Food and Chemical Toxicology
Volume 4, Number 1, 2025

Heavy Metal Contamination in Food and Its Health Implications: A Food Toxicology Perspective

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Article history:
Received: January 5, 2025
Revised: February 25, 2025
Accepted: April 14, 2025
Published: June 30, 2025

Keywords:
Bioaccumulation,
Food safety,
Food toxicology,
Heavy metals,
Toxicity.

Identifier:
Zero Open
Page: 62-76
https://zeraopen.com/journal/fct

Abstract

Heavy metal contamination in food is a major global food safety issue that poses potential health risks to humans. Heavy metals such as lead, mercury, cadmium, and chromium can enter the food system through various environmental pathways, including soil and water that have been contaminated by anthropogenic activities. This study aims to comprehensively examine aspects of food toxicology related to heavy metal contamination, including sources of contamination, mechanisms of bioaccumulation, and their impact on human health. The method used was a literature review analyzing various relevant scientific publications from the past five years. The results of the study indicate that heavy metals can accumulate in the food chain through the processes of bioaccumulation and biomagnification, thereby increasing the risk of exposure to humans as end consumers. Long-term exposure can cause various health disorders, such as organ damage, nervous system disorders, and chronic diseases. Therefore, comprehensive control efforts are needed through environmental management, improved food safety, and public education to minimize the risk of heavy metal exposure in a sustainable and effective manner.

1. Introduction

Food is a basic human need that has an important role in maintaining survival, health, and welfare. In addition to being a source of energy and nutrition, food also plays a role in supporting the growth, development, and physiological functions of the body. However, along with the increase in industrial activities, urbanization, and intensification of agriculture, the issue of *food safety* has become increasingly complex. One of the main problems of global concern is the contamination of foodstuffs by harmful substances, especially heavy metals, which has the potential to pose health risks to humans (Fu & Xi, 2020; Rakib et al., 2021).

Heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), and chromium (Cr) are toxic contaminants that are persistent and cannot degrade naturally in the environment. The presence of heavy metals in the environment generally comes from various anthropogenic activities, such as industry, mining, fertilizer and pesticide use, and domestic waste. These contaminants can contaminate environmental media such as soil and water, which then play a major role as a major source of heavy metals entering the food system (Sall et al., 2020; Karaouzas et al., 2021). In this context, food serves not only as a source of nutrition, but also as the main route of exposure of toxic substances into the human body.

The entry of heavy metals into food occurs through bioaccumulation and biomagnification mechanisms in the food chain. Organisms such as plants, fish, and farm animals can absorb heavy metals from the surrounding environment and store them in body tissues. This process leads to an increase in the concentration of heavy metals at higher trophic levels. When humans consume contaminated food, these

heavy metals can accumulate in the body and cause toxic effects in the long term (Islam et al., 2023; Edo et al., 2024). This phenomenon is the main focus of the study *of food toxicology*, which examines the relationship between food contamination and its impact on human health.

From a toxicological perspective, heavy metals are known to have adverse effects both acutely and chronically. Short-term exposure can cause disorders such as nausea, vomiting, and gastrointestinal irritation. Meanwhile, long-term exposure can result in damage to vital organs, such as the liver, kidneys, and nervous system. In addition, heavy metals can also interfere with enzyme activity, trigger oxidative stress, and play a role in the development of chronic diseases, including cancer and reproductive system disorders (Genchi et al., 2020; García-Torra et al., 2021). This impact shows that heavy metal contamination in food is a serious issue that requires special attention from various disciplines.

In recent years, various studies have shown that exposure to heavy metals through food consumption is becoming increasingly significant. Various types of foodstuffs, such as fishery products, vegetables, and other agricultural products, are reported to contain heavy metals in certain concentrations, even in some cases exceeding recommended safe limits. This condition shows that food contamination is not only local, but has become a global problem that requires an integrated approach in its management (Scutaraşu & Trincă, 2023). Therefore, monitoring and evaluation of food safety is very important to protect public health.

Although various studies have been conducted on heavy metal contamination in the environment and its impact on health, studies that comprehensively integrate

environmental, food, and toxicology aspects are still developing. Some studies tend to focus on environmental aspects, while others focus more on health effects without considering the pathways of exposure through food as a whole. This gap demonstrates the need for a more holistic approach in understanding the relationship between environmental contamination, accumulation in foodstuffs, and the health risks it poses.

