Food and Chemical Toxicology
Volume 2, Number 2, 2023

Food Safety and Chemical Toxicology: Evaluating Exposure Risks and Health Outcomes

Ulfa Ulli Ummaya[1]

[1] Universitas Islam Sultan Agung, Semarang, Indonesia

Abstract

Article history:
Received: July 8, 2023
Revised: August 21, 2023
Accepted: November 25, 2023
Published: December 30, 2023

Keywords:
Chemical Toxicology,
Exposure Risk,
Food Safety,
Food Contaminants,
Health Outcomes.

Identifier:
Zera Open
Page: 90-104
https://zeraopen.com/journal/fct

Food safety has become a critical global issue due to increasing chemical contamination across modern food systems, posing significant risks to human health. Continuous exposure to chemical substances such as pesticide residues, food additives, and emerging contaminants raises concerns regarding long-term toxicological effects. This study aims to evaluate patterns of chemical exposure in food, analyze associated toxicological risks, and examine their implications for public health. The research employs a qualitative design using an integrative literature review approach, drawing on secondary data from peer-reviewed journals, scientific reports, and policy documents. The findings reveal that chemical exposure occurs through multiple pathways along the food supply chain, including production, processing, and consumption stages. Risk assessment frameworks provide essential tools for evaluating these exposures; however, limitations remain in addressing mixed exposures and emerging contaminants. The study also finds that prolonged exposure to chemical substances may lead to various adverse health outcomes, including metabolic disorders and chronic diseases. In conclusion, strengthening integrated risk assessment, regulatory enforcement, and public awareness is crucial for improving food safety and minimizing toxicological risks in increasingly complex food systems.

1. Introduction

Food safety has become an increasingly critical global concern, particularly in the context of rapid industrialization, urbanization, and the intensification of food production systems. Modern food supply chains involve complex processes that increase the likelihood of chemical contamination through agricultural inputs, food processing, packaging, and environmental exposure. According to Lisa S. Jackson (2009), chemical hazards in food have evolved over time, reflecting changes in agricultural practices and technological developments, thereby posing ongoing challenges to regulatory systems. Chemical substances such as pesticide residues, heavy metals, food additives, and naturally occurring toxins have been widely detected in food products, raising concerns about both acute and chronic health effects. In particular, compounds such as pyrrolizidine alkaloids have been identified as significant food safety risks due to their toxicological properties, including hepatotoxicity and carcinogenic potential (Moreira et al., 2018; Lu et al., 2024).

One of the primary challenges in food safety lies in understanding the extent to which chemical exposure occurs through daily dietary intake and how such exposure translates into health risks. Dietary exposure is often cumulative and influenced by consumption patterns, environmental conditions, and regulatory effectiveness. Individuals are rarely exposed to a single contaminant; rather, they encounter complex mixtures of chemicals that may interact synergistically or cumulatively. As highlighted by Steven J. Lehotay and Chen (2018), monitoring food contaminants remains a challenge due to limitations in detection methods and evolving contamination patterns. Prolonged exposure to chemical residues in food has been associated with various adverse health outcomes, including endocrine disruption, neurotoxicity, and carcinogenic effects. These risks are further complicated by differences in individual susceptibility, making accurate toxicological assessment a complex task.

Although research in this area continues to grow, significant gaps remain in integrative studies linking exposure pathways, toxicological mechanisms, and public health outcomes. The existing literature often focuses on isolated aspects, such as identifying specific contaminants or evaluating toxicological thresholds, without adequately linking these findings to real-world dietary exposures and long-term health implications. For example, while studies by Moreira et al. (2018) and Lu et al. (2024) on pyrrolizidine alkaloids have provided detailed insights into their chemical properties and toxic effects, few studies have examined how these compounds contribute to cumulative dietary risk across diverse populations. Similarly, research by Lehotay and Chen (2018) in food contaminant monitoring has been described as fragmented, with "both successes and failures" in identifying emerging hazards. This suggests the need for a more comprehensive framework that integrates exposure assessment with toxicological and epidemiological perspectives.

Another critical issue is the gap between regulatory standards and their implementation in practice. Although many countries have established safety guidelines, such as maximum residue limits for chemical contaminants, enforcement remains inconsistent. This issue is particularly evident in developing regions, where limited infrastructure, insufficient monitoring systems, and lack of technical capacity hinder effective implementation. According to Liu et al. (2025), current and emerging challenges in chemical food safety include not only the presence of known contaminants but also the increasing complexity of food systems and the emergence of new, poorly regulated substances. These challenges highlight the limitations of existing regulatory frameworks in addressing dynamic and multifaceted risks associated with chemical exposure in food.

