Bioscene

Bioscene
Volume- 22 Number- 02
ISSN: 1539-2422 (P) 2055-1583 (O)
www.explorebioscene.com

Heavy Metal Toxicity in Vegetables and its Impact on Human Health: A Comprehensive Review

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Abstract: Global concern over heavy metal contamination in vegetables is rising due to its adverse health effects. This article examines the sources, accumulation, and impacts of these contaminants, focusing on lead, mercury, cadmium, arsenic, and chromium, which primarily enter the body through ingestion of contaminated vegetables. Once absorbed, these metals deposit in tissues, displacing vital minerals and gradually causing various diseases. While vegetables are essential for a balanced diet, they can become a health risk by absorbing heavy metals from polluted soil and water, the presence of which is increased by industrialisation, mining, and agriculture, in addition to natural sources like volcanic activity and dust. This review investigates the impact of heavy metal toxicity in vegetables on human health, emphasising contamination sources and potential hazards. It also highlights the need for strategies and policies to manage this contamination and identify vegetables prone to high accumulation to raise awareness and implement necessary precautions.

Keywords: Heavy metal contamination, Vegetables, Human health, accumulation, exposure pathways

1. Introduction

Vegetables are a major dietary source of essential nutrients, but can also be a significant route of heavy metal exposure. Heavy metals, persistent environmental pollutants originating from the Earth's crust and human activities, are absorbed by plant roots from soil and can also be taken up from the air (Ahmad et al., 2019;Alsafran et al., 2021; Gupta et al., 2019). Vegetables, a crucial part of the Indian diet providing essential nutrients and disease prevention (Ametepy et al., 2018; Lima et al., 2014), have recommended daily intakes (Mahmud et al., 2020), making their contamination a significant concern. Rising heavy metal levels in developing countries like China and India are linked to urbanization and industrialization (Sharma et al., 2008; Khillare et al., 2012). Anthropogenic sources of contamination include agricultural chemicals, industrial waste, metal plating, battery waste, mining, and textile processing, while natural sources include volcanic activity and weathering (Islam et al.,2014;

Muhammad et al., 2021). Fertilizers and contaminated irrigation water are also significant contributors (Sharma et al.,2006; Sharma et al., 2007). Heavy metals bioaccumulate, don't decompose, and can disrupt biological molecules (Ruzaidya and Amid, 2020), leading to neurodegenerative diseases, mental health issues, kidney problems, and impaired liver, urinary, lung, and brain function (Islam et al., 2015). In developing India, increasing industrial waste contaminates the environment, prompting research into heavy metal levels in food crops and associated health risks (Gupta et al., 2022). Recognizing food contamination as a serious issue, this study aims to educate about environmental pollution, food safety, and healthy living by examining heavy metals in vegetables, their health effects, and contributing factors, providing information for researchers and the public and highlighting the importance of monitoring and mitigation.

1.1 Heavy metals uptake by vegetables

Environmental metal contamination threatens food production and human health. Toxic metals accumulate in vegetables and, upon consumption, can damage organs and cause various disorders. Industrial waste disposal pollutes water sources used for irrigation, leading to vegetable contamination and human ingestion of toxins like lead, cadmium, manganese, and arsenic through the digestive system. A study revealed that vegetables grown in Bangalore using wastewater from four local lakes were contaminated with heavy metals. Studies highlight heavy metal contamination in vegetables due to wastewater irrigation in Bangalore and mining activities. Bangalore vegetables irrigated with lake wastewater showed high cadmium and chromium levels, with leafy greens like amaranth and spinach exceeding safety limits for cadmium, lead, and nickel. Similarly, vegetables near mines contained significant toxic elements above safety limits in some instances, posing potential health risks, particularly for consumers of root vegetables and potentially women due to higher intake (Varalakshmi et al., 2010; Harmanescu et al.,2011). In Nigeria, proximity to a mine resulted in slightly elevated heavy metal levels in nearby crops, though still within FAO and WHO safety limits. Conversely, a study in Saudi Arabia revealed concerningly high levels of heavy metals in vegetables from major cities, particularly leafy greens, likely due to industrial air pollution, suggesting potential health risks. These geographically diverse studies underscore the varying impacts of industrial activities and local environmental conditions on the accumulation of heavy metals in food crops, necessitating continued monitoring and assessment of potential health implications (Omono and Kalulu,2012; Ali and Qahtani, 2012). In 2013, a study in Mardan, Pakistan, found that vegetables grown with wastewater irrigation had significantly higher levels of heavy metals compared to those irrigated with tube well water. Onions were especially contaminated, with manganese levels 50 times higher in wastewater-irrigated onions. This suggests that consuming vegetables grown with wastewater could expose people to harmful levels of heavy metals (Amin et al.,2013). A study

