MSI Journal of
Multidisciplinary Research (MSIJMR)

Health Effects of Heavy Metals in Edible Tubers (Cassava, Sweet Potato, and Yam): A Review of Implications for Food Safety and Public Health

Bilyaminu, Habibu[1*], Chukwuma, Stephen Ezeonu[2]

[1*2] Department of Biochemistry, Faculty of Biosciences, Federal University Wukari, Taraba state, Nigeria.

*** Correspondence:** Bilyaminu, Habibu

The authors declare that no funding was received for this work.

OPEN ACCESS

Received: 20-December-2025

Accepted: 30-January-2026

Published: 29-January-2026

This article is published in the **MSI Journal of Multidisciplinary Research (MSIJMR) ISSN 3049-0669 (Online)**

The journal is managed and published by MSI Publishers.

Volume: 3, Issue: 1 (January-2026)

ABSTRACT: Cassava (Manihot esculenta), sweet potato (Ipomoea batatas), and yam (Dioscorea spp.) are critical staple foods for millions of people, particularly in sub-Saharan Africa, Asia, and Latin America. Their cultivation in marginal and often contaminated soils increases the risk of heavy metal accumulation in edible tissues. Heavy metals such as cadmium (Cd), lead (Pb), mercury (Hg), arsenic (As), chromium (Cr), nickel (Ni), copper (Cu), and zinc (Zn) are persistent environmental contaminants that can enter the human food chain through tuber crops and pose significant health risks upon chronic exposure. This review critically evaluates current evidence on the sources, uptake mechanisms, and concentration levels of heavy metals in cassava, sweet potato, and yam, as well as their associated health effects. Reported concentrations are compared with international food safety limits, and human health risk assessment outcomes are synthesized. The review highlights substantial exceedances of FAO/WHO guideline values in contaminated regions and underscores the need for strengthened monitoring, soil management, and policy interventions to safeguard public health.

Keywords: *heavy metals, cassava, sweet potato, yam, food safety, health risk assessment, FAO/WHO limits.*

1. Introduction

Root and tuber crops are indispensable to global food systems, contributing over 800 million tonnes annually to world food production. Cassava, sweet potato, and yam are especially important in low- and middle-income countries, where they serve as primary energy sources and buffers against food insecurity. However, their growth in close contact with soil renders them particularly susceptible to heavy metal contamination (Khan *et al*., 2008; Alloway, 2013).

Cassava also is a starchy root crop with numerous varieties broadly classified as either sweet or bitter. These classifications are primarily based on the amount of cyanogenic compounds (toxins) they contain. Sweet cassava has lower levels of these toxins and is often consumed directly, while bitter cassava has higher levels and is typically processed.

(a) (b)

Fig;1. a. Cassava plant and b. tuberous root. (Olsen and Schaal, 1999; modified 2022; Bilyaminu *et al*., 2024).

Potatoes

Potatoes; also known as Anamo in Yoruba, Nduku in Igbo and Dankali in Hausa. Come in a wide variety of types, broadly categorized by color, size, and starch content. Some common types include russets, red, white, yellow (like Yukon Gold), purple/blue, fingerling, and petite potatoes. Russets are known for their high starch content, making them good for baking and mashing. Red potatoes are waxy and work well in salads. Yukon Gold potatoes offer a balanced starch and waxy content, making them versatile. Purple and blue potatoes have a medium starch content and are often used in salads or roasted with other colors, like reds and whites (Habibu *et al.,* 2024).

Figure; 2. White potatoes; modified by Habibu *et al.,* (2025).

Yam

Yam (*Dioscorea spp)* also known as Isu in Yoruba, Ji in Igbo and Doya in Hausa. are a type of tuber crop belonging to the genus Dioscorea, and there are several varieties that are commonly cultivated. The most important staple yams are *Dioscorea rotundata* (white guinea yam), *Dioscorea cayennensis* (yellow guinea yam), and *Dioscorea alata* (water yam).

Figure; 3. Assorted yams on blue background - Static Media / Shutter stock; modified (2025)

Heavy metals are non-biodegradable, capable of persisting in soils for decades, and may bioaccumulate in plant tissues at concentrations that pose risks to human health. Chronic dietary exposure through staple foods is increasingly recognized as a major exposure pathway, often exceeding that from drinking water or air in agrarian communities (Jarup, 2003; WHO, 2017). This review synthesizes current knowledge on heavy metal contamination of cassava, sweet potato, and yam, with a focus on reported concentration levels relative to international safety standards and the implications for human health.

Enrichment of heavy metals in the environment is of major concern because of their toxicity and threat to human life and the environment. Heavy metals are introduced into the terrestrial environment and most especially into the soil and transported to the plants from different sources such as industrial, agricultural and municipal waste, automobile emissions, mining activities and agricultural practices (Vulkan *et al*., 2022; Bilyaminu *et al*., 2024). The accumulation of heavy metals in plants tuber crops can lead to physiological stress, manifesting as reduced chlorophyll content, impaired photosynthesis, and oxidative damage. Antioxidant enzymes such as catalase (CAT), superoxide dismutase (SOD), and glutathione (GSH) play crucial roles in mitigating oxidative stress induced by metal toxicity (Igwegbe *et al*., 2019; Bilyaminu *et al.,* 2024).

2. Heavy Metals of Concern in Tuber Crops

The heavy metals most frequently reported in edible tubers include Cd, Pb, Hg, As, Cr, Ni, Cu, and Zn. Cd and Pb are of particular concern due to their high toxicity and lack of biological function. While Cu and Zn are essential micronutrients, excessive intake can lead to gastrointestinal, hepatic, and neurological disorders (WHO, 2017; ATSDR, 2019). Arsenic and hexavalent chromium are recognized human carcinogens, with no established safe exposure threshold.

3. Sources and Pathways of Contamination

3.1 Geogenic and Anthropogenic Inputs

Natural soil parent materials may contribute to baseline heavy metal levels; however, elevated concentrations in tuber crops are predominantly linked to anthropogenic activities. These include mining and smelting, oil and gas exploration, industrial emissions, traffic-related pollution, application of phosphate fertilizers, pesticide use, and irrigation with contaminated wastewater (Nriagu & Pacyna, 1988; Khan *et al.,* 2008).

3.2 Soil–Plant Transfer Mechanisms

Metal uptake is governed by soil pH, redox potential, organic matter content, and metal speciation, as well as plant genotype and root physiology. Tubers accumulate metals primarily through root absorption, with subsequent sequestration in storage tissues. Cassava has been reported to show relatively high Cd and Pb accumulation factors, whereas sweet potato and yam exhibit strong cultivar- and species-dependent variability (Alloway, 2013; Ogunkunle & Fatoba, 2014).

4. Reported Heavy Metal Concentrations in Edible Tubers

Table 1: summarizes representative ranges of heavy metal concentrations reported in cassava, sweet potato, and yam from contaminated and uncontaminated regions, alongside FAO/WHO maximum permissible limits.

Table 1. Reported concentrations of selected heavy metals in edible tubers compared with FAO/WHO limits (mg/kg dry weight)

Heavy metal	**Cassava (range)**	**Sweet potato (range)**	**Yam (range)**	**FAO/WHO limit***
Cadmium (Cd)	0.01–1.20	0.02–0.95	0.01–0.88	0.10–0.30
Lead (Pb)	0.05–3.40	0.04–2.60	0.03–2.10	0.10
Arsenic (As)	0.01–0.45	0.01–0.38	0.01–0.31	0.10
Chromium (Cr)	0.10–2.80	0.08–2.10	0.06–1.90	1.00
Nickel (Ni)	0.05–2.50	0.04–2.00	0.03–1.80	0.50
Copper (Cu)	1.20–15.6	1.00–18.2	0.90–14.4	40.0
Zinc (Zn)	5.4–68.0	6.0–72.5	4.8–60.3	60.0

Limits based on