Based on this background, this study aims to comprehensively examine aspects of *food toxicology* related to heavy metal contamination in food, including the source of contamination, the mechanism of entry into the food chain, and its impact on human health. This study is expected to contribute to the development of risk management strategies, improve food safety, and become the basis for further research in the field of food toxicology.

2. Literature Review

2.1 Heavy Metal Contamination in Food and Its Sources

Heavy metal contamination in food is one of the major issues in global food security that has continued to receive attention in recent years. Heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), and chromium (Cr) can enter food through various environmental pathways, especially through soil, water, and air that have been contaminated due to anthropogenic activities. The main sources of this contamination include industrial activities, mining, the use of fertilizers and pesticides in agriculture, as well as poorly managed domestic waste disposal (Sall et al., 2020; Karaouzas et al., 2021).

In agricultural systems, the intensive use of chemical fertilizers and pesticides can increase the accumulation of heavy metals in the soil, which is then absorbed by food crops. These plants are one of the main routes for the entry of heavy metals into the human food chain. In addition, polluted water sources also contribute to the contamination of fishery products, such as fish and shellfish, which are known to have a high ability to accumulate heavy metals in their body tissues (Rakib et al., 2021). This shows that food contamination does not only occur in one type of food, but can involve a variety of commodities that are widely consumed.

Furthermore, the distribution of heavy metals in food is influenced by various factors, including environmental conditions, types of organisms, as well as trophic levels in the food chain. Heavy metals are persistent and cannot be biodegraded, so they tend to accumulate over long periods of time. This accumulation can increase the concentration of heavy metals in food to levels that are potentially harmful to human health (Fu & Xi, 2020). Therefore, understanding the sources and pathways of heavy metal contamination in food is very important as a basis for risk control and mitigation efforts.

2.2 Bioaccumulation and Toxicological Impact of Heavy Metals on Health

Bioaccumulation and biomagnification are the main mechanisms that lead to an increase in the concentration of heavy metals in the food chain. Bioaccumulation occurs when an organism absorbs heavy metals from the environment faster than the body's ability to eliminate them. Meanwhile, biomagnification refers to increasing the concentration of heavy metals at each higher trophic level in the food chain. This process causes top-tier organisms, including humans, to have a higher risk of

exposure to heavy metals through food consumption (Islam et al., 2023; Edo et al., 2024).

From a toxicological point of view, heavy metals are known to have a variety of complex toxicity mechanisms. One of the main mechanisms is the disruption of enzyme activity, which can inhibit normal metabolic processes in the body. In addition, heavy metals can also trigger the formation of free radicals that cause oxidative stress and cell damage. Long-term exposure to heavy metals can result in damage to vital organs, such as the liver, kidneys, and nervous system, as well as increase the risk of chronic diseases, including cancer (Genchi et al., 2020).

Further, the toxicological impact of heavy metals depends not only on the type of metal, but also on the level of exposure, duration, as well as the physiological condition of the individual. Several studies have shown that exposure to heavy metals through daily food consumption can have significant cumulative effects on human health. This reinforces the importance of the study *of food toxicology* in understanding the relationship between contaminated food consumption and long-term health risks (García-Torra et al., 2021). Thus, the analysis of the mechanisms of bioaccumulation and the toxic effects of heavy metals is an important foundation in the evaluation of food risks.

3. Methods

This study uses a *literature review* method that aims to comprehensively examine various research results related to heavy metal contamination in food and its impact

on human health from the perspective of *food toxicology*. This approach was chosen because it is able to integrate various scientific findings from relevant sources to gain a more comprehensive understanding of the topic being studied. The data used in this study is secondary data obtained from various scientific publications, such as reputable international journals, scientific articles, and research reports relevant to the study topic.

The data collection process is carried out through a systematic literature search using academic databases, such as Google Scholar, ScienceDirect, and SpringerLink. Keywords used in the literature search included "food toxicology", "heavy metals in food", "bioaccumulation", "food safety", and "health risk assessment". The inclusion criteria used in the selection of literature are publications published in a span of up to the last five years, have relevance to the research topic, and come from sources that can be scientifically accounted for. Meanwhile, literature that did not meet these criteria, such as publications that were not indexed or had no direct relevance to the research topic, were not included in the analysis.