examined the levels of toxic metals (iron, zinc, copper, lead, cadmium, manganese, and chromium) in vegetables grown near a cement factory in Rewa district, Madhya Pradesh (India). The vegetables tested included spinach, cabbage, cauliflower, eggplant, okra, tomato, and radish (Chauhan, 2014). Growing food in cities (urban agriculture) is gaining popularity, but raises concerns about pollution in crops. A study in India found that spinach and tomatoes grown near a polluted river had dangerously high levels of lead, cadmium, copper, and zinc. The levels of lead and cadmium in these vegetables exceeded the safe limits set by international organizations. The high levels of cadmium, in particular, are believed to be harmful to human health, including potentially causing cancer (Mohod, 2015). Research in western Saudi Arabia revealed that okra contained unsafe levels of heavy metals like cadmium, chromium, nickel, and lead, exceeding established safety limits. Consequently, the study deemed this okra unfit for consumption and cautioned that eating vegetables grown in contaminated soil and irrigated with polluted water could lead to the slow accumulation of heavy metals in the body, resulting in poisoning (Balkhair et al.,2016). Daily consumption of common vegetables like tomatoes, eggplants, amaranth, bacon weed, spinach, and coriander from the coal-rich region of Korba, India, elevates the risk of heavy metal exposure. The soil in this area is significantly contaminated with harmful metals like arsenic, lead, and mercury.These toxins accumulate within the plants, and their prolonged intake can disrupt vital biological and metabolic processes in the human body. (Ramteka et. al., 2016). Vegetables and fruits grown near factories in Bangladesh were high in harmful metals, especially lead, arsenic, and cadmium. This is likely because the soil in this area is contaminated. People who eat these vegetables, particularly root and leafy vegetables, are consuming too much of these metals. The study suggests this is a serious health risk, increasing the chances of cancer and other health problems. Due to this risk, the area is not suitable for growing vegetables, especially root and leafy ones (Sultana et al.,2017). Research in China highlights significant heavy metal contamination in vegetables, especially leafy types, posing health risks in regions like Guizhou, Yunnan, and Liaoning (Zhong et al., 2018). Furthermore, a study in Daye, China, revealed elevated heavy metal levels in soil and vegetables near a mine, increasing health risks for nearby residents, particularly children, with cadmium and arsenic being the primary contaminants (Yang et al., 2018). Bangladesh faces significant health risks from heavy metal contamination in local food.Studies reveal dangerously high levels of arsenic, cadmium, chromium, nickel, and lead in vegetables and rice in Tangail, potentially leading to severe illnesses.Near factories, polluted irrigation water contaminates vegetables with metals like chromium and copper, with seasonal variations in absorption from water and soil. These findings underscore a critical threat to food safety in the region(Proshad et al.,2019; Ahmad et al.,2019). Wastewater irrigation in Faisalabad, Pakistan, contaminates vegetables like spinach, coriander, cauliflower, and tomato with unsafe levels of manganese,