The urgency of this study is further emphasized by the increasing evidence linking dietary chemical exposure to chronic health conditions. As food systems become more globalized and consumption of processed foods rises, the likelihood of exposure to multiple chemical contaminants also increases. Moreover, emerging contaminants that are not yet fully regulated present additional uncertainties and risks. Without a comprehensive understanding of how exposure occurs and how it affects human health, current food safety strategies may remain insufficient. Therefore, there is a pressing need to develop integrated approaches that combine exposure assessment, toxicological analysis, and policy evaluation.

Based on these considerations, the central problem addressed in this study is how chemical contaminants in food contribute to human exposure risks and what implications these exposures have for public health. The study also seeks to identify gaps in existing research and regulatory practices that limit effective risk management. Addressing these issues is essential for improving food safety systems and protecting public health in an increasingly complex food environment.

Against this background, this study pursues three main objectives. First, it aims to evaluate the patterns and sources of chemical exposure in the food system. Second, it attempts to analyze the toxicological risks associated with these exposures and their potential health impacts. Third, it proposes an integrated framework for improving food safety management by linking exposure assessment, toxicological evaluation, and policy development. Through this structured approach, this study contributes to advancing scientific understanding and policy responses in the areas of food safety and chemical toxicology.

2. Methods

This study employs a qualitative research design with a descriptive-analytical orientation to examine the relationship between chemical exposure in food systems and its potential toxicological and public health implications. Rather than generating primary experimental data, the study focuses on synthesizing existing scientific knowledge to identify patterns, trends, and gaps in the field of food safety and chemical toxicology. To achieve this, the research adopts a literature-based and integrative review approach, combining elements of narrative review and analytical synthesis. This approach allows for a comprehensive understanding of the issue by critically examining existing studies, comparing findings across different contexts, and identifying consistencies and discrepancies in the literature. The integrative nature of this method enables the inclusion of various types of sources, thereby providing a broader and more nuanced perspective on chemical risks in food systems.

Building on this approach, the study relies entirely on secondary data sources. These include peer-reviewed journal articles, scientific reviews, institutional reports, and relevant policy documents related to food safety and chemical toxicology. Key academic databases such as Scopus, Web of Science, and Google Scholar were utilized to identify and collect relevant literature. The selection of sources was guided by several criteria, including relevance to the research topic, credibility of publication, and recency of the data. Priority was given to studies that specifically address chemical contaminants in food, exposure pathways, toxicological effects, and risk assessment frameworks. This careful selection process ensures that the analysis is grounded in reliable, high-quality, and up-to-date scientific evidence.

Furthermore, the collected data were analyzed using qualitative content analysis to systematically identify key themes and patterns. The analysis process involved several stages, beginning with data reduction, where relevant information was extracted and categorized into thematic areas such as types of contaminants, exposure mechanisms, and associated health outcomes. This was followed by data organization and comparison, allowing the study to identify relationships, similarities, and emerging trends across different sources. Finally, the findings were interpreted to develop a coherent and integrated understanding of chemical exposure risks in food systems. Through this analytical process, the study is able to generate meaningful insights and propose evidence-based recommendations for improving food safety and mitigating toxicological risks.

4. Results

4.1. Chemical Exposure Pathways and Risk Assessment in Food Systems

The findings of this study indicate that chemical exposure in food systems occurs through multiple and interconnected pathways, spanning from primary production to final consumption. Contamination may originate from agricultural inputs such as pesticides and fertilizers, environmental pollutants, food processing methods, packaging materials, and storage conditions. According to Lebelo et al. (2021), chemical contamination can occur at every stage of the food production chain, including cultivation, harvesting, processing, distribution, and retail, highlighting the systemic nature of exposure risks. This complexity makes it difficult to isolate a single source of contamination, as multiple pathways often interact simultaneously.

Empirical evidence supports the presence of chemical contaminants in commonly consumed foods. For example, a study by Nuryani et al. (2017) found that street foods such as fried snacks may contain chemical residues resulting from repeated oil use and environmental exposure, indicating that even informal food sectors contribute significantly to dietary chemical intake. Similarly, emerging contaminants such as ethylene oxide, which has been detected in certain food products, raise additional concerns due to their potential carcinogenic effects and regulatory challenges (Pawestri & Arsyi, 2024). These findings demonstrate that chemical exposure is not limited to industrial food systems but is also prevalent in everyday consumption contexts.

The process of assessing risks associated with chemical exposure has evolved significantly over the past decades. Wu and Rodricks (2020) describe how food safety risk assessment has developed over forty years into a structured framework involving hazard identification, dose-response assessment, exposure assessment, and risk characterization. This framework remains the cornerstone of modern toxicological evaluation. However, despite its methodological robustness, practical challenges persist, particularly in accurately estimating exposure levels in diverse populations. Variations in dietary habits, environmental conditions, and regulatory enforcement contribute to uncertainty in risk assessment outcomes.