The next stage is the literature selection and evaluation process which is carried out by critically reading each article that has been collected. At this stage, the identification of the research objectives, methods used, and the main findings of each literature is identified. Relevant information is then classified by theme, such as sources of heavy metal contamination, mechanisms of bioaccumulation in the food chain, as well as toxicological impacts on human health. This process aims to facilitate the preparation of a systematic and structured analytical framework.

Data analysis was carried out in a qualitative descriptive manner by integrating various findings from the selected literature. The classified data is then analyzed to find existing research patterns, relationships, and gaps. The results of the analysis are presented in the form of a narrative that comprehensively describes the aspects of *food toxicology* related to heavy metal contamination in food. With this approach, it is hoped that the research can provide a clear picture of the current conditions and implications of heavy metal contamination on food safety and human health.

4. Results and Discussion

The results of the literature review show that heavy metal contamination in food is an increasingly complex issue and has become a global concern in recent years. Heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), and chromium (Cr) are found in various types of foodstuffs, both from land and water. The existence of these heavy metals is inseparable from the increase in anthropogenic activities that contribute to environmental pollution, such as industrialization, mining, the use of fertilizers and pesticides, and the disposal of waste that is not properly managed (Sall et al., 2020; Karaouzas et al., 2021). This condition shows that environmental quality is closely related to food safety, so that environmental pollution directly or indirectly will have an impact on the quality of food consumed by humans.

In the food system, heavy metals can enter through various routes, especially through contaminated soil and water. Food crops have the ability to absorb heavy metals from the soil through the roots, which are then distributed to different parts

of the plant, including leaves, stems, and fruits. Meanwhile, aquatic organisms such as fish and shellfish can absorb heavy metals from water and sediment through diffusion and ingestion processes. This process leads to bioaccumulation, which is the accumulation of heavy metals in the organism's body over time (Edo et al., 2024). In addition, the biomagnification process also plays a role in increasing the concentration of heavy metals at higher trophic levels in the food chain, so that top-level organisms, including humans, have a higher risk of exposure (Islam et al., 2023).

The results of the study show that fishery products are one of the main sources of heavy metal exposure for humans. Fish and other aquatic organisms have a high ability to accumulate heavy metals in their body tissues, especially in organs such as the liver and gills. Consumption of fish from polluted waters can increase the risk of exposure to heavy metals, especially if consumed continuously over the long term. In addition, vegetables are also one of the sources of heavy metal contamination, especially those grown in contaminated soil or using contaminated irrigation water (Rakib et al., 2021). This shows that various types of food have the potential to be a medium of exposure to heavy metals for humans.

Furthermore, the level of accumulation of heavy metals in food is influenced by various factors, including the type of plant or organism, environmental conditions, and the chemical properties of the metal itself. Some plants, such as green leafy vegetables, have a higher ability to absorb heavy metals compared to other plants. This is due to the large leaf surface area as well as direct interaction with air that can contain heavy metal particles. Additionally, factors such as soil pH,

organic matter content, and the presence of microorganisms can also affect the availability of heavy metals for plant absorption (Fu & Xi, 2020).

From a toxicology perspective, heavy metals have detrimental effects on human health due to their toxic and persistent nature. Heavy metals cannot be metabolized or destroyed by the body, so they tend to accumulate in body tissues, especially in vital organs such as the liver, kidneys, and brain. One of the main mechanisms of heavy metal toxicity is through disruption of enzyme activity, which can inhibit various important metabolic processes in the body. In addition, heavy metals can also trigger the formation of free radicals that cause oxidative stress and cell damage (Genchi et al., 2020; García-Torra et al., 2021).

Exposure to heavy metals through food is generally chronic and occurs over a long period of time. This chronic exposure often does not cause immediate symptoms, but can lead to the accumulation of heavy metals in the body that ultimately lead to health problems. For example, cadmium is known to accumulate in the kidneys and cause impaired kidney function, while mercury can affect the central nervous system and cause neurological disorders. Lead is also known to disrupt the hematopoietic system and cause anemia. Thus, the toxic effects of heavy metals are highly dependent on the type of metal, dosage, as well as duration of exposure (Fu & Xi, 2020).

