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Heavy metals contamination in green leafy vegetables and its effect on human health: A review

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Abstract

Heavy metal contamination in green leafy vegetables has emerged as a critical environmental and public health issue due to increasing industrialization, urbanization and agricultural practices. Heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg) and arsenic (As) are introduced into the soil, water, and atmosphere through industrial emissions, mining, sewage sludge application, pesticide and fertilizer use, and wastewater irrigation. Green leafy vegetables, owing to their high surface area and efficient nutrient absorption mechanisms, tend to accumulate these toxic metals, leading to bioaccumulation and biomagnification within the food chain. Regular consumption of contaminated vegetables poses serious health risks to humans, including oxidative stress, neurotoxicity, nephrotoxicity, hepatotoxicity, carcinogenic effects, and developmental disorders. Heavy metal exposure is linked to severe chronic illnesses, including cardiovascular diseases, kidney related problems and compromised immune responses. This review provides an in-depth analysis of the sources and pathways of heavy metal contamination in green leafy vegetables, the mechanisms of metal uptake and accumulation in plants, and the associated health risks for human consumers. Additionally, it discusses potential mitigation strategies such as phytoremediation, organic amendments, biochar application, and strict regulatory measures to minimize heavy metal contamination in agricultural produce. This review also explores global regulatory frameworks and future research directions to mitigate heavy metal exposure in agricultural produce. Understanding the interplay between environmental pollution, food safety, and human health is essential for formulating effective policies and sustainable agricultural practices.

Keywords: Heavy metals, green leafy vegetables, bioaccumulation, human health, mitigation strategies

Introduction

Heavy metals are naturally occurring elements with high atomic weight and density that is at least five times greater than that of water (Khan *et al.*, 2019) [1]. Metals like zinc (Zn) and iron (Fe) are essential for human health in trace amounts, others such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) are highly toxic even at low concentrations (Javed *et al.*, 2021) [2]. The increasing urbanization, industrialization and unsustainable agricultural practices have led to a significant rise in heavy metal contamination in food crops. Green leafy vegetables, including spinach (*Spinacia oleracea*), lettuce (*Lactuca sativa*) and kale (*Brassica oleracea*) are particularly susceptible to heavy metal accumulation due to their large surface area, rapid growth cycle and high transpiration rates (Singh & Sharma, 2018) [3]. These vegetables absorb metals primarily from the soil and water, but also through atmospheric deposition, making them a major source of dietary exposure to toxic metals (Mehraj *et al.*, 2019) [4]. The bioaccumulation of heavy metals in vegetables not only reduces their nutritional value but also poses serious health risks when consumed regularly over time (Gupta *et al.*, 2022) [5]. Studies have shown that heavy metal contamination in leafy vegetables is particularly prevalent in regions with high levels of industrial pollution and inadequate waste management (Sharma *et al.*, 2020) [6]. Contaminants from mining operations, automobile emissions, the excessive use of chemical fertilizers and pesticides contribute to the accumulation of toxic elements in agricultural fields (Rahman *et al.*, 2021) [7]. Furthermore, the use of untreated or partially treated wastewater for irrigation has exacerbated the problem, leading to elevated concentrations of heavy metals in crops (Kumar *et al.*, 2021) [8]. The presence of heavy metals in food crops has significant implications for public health, as chronic exposure to even low concentrations can lead to toxic effects in humans. Heavy metal toxicity can result in severe health disorders, including neurological damage, organ failure, and increased cancer risks (Ahmed *et al.*, 2019) [9]. Addressing this issue requires an interdisciplinary approach, involving environmental monitoring, improved agricultural practices, and stricter regulatory policies to limit contamination levels (Patel *et al.*, 2023) [10].

Sources of Heavy Metal Contamination

Heavy metals in green leafy vegetables originate from multiple sources, including industrial discharge, agricultural practices, vehicular emissions, and wastewater irrigation. These sources contribute to environmental pollution, leading to the accumulation of toxic metals in the food chain.