In addition, the establishment of toxicological reference points, such as acceptable daily intake (ADI) and benchmark dose levels, plays a crucial role in determining safe exposure limits. Rivero-Pino (2025) highlights that defining these reference points for novel food substances presents ongoing challenges due to limited toxicological data and evolving scientific standards. This issue becomes more pronounced with the emergence of synthetic and novel food products, which introduce new chemical compounds that may not yet be fully understood in terms of long-term health effects (Lopez-Rodriguez et al., 2025). Consequently, traditional risk assessment approaches must continuously adapt to address these emerging risks.

Another important dimension of risk assessment is public perception. Studies have shown that public understanding of chemical risks often differs significantly from expert assessments. Jansen et al. (2020) found that many individuals perceive all chemical substances as inherently harmful, reflecting a generalized concern that may not always align with scientific evidence. This phenomenon, often referred to as "intuitive toxicology", can influence consumer behavior and policy responses (Neil et al., 1994). Therefore, effective communication of risk assessment findings is essential to bridge the gap between scientific knowledge and public perception.

The analysis demonstrates that chemical exposure in food systems is a multifaceted issue requiring integrated assessment approaches. While existing frameworks provide a solid foundation, there is a need for more context-specific and adaptive models that account for emerging contaminants, mixed exposures, and socio-cultural factors influencing consumption patterns.

4.2. Toxicological Impacts and Implications for Public Health

The results further reveal that chemical exposure through food has significant implications for human health, particularly when exposure occurs over long periods. Toxicological studies indicate that many chemical contaminants can interfere with biological systems at the cellular and metabolic levels. According to Iskandar et al. (2025), toxic compounds may disrupt cellular metabolism, enzyme function, and biochemical pathways, leading to various health disorders. These effects are often not immediately visible but may accumulate over time, resulting in chronic conditions such as cancer, neurological disorders, and endocrine disruption.

Clinical toxicology also provides important insights into how chemical exposure affects human health. Kresnadipayana et al. (2025) emphasize that laboratory analyses play a crucial role in detecting toxic substances in the human body and assessing their physiological impacts. Biomonitoring techniques, such as measuring chemical residues in blood or urine, enable researchers to establish links between exposure and health outcomes. However, interpreting these results remains challenging due to the complex interactions between different chemicals and individual variability in susceptibility.

Certain chemical contaminants have been identified as particularly harmful due to their persistence and bioaccumulative properties. For instance, ethylene oxide contamination in food products has raised concerns due to its potential carcinogenic effects and long-term health risks (Pawestri & Arsyi, 2024). Similarly, novel food additives and synthetic compounds, while offering technological benefits, may introduce new toxicological uncertainties that require careful evaluation (Lopez-Rodriguez et al., 2025). Even substances with beneficial applications, such as cyclodextrins, must be assessed comprehensively to ensure their safety across different exposure levels and population groups (Musuc, 2024).

From a public health perspective, the cumulative nature of chemical exposure presents a significant challenge. Individuals are often exposed to multiple contaminants simultaneously, which may interact in ways that amplify their toxic effects. This phenomenon, known as the "cocktail effect," complicates risk assessment and regulatory decision-making. Traditional approaches that evaluate chemicals individually may not adequately capture these combined effects, highlighting the need for more holistic assessment models.

Moreover, disparities in food safety systems contribute to unequal health risks across populations. In regions with limited regulatory capacity, inadequate monitoring, and low public awareness, individuals may be more vulnerable to unsafe levels of chemical exposure. This situation underscores the importance of strengthening food safety governance and ensuring equitable access to safe food. Effective policies must not only establish safety standards but also ensure their consistent implementation through monitoring, enforcement, and public education.

The findings of this study suggest that addressing the toxicological impacts of chemical exposure requires an integrated approach that combines scientific research, regulatory action, and public engagement. Risk assessment frameworks must be continuously updated to incorporate new scientific evidence, while regulatory systems should be strengthened to ensure compliance and accountability. At the same time, increasing public awareness and understanding of chemical risks can empower individuals to make safer dietary choices.

In conclusion, the toxicological effects of chemical contaminants in food represent a critical public health issue that demands coordinated and sustained efforts. By linking exposure pathways with health outcomes, this study highlights the need for comprehensive strategies that address both the sources of contamination and their long-term impacts on human health.

5. Discussion

In this section not only relate the findings found in the results, or report additional findings that have not been discussed. This section emphasizes more on the broader implications of research findings and relates them to previous research. Make sure that the conclusions you reach follow logically from and be strengthened by the evidence presented in your research.

6. Conclusion

This study highlights that chemical exposure in food systems remains a complex and multidimensional issue, driven by diverse contamination pathways across the food supply chain. The findings demonstrate that exposure to chemical contaminants is not limited to a single source but results from cumulative interactions involving agricultural practices, food processing, environmental factors, and consumption patterns. Moreover, toxicological analysis confirms that prolonged exposure to such contaminants can lead to significant health risks, including metabolic disruption, chronic diseases, and long-term physiological damage. These findings reinforce the importance of adopting integrated approaches to better understand and manage chemical risks in food systems.