nickel, and zinc, rendering them unfit for consumption (Jabeen et al., 2020). Similarly, in Ethiopia's Mojo area, vegetables exhibit elevated levels of chromium, cadmium, zinc, iron, lead, arsenic, manganese, and mercury, exceeding safety limits and posing significant cancer and other health risks, with leafy vegetables like cabbage accumulating more metals (Gebeyehu and Bayissa, 2020).A study in Santa, Cameroon found locally grown carrots and cabbage contaminated with arsenic, copper, and lead and both vegetables exceeded the safety limits established by the WHO and FAO for human consumption (Fong et al.,2021). Studies in Gamo, Ethiopia, and Tabriz, Iran, highlight health concerns due to heavy metal contamination in vegetables. In Ethiopia, wastewater-irrigated vegetables near the Kulfo River, especially cabbage and Swiss chard, accumulated high levels of cadmium, chromium, and lead exceeding safety limits, despite some safer soil levels of copper and zinc (Abraham and Gholap, 2021). Similarly, in Tabriz, Iran, market vegetables, particularly leafy greens, showed concerning levels of chromium, cadmium, and arsenic, posing potential health risks to consumers (Khezerlou et al., 2021). Research on tannery waste-polluted soil in Bangladesh showed spinach, amaranth, jute mallow, and water spinach accumulating high levels of chromium and cadmium, exceeding safety limits and posing risks of chronic health issues and cancer with regular consumption (Ahmed et al., 2022). Recent studies continue to highlight concerns about heavy metal contamination in food crops across various regions. In Accra, Ghana, vegetables from a farm near the polluted Korle Lagoon showed significant contamination, particularly with chromium and lead, deemed unsafe for consumption and posing a potential cancer risk (Osae et al., 2023). Similarly, vegetables grown with wastewater in Bhakkar, Pakistan, showed concerning metal content, especially lead and cadmium, suggesting potential health issues with regular consumption (Khan et al., 2023).Finally, a study in Punjab, India, investigating cooked beans and vegetables, found a potential cancer risk from cadmium exposure in cooked vegetables consumed by adults in Ludhiana, emphasising the need for continued monitoring even in staple foods (Kharkwal et al., 2023). Recent studies in Bangladesh paint a concerning picture of heavy metal contamination in commonly consumed vegetables. One study found alarmingly high levels of lead, cadmium, chromium, nickel, and iron in 15 vegetable types, exceeding international safety standards and indicating potential non-cancer and carcinogenic risks, particularly from lead and chromium in fruits/pods and cadmium in fruits/roots/stems (Chowdhury et al., 2024). Another study linked untreated textile wastewater irrigation to significant increases in lead, cadmium, chromium, and nickel in vegetables like amaranth, radish, and spinach, posing health risks and highlighting the urgent need for wastewater treatment before agricultural use (Hassan et al., 2024). This studyanalysed the concentration of cadmium, lead, copper, and zinc in vegetables grown in the industrial areas of Pshder and Rania, Iraq. Broccoli (Zn), onion (Cu), lettuce (Pb), and zucchini (Cd) had the greatest metal

concentrations.Even though the projected daily consumption was within safe limits, health risk evaluations showed that there may be health concerns, particularly for children, based on the hazard index values and the hazard quotient for lead. Our findings emphasise the critical necessity for efficient mitigation techniques, consistent monitoring, and public awareness to guarantee food safety and safeguard the population's health(Qadar and Amin , 2025).