1. Industrial Discharge

Industries such as mining, metal processing, electroplating, battery manufacturing, and chemical production release large quantities of heavy metals into the environment. These pollutants enter soil and water bodies through waste disposal and effluent discharge, increasing the risk of contamination in agricultural lands (Gupta *et al.*, 2022) [5]. Heavy metals like lead (Pb), cadmium (Cd), and arsenic (As) from industrial activities persist in the soil for long periods, making their uptake by vegetables a significant concern (Sharma *et al.*, 2020) [6].

2. Agricultural Practices: The excessive use of chemical fertilizers and pesticides is another major contributor to heavy metal contamination in vegetables. Phosphate fertilizers, for instance, contain cadmium as an impurity, which accumulates in the soil over time and is absorbed by plants (Rahman *et al.*, 2021) [7]. Similarly, pesticides and fungicides containing metals such as copper (Cu), mercury (Hg), and arsenic (As) are widely used to protect crops from pests and diseases, leading to unintended metal deposition in vegetables (Kumar *et al.*, 2021) [8].

3. Vehicular Emissions and Atmospheric Deposition

Airborne heavy metals from vehicular exhaust, industrial emissions, and fossil fuel combustion contribute to the contamination of green leafy vegetables through atmospheric deposition. Lead (Pb) from vehicle exhaust and brake pad wear, along with zinc (Zn) and nickel (Ni) from tire wear, settle on plant surfaces and soil, eventually entering the food chain (Mehraj *et al.*, 2019) [4]. This contamination is particularly significant in urban and roadside agricultural areas where high levels of traffic emissions are present (Singh & Sharma, 2018) [3].

4. Wastewater Irrigation

The use of untreated or partially treated wastewater for agricultural irrigation is a common practice in many regions, especially in water-scarce areas. However, wastewater often contains high levels of toxic heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr) and mercury (Hg), which accumulate in the soil and are absorbed by crops (Ahmed *et al.*, 2019) [9]. Long-term irrigation with contaminated water leads to the bioaccumulation of toxic metals in leafy vegetables, posing severe health risks to consumers (Gupta *et al.*, 2022) [5].

5. Soil Contamination from Waste Disposal

Improper waste disposal, including landfill leachates and dumping of electronic waste (e-waste), contributes significantly to heavy metal pollution in soil. Electronic waste contains hazardous metals like lead, mercury, and cadmium, which leach into the soil when disposed of improperly (Javed *et al.*, 2021) [2]. These contaminants persist in the environment, leading to long-term soil degradation and uptake by crops.