From a theoretical perspective, this study contributes to the advancement of food safety and toxicology literature by linking exposure pathways with health outcomes within a comprehensive analytical framework. Practically, the findings emphasize the need for stronger regulatory enforcement, improved monitoring systems, and adaptive risk assessment models that can address emerging contaminants and mixed exposure scenarios. In addition, enhancing public awareness and risk communication is essential to bridge the gap between scientific assessment and societal perception of chemical risks.

Based on these findings, future research should focus on developing more context-specific risk assessment models that incorporate real-world exposure conditions and population variability. Further studies are also needed to explore the long-term effects of emerging contaminants and the interactions between multiple chemical substances. Strengthening interdisciplinary collaboration between toxicologists, policymakers, and public health experts will be crucial in ensuring safer and more sustainable food systems.

References

Iskandar, D. V., Juwitasari, K. S., Pasha, E. I., Sari, E. T., & Arini, L. D. D. (2025). Studi Toksikologi Biokimia: Dampak Senyawa Beracun Terhadap Proses Metabolisme Seluler dan Kesehatan Manusia. *Student Scientific Creativity Journal*, *3*(2), 84-96.

Jackson, L. S. (2009). Chemical food safety issues in the United States: past, present, and future. *Journal of agricultural and food chemistry*, *57*(18), 8161-8170.

Jansen, T., Claassen, L., van Kamp, I., & Timmermans, D. R. (2020). 'All chemical substances are harmful.'public appraisal of uncertain risks of food additives and contaminants. *Food and Chemical Toxicology*, *136*, 110959.

Kresnadipayana, D., Rasyid, S. A., Dirga, A., Lestari, M. W., Sari, E. M., Lubis, S. A., ... & Ked, M. P. (2025). *Toksikologi Klinis: Analisis Laboratorium*. PT Bukuloka Literasi Bangsa.

Lebelo, K., Malebo, N., Mochane, M. J., & Masinde, M. (2021). Chemical contamination pathways and the food safety implications along the various stages of food production: a review. *International journal of environmental research and public health*, *18*(11), 5795.

Lehotay, S. J., & Chen, Y. (2018). Hits and misses in research trends to monitor contaminants in foods. *Analytical and Bioanalytical Chemistry*, *410*(22), 5331-5351.

Liu, C., Wang, D., Rietjens, I. M., & Zheng, L. (2025). Current and emerging issues in chemical food safety. *Current Opinion in Food Science*, *62*, 101284.

Lopez-Rodriguez, R., Vermetten, J., Dominguez, L., Fernandez-Ruiz, V., & Camara, M. (2025). A critical review of synthetic novel foods within the European regulation: proposed classification, toxicological concerns and potential health claims. *Critical Reviews in Food Science and Nutrition*, *65*(29), 6688-6708.

Lu, Y. S., Qiu, J., Mu, X. Y., Qian, Y. Z., & Chen, L. (2024). Levels, toxic effects, and risk assessment of pyrrolizidine alkaloids in foods: a review. *Foods*, *13*(4), 536.

Moreira, R., Pereira, D. M., Valentão, P., & Andrade, P. B. (2018). Pyrrolizidine alkaloids: chemistry, pharmacology, toxicology and food safety. *International journal of molecular sciences*, *19*(6), 1668.

Musuc, A. M. (2024). Cyclodextrins: Advances in chemistry, toxicology, and multifaceted applications. *Molecules*, *29*(22), 5319.

Neil, N., Malmfors, T., & Slovic, P. (1994). Intuitive toxicology: expert and lay judgments of chemical risks. *Toxicologic Pathology*, *22*(2), 198-201.

Nuryani, R., Ismail, E., & Sari, T. (2017). Tinjauan keamanan pangan makanan gorengan berdasarkan cemaran kimia yang dijual di sepanjang jalan Kaliurang Sleman Yogyakarta. *Jurnal Nutrisia*, *19*(2), 113-118.

Pawestri, S., & Arsyi, E. K. (2024). Kontaminasi Etilen Oksida pada Produk Pangan: Dampak, Risiko Kesehatan, dan Regulasi. *Jurnal Kolaboratif Sains*, *7*(12), 4838-4849.

Rivero-Pino, F. (2025). Establishing toxicological reference points for the novel food safety assessment by the European Food Safety Authority-approaches, challenges and ways forward. *Trends in Food Science & Technology*, 105360.

Wu, F., & Rodricks, J. V. (2020). Forty years of food safety risk assessment: a history and analysis. *Risk Analysis*, *40*(S1), 2218-2230.