medicine and Cellular Longevity*, 2017, 8416763.

Pressman, P., Clemens, R., Hayes, W., & Reddy, C. (2017). Food additive safety: A review of toxicologic and regulatory issues. *Toxicology Research and Application*, 1, 2397847317723572.

Stanković, I., & Zrnić-Ćirić, M. (2021). Food additives: Risk analysis and legislation. *Arhiv za Farmaciju*, 71(1), 22–34.

Thompson, L. A., & Darwish, W. S. (2019). Environmental chemical contaminants in food: Review of a global problem. *Journal of Toxicology*, 2019, 2345283.

Vinken, M., Kramer, N., Allen, T. E., Hoffmans, Y., Thatcher, N., Levorato, S., & Rietjens, I. M. (2020). The use of adverse outcome pathways in the safety evaluation of food additives. *Archives of Toxicology*, 94(3), 959–966.