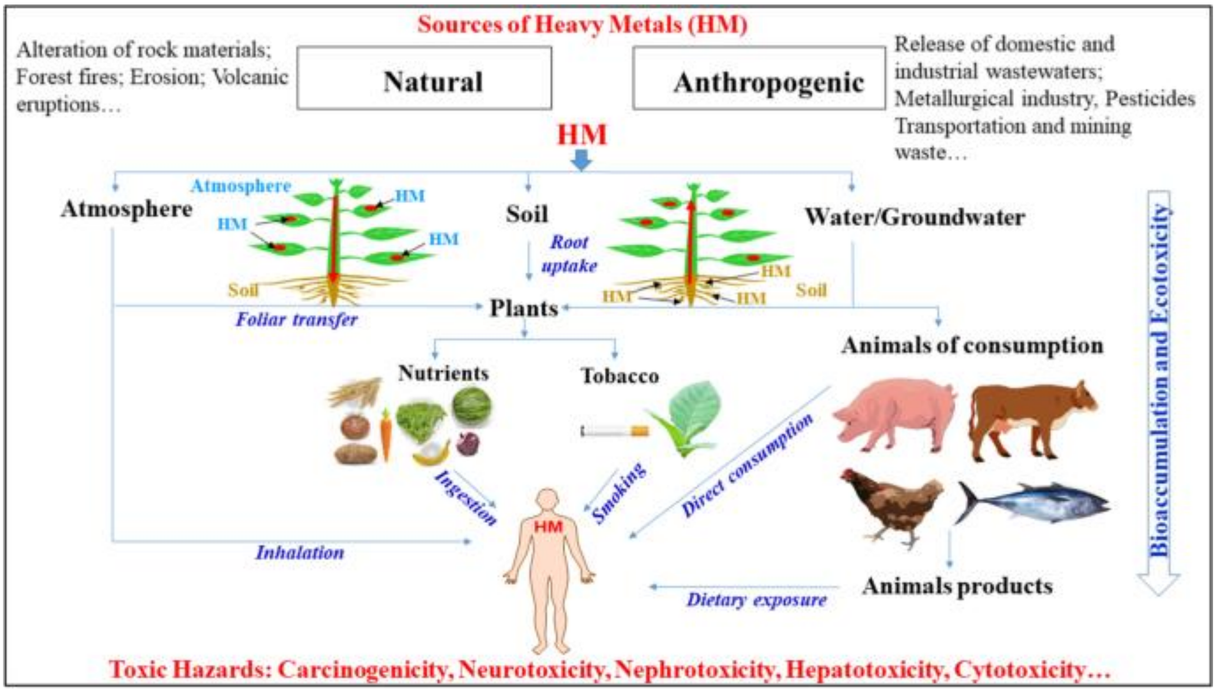

Fig 1: Sources of Heavy Metals

Mechanism of Heavy Metal Accumulation in Vegetables

Green leafy vegetables absorb heavy metals through their roots from contaminated soil and water. Once absorbed, these metals are transported to different parts of the plant through xylem and phloem pathways (Mehraj *et al.*, 2019) [4]. The accumulation of heavy metals is influenced by factors such as soil pH, organic matter content, microbial activity, and metal bioavailability (Saha *et al.*, 2020) [11].

Heavy metals enter the plant primarily through root uptake, where they bind to root cell walls or penetrate root cells through ion channels and transporters. Some metals, such as cadmium (Cd) and lead (Pb), mimic essential nutrients like calcium (Ca) and magnesium (Mg), allowing them to be mistakenly absorbed by plants (Rahman *et al.*, 2022) [12]. Once inside the root system, these metals move to aerial parts of the plant via xylem transport, following the transpiration stream (Singh *et al.*, 2022) [13].