The Hidden Danger: Health Risks of Consuming Contaminated Vegetables

Trace metals in contaminated vegetables pose serious health threats, including cancer and death, with even essential metals becoming harmful at high concentrations due to human activities. The consumption of these contaminated vegetables can endanger human health because toxic metals bioaccumulate due to their long biological half-lives and resistance to biodegradation. Chronic ingestion leads to the insidious accumulation of these elements in vital organs like the kidneys and liver, potentially disrupting biochemical processes and causing heart disease, bone disorders, urinary problems, and neurological conditions (Onapka et al., 2018). Exposure to toxins like mercury and lead can also trigger autoimmune reactions, where the immune system attacks the body's own cells, leading to conditions like rheumatoid arthritis and affecting the kidneys, cardiovascular, and nervous systems (Lauwerys et al., 2007).Cadmium poses a significant health risk due to its ability to be ingested, cross the placenta during pregnancy, and potentially damage genes and cell membranes. Once in the body, cadmium can persist for up to 33 years, potentially causing kidney dysfunction and abnormal protein in urine (Guerra et al., 2012). Furthermore, cadmium exposure can lead to a decrease in skeletal calcium and an increase in calcium loss through urine, which can ultimately result in mortality (WHO, 2004). Acute mercury exposure harms lungs, while chronic poisoning causes neurological and psychological issues like tremors and mood changes (Jarup et al., 2003). Mercury is also linked to pregnancy complications (Benefice et al., 2010) and impaired fetal development. Acute lead poisoning causes headaches, neurological problems, and in children, behavioral and learning difficulties, with severe cases leading to altered consciousness (Jarup et al., 2003). Long-term exposure impairs memory and cognition. Studies near industrial sites showed elevated lead levels in children (Pruvot et al., 2006), and high heavy metals in Turkey were linked to increased cancer rates. Overall, consuming contaminated food can deplete nutrients, weaken immunity, and harm development. While essential in small amounts, copper and chromium can be harmful in excess. Chromium aids glucose metabolism, and copper is vital for iron metabolism, preventing anemia (McDowell, 2003; Broadhurst and Domenico, 2006). Acute copper poisoning causes anemia, liver and kidney damage, and gastrointestinal issues. Chronic copper poisoning (Wilson's disease) leads to hemolytic anemia, swallowing difficulties, tremors, kidney dysfunction, and liver failure. Chromium poisoning, often from skin exposure, can cause skin irritation and psoriasis

(Barceloux, 1999). Heavy metals can also impair female reproductive function by affecting ovaries and hormones potentially impacting fetal development (Silberstein et al., 2006). Arsenic is a particularly concerning heavy metal linked to cancer and cardiovascular disease (Soza-Ried et al., 2019), with acute poisoning possible through intentional or accidental ingestion (Chowdhury, 2022; Zhu et al., 2023). Elevated nickel levels are associated with worsened eczema and may contribute to hair loss. Various illnesses induced by heavy metals have significant implications for human well-being (Table 1).

Table1.Adverseimpacts of certainheavymetalson humanwell-being

Heavymetals	Toxicity
Arsenic	Cancer, Arsenicosis (Skin conditions such as skin pigmentation, and skin lesions), Cardiovascular diseases, Gastrointestinal disorders
Chromium	Lungcancer,injurytotheskin,dermatitis,kidneyandhepatic injury, cancer
Cadmium	Renaland hepaticdisorder, respiratorydisorders
Copper	Anaemia, osteoporosis, skeletal problems, gastrointestinal distress, liver and kidney toxicity
Lead	Neurological, cardiovascular, renal, gastrointestinal, haematological and reproductive effects
Mercury	Impairment of intelligence and mood, low birth weight, behavioural dysfunction, delayed neurodevelopment in children
Nickel	Hairloss,eczema,oralandprostatecancer, birthdefects, asthma and chronic bronchitis

The severity of health impacts from heavy metal exposure can vary depending on factors like duration and intensity. Even prolonged exposure to low levels can have significant negative consequences. To mitigate these risks, it is crucial to implement strategies that reduce heavy metal emissions, improve waste management practices, and promote the consumption of uncontaminated food and water.

Conclusion

This review highlights the significant global issue of toxic metal contamination in vegetables and its potential harm to multiple organs. Influenced by natural and human activities like industry and agriculture, heavy metals such as lead, mercury, cadmium, arsenic, and chromium are major pollutants. The review stresses the importance of monitoring and assessing this contamination to protect public health. It concludes that a combined approach of pollution prevention, effective waste management, and public awareness is crucial. Collaboration

among governments, scientists, and medical professionals is essential to minimize exposure and safeguard well-being. Ultimately, this review enhances understanding of the harmful effects of heavy metal pollution and advocates for prevention and sustainable practices to protect public health. Encouraging the agricultural community to reduce synthetic fertilizers and use compost and manures is also vital.

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