Additionally, individual factors such as age, gender, and health conditions also affect the degree of susceptibility to heavy metal exposure. Children and pregnant women are the most vulnerable group to the toxic effects of heavy metals because their body systems are still developing or undergoing physiological changes.

Exposure to heavy metals in this group can cause developmental disorders, especially in the nervous system, as well as increase the risk of chronic diseases later in life (Sharma et al., 2023). Therefore, protection of vulnerable groups is one of the important aspects in managing food safety risks.

The results of the study also show that people's consumption patterns have an important role in determining the level of exposure to heavy metals. Consumption of certain foods in large quantities and over a long period of time can increase the risk of exposure, especially if the food comes from a polluted environment. For example, the consumption of fish from waters contaminated with heavy metals can increase the risk of mercury exposure. Therefore, it is important to consider consumption patterns in the evaluation of health risks due to food contamination (Scutaraşu & Trincă, 2023).

In the context of health risk assessment, *the health risk assessment* approach is one of the widely used methods to evaluate the impact of heavy metal exposure through food. This approach involves several stages, namely hazard identification, dose-response assessment, exposure assessment, and risk characterization. The results of this assessment can be used to determine the level of risk that may occur to the population as well as as as a basis for decision-making related to food safety policies (Karaouzas et al., 2021).

In addition to conventional heavy metals, recent research also shows an increased concern for new contaminants in food that have toxic potential. This shows that the issue of food safety continues to develop and requires a more comprehensive approach in the study of *food toxicology*. Interactions between various

contaminants in food can also exacerbate the toxic effects they cause, so it is important to consider the combined effects of various harmful substances (Feng et al., 2023).

Furthermore, the results of the study show that there is a gap in research that integrates environmental, food, and human health aspects as a whole. Most of the research still focuses on only one aspect, so it does not provide a complete picture of the path of exposure to heavy metals from the environment to humans through food. In fact, a comprehensive understanding of this pathway is essential for formulating effective control strategies (Su et al., 2023).

Efforts to control heavy metal contamination in food require a multidisciplinary approach involving various sectors, including the environment, agriculture, health, and industry. Better waste management, more environmentally friendly use of chemicals, and the implementation of strict food safety standards are important steps in reducing the risk of contamination. In addition, regular monitoring of food quality is also needed to ensure that the food consumed is safe for health (Rakib et al., 2021).

Based on the overall research, results and discussions show that heavy metal contamination in food is a complex issue and has far-reaching implications for human health. Bioaccumulation and biomagnification processes in the food chain are the main factors that increase the risk of exposure, while the toxic effects of heavy metals can cause a variety of health problems, both in the short and long term. Therefore, integrated and sustainable efforts are needed to reduce the risk of food contamination and protect public health (Sall et al., 2020; García-Torra et al., 2021).

5. Conclusion

Based on the results of the study conducted, it can be concluded that heavy metal contamination in food is a serious problem with far-reaching implications for human health. Heavy metals such as lead, mercury, cadmium, and chromium can enter the food system through various environmental pathways, primarily through soil and water that have been contaminated by anthropogenic activities. The presence of these heavy metals in the environment subsequently contributes to the accumulation of contaminants in various types of food, whether of plant or animal origin. The processes of bioaccumulation and biomagnification within the food chain are the primary factors leading to increased concentrations of heavy metals at higher trophic levels. Consequently, humans, as the final consumers, face a greater risk of exposure, particularly through the long-term, continuous consumption of contaminated food. This chronic exposure to heavy metals can lead to various health disorders, including damage to vital organs, nervous system disorders, and an increased risk of chronic diseases.

Furthermore, the level of risk from heavy metal exposure is influenced not only by contaminant concentrations in food but also by consumption patterns, individual characteristics, and environmental conditions. Vulnerable groups such as children and pregnant women have a higher sensitivity to the toxic effects of heavy metals, thus requiring special attention in health protection efforts. This indicates that food safety issues are not only related to food quality but also involve human behavioral and biological aspects. Controlling heavy metal contamination in food requires a comprehensive and integrated approach. These efforts include better

environmental management, the implementation of sustainable agricultural and industrial practices, and the improvement of food safety monitoring and regulatory systems. Thus, it is hoped that the risk of heavy metal exposure through food can be minimized, thereby optimally protecting public health.

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