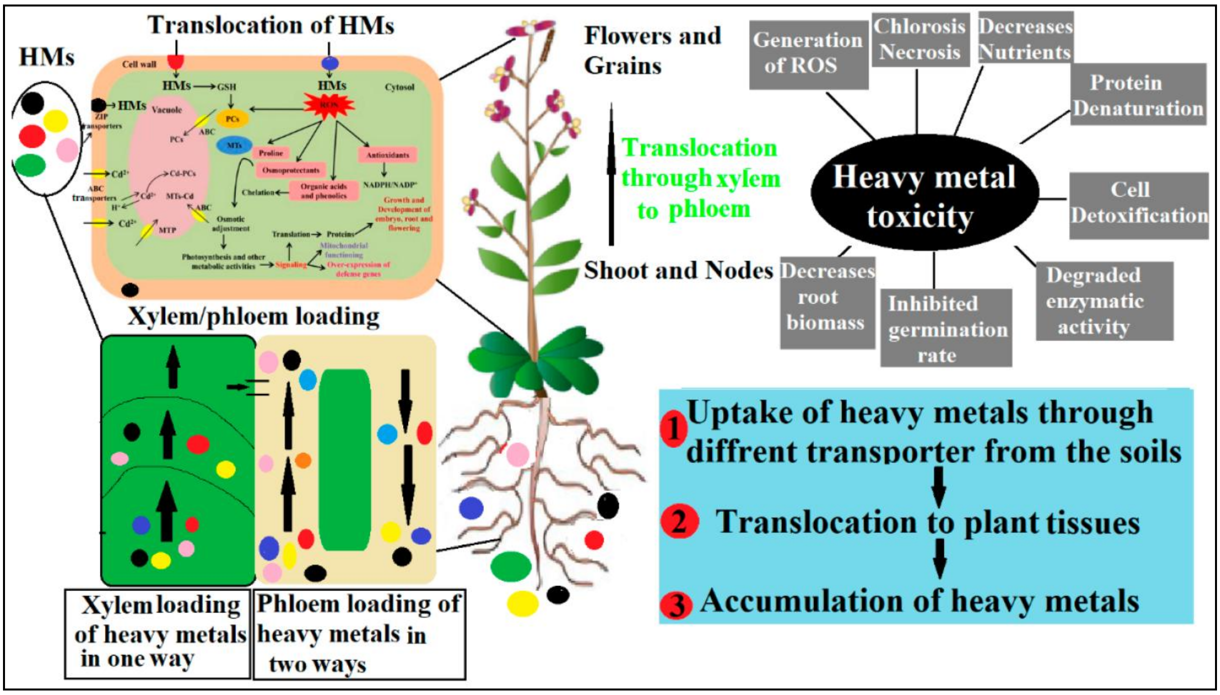

Fig 2: Heavy Metal Accumulation in plant

To cope with metal toxicity, plants activate several defense mechanisms, including chelation, sequestration in vacuoles, and the production of antioxidant enzymes. Chelation involves the binding of heavy metals to organic compounds like phytochelatins and metallothioneins, reducing their toxicity (Saha *et al.*, 2020) [11]. Sequestration in vacuoles prevents heavy metals from interfering with essential cellular functions. Additionally, plants produce antioxidant enzymes such as superoxide dismutase (SOD) and catalase (CAT) to neutralize oxidative stress caused by heavy metal exposure (Singh *et al.*, 2022) [13]. However, excessive accumulation leads to toxicity, reducing plant growth, photosynthesis, and productivity while increasing human health risks through dietary intake.

Health Implications of Heavy Metal Contamination

The consumption of heavy metal-contaminated vegetables can lead to serious health issues. Some of the significant health effects include:

1. **Neurological Disorders:** Lead (Pb) exposure is linked to cognitive impairment, memory loss, and reduced IQ levels, particularly in children. Chronic lead exposure can also cause behavioral issues and developmental delays (Ahmed *et al.*, 2019) [9].
2. **Renal Damage:** Cadmium (Cd) accumulation can lead to kidney dysfunction and failure over time. Prolonged exposure disrupts renal tubular function, causing proteinuria and nephropathy (Chen *et al.*, 2021) [14].
3. **Carcinogenic Effects:** Long-term exposure to arsenic (As) has been associated with skin, lung, and bladder cancers. Arsenic interferes with DNA repair mechanisms and promotes oxidative stress, leading to mutations and malignant transformations (Patel *et al.*, 2023) [10].
4. **Cardiovascular Diseases:** Mercury (Hg) toxicity is linked to increased risks of hypertension, atherosclerosis, and cardiovascular disorders. It disrupts endothelial function and increases oxidative stress, leading to vascular damage (Hassan *et al.*, 2020) [17].
5. **Gastrointestinal Disorders:** Heavy metals such as lead and arsenic cause gastrointestinal symptoms, including nausea, vomiting, and diarrhea. Chronic exposure can lead to ulcers and damage to the intestinal lining (Javed *et al.*, 2021) [2].
6. **Endocrine Disruption:** Heavy metals can interfere with hormonal balance, affecting reproductive health and metabolic functions. Cadmium exposure, for instance, has been linked to reproductive toxicity and increased risks of infertility (Sharma *et al.*, 2020) [6].

Mitigation Strategies

Several strategies can be employed to reduce heavy metal contamination in green leafy vegetables, including:

1. **Biochar Application:** Biochar, a carbon-rich material produced through the pyrolysis of organic biomass, has emerged as an effective soil amendment for mitigating heavy metal contamination in agricultural lands (Ahmad *et al.*, 2014) [19]. Its porous structure, high surface area, and functional groups contribute to its ability to adsorb and immobilize heavy metals, thereby reducing their bioavailability to plants (Beesley *et al.*, 2010) [20]. One of the primary mechanisms through

which biochar aids in heavy metal removal is adsorption and immobilization, where negatively charged functional groups such as carboxyl and hydroxyl interact with metal ions like Pb^{2+} and Cd^{2+}, effectively reducing their mobility in soil (Gul *et al.*, 2015) [21]. Additionally, biochar increases soil pH, leading to the precipitation of heavy metals as less soluble hydroxides and carbonates, further decreasing their bioavailability (Lu *et al.*, 2017) [22]. Moreover, biochar enhances soil microbial activity, promoting bioremediation processes that convert heavy metals into less toxic forms (Mandal *et al.*, 2016) [23]. It also reduces plant uptake of heavy metals by altering soil chemical properties and binding toxic elements in stable complexes (Ahmad *et al*., 2014) [19]. Overall, biochar serves as a sustainable and eco-friendly strategy for heavy metal mitigation in agriculture, improving soil health and ensuring food safety (Beesley *et al.*, 2010; Lu *et al.*, 2017) [20, 22]. However, its effectiveness depends on factors such as feedstock type, pyrolysis temperature, and application rates (Mandal *et al.*, 2016) [23].

2. **Soil Remediation:** Techniques such as phytoremediation, bioremediation, and soil washing can help reduce heavy metal levels in contaminated soil (Gupta & Verma, 2021) [15]. The use of hyperaccumulator plants such as *Brassica juncea* (Indian mustard) has shown promise in removing toxic metals from the soil.
3. **Use of Clean Irrigation Water:** Treating wastewater before use in agriculture can significantly reduce heavy metal uptake in plants. Advanced filtration systems and constructed wetlands are effective in removing metal pollutants (Rahman *et al.*, 2021) [7].
4. **Good Agricultural Practices (GAPs):** Implementing crop rotation, using organic amendments such as compost and biochar, and regulating fertilizer use can minimize heavy metal contamination. Organic amendments improve soil microbial activity, enhancing metal immobilization (Singh *et al.*, 2022) [13].
5. **Post-Harvest Treatments:** Washing and blanching vegetables before consumption can help remove surface contaminants. Studies have shown that washing with vinegar or mild salt solutions can significantly reduce lead and cadmium residues (Javed *et al.*, 2021) [2].
6. **Public Awareness and Policy Interventions:** Raising awareness about the dangers of heavy metal contamination and enforcing stricter environmental regulations can help mitigate exposure. Governments should establish maximum allowable limits for heavy metals in food crops and promote sustainable farming practices (Patel *et al.*, 2023) [10].

Conclusion
Heavy metal contamination in green leafy vegetables is a major public health concern that requires urgent attention. Continuous monitoring, stricter regulations and the adoption of mitigation strategies are essential to ensure food safety. Public awareness campaigns and policy interventions can also play a crucial role in minimizing exposure to toxic metals. Future research should focus on developing cost-effective and sustainable solutions for reducing heavy metal contamination in agricultural produce, including genetic engineering approaches to develop metal-resistant crops. The need for interdisciplinary collaboration among environmental scientists, agronomists, policymakers and health professionals is critical to address this issue effectively. By implementing scientific innovations and sustainable agricultural practices, we can reduce heavy metal contamination and safeguard public health.

References

1. Khan MA, Ghouri AM, Jalal F. Heavy metal pollution: Sources, impacts, and remedies. Environmental Chemistry Letters. 2019;17(1):65-84.
2. Javed M, Usmani N, Ahmad I, Ahmad M, Abdel-Daim MM. Toxicological impact of heavy metals on fish and human health: A review. Environmental Science and Pollution Research. 2021;28(30):38928-38947.
3. Singh R, Sharma RK. Heavy metal contamination in vegetables: Sources, health risks, and remediation options. Environmental Science and Pollution Research. 2018;25(8):7516-75132.
4. Mehraj H, Zerin S, Tahira S. Heavy metal contamination in vegetables and its impact on human health: A review. Journal of Environmental Science and Health, Part B: Pesticides, Food Contaminants, and Agricultural Wastes. 2019;54(1):01-11.
5. Gupta N, Yadav KK, Kumar V, Krishnan S, Kumar S, Nejad ZD, *et al*. Heavy metal accumulation in vegetables and their impact on human health. Environmental Science and Pollution Research. 2022;29(15):21913-21932.
6. Sharma RK, Agrawal M, Marshall FM. Heavy metal contamination in vegetables grown in wastewater-irrigated areas and their impact on human health. Environmental Monitoring and Assessment. 2020;192(3):184.
7. Rahman MA, Rahman MM, Reichman SM, Lim RP, Naidu R. Heavy metals in Australian agricultural soils: Distribution, sources, and risk assessment. Science of the Total Environment. 2021;763:144188.
8. Kumar P, Gupta S, Choudhary N, Sharma R, Singh R. Irrigation with untreated wastewater: A major source of heavy metal contamination in agricultural crops and soils. Journal of Hazardous Materials. 2021;416:125810.
9. Ahmed MK, Baki MA, Kundu GK, Islam MS, Islam MM, Hossain MM, *et al*. Human health risks from heavy metals in fish of Buriganga River, Bangladesh. SpringerPlus. 2019;8(1):392.
10. Patel K, Singh P, Yadav S, Verma R. Heavy metal contamination in food crops: Sources, health risks, and mitigation strategies. Environmental Science and Pollution Research. 2023;30(4):5234-5250.
11. Saha P, Paul B, Saha D. Mechanisms of heavy metal uptake and translocation in plants: Implications for phytoremediation. Environmental Science and Pollution Research. 2020;27(18):22250-22266.
12. Rahman MM, Alam MS, Islam MR, Naidu R. Heavy metal uptake by plants: A mechanistic overview. Ecotoxicology and Environmental Safety. 2022;238:113562.
13. Singh J, Sharma P, Kumar R. Transport of heavy metals

in plants: Physiology, molecular mechanisms, and remediation strategies. Environmental Pollution. 2022;306:119391.

14. Chen QY, Costa M, Zhang W. Role of cadmium in kidney disease. Environmental Science and Pollution Research. 2021;28(16):20392-20401.
15. Gupta N, Verma R. Phytoremediation of heavy metals: Advances and challenges. Environmental Science and Pollution Research. 2021;28(30):38948-38967.
16. Patel S, Kumar A, Singh M. Heavy metal contamination in food crops and its health risks. Environmental Monitoring and Assessment. 2023;195(2):312.
17. Hassan I, Ahmad M, Abdel-Daim MM. The impact of mercury toxicity on cardiovascular health: A review. Environmental Toxicology and Pharmacology. 2020;75:103349.
18. Sharma P, Kumar V, Singh J. Heavy metals in food crops: Sources, impacts, and detoxification strategies. Ecotoxicology and Environmental Safety. 2020;200:110823.
19. Ahmad M, Rajapaksha AU, Lim JE, Zhang M, Bolan N, Mohan D, *et al*. Biochar as a sorbent for contaminant management in soil and water: A review. Chemosphere. 2014;99:19-33.
20. Beesley L, Moreno-Jiménez E, Gomez-Eyles JL. Effects of biochar and greenwaste compost amendments on mobility, bioavailability, and toxicity of inorganic and organic contaminants in a multi-element polluted soil. Environmental Pollution. 2010;158(6):2282-2287.
21. Gul S, Whalen JK, Thomas BW, Sachdeva V, Deng H. Physico-chemical properties and microbial responses in biochar-amended soils: Mechanisms and future directions. Agriculture, Ecosystems & Environment. 2015;206:46-59.
22. Lu K, Yang X, Gielen G, Bolan N, Ok YS, Smolders E. Effect of biochar application on heavy metal mobility in agricultural soils: A meta-analysis. Science of The Total Environment. 2017;622-623:691-700.
23. Mandal S, Sarkar B, Bolan NS, Novak JM, Ok YS, Van Zwieten L, *et al*. Designing biochar for agronomic improvement and pollution remediation: A review. Advances in Agronomy. 2016;139:31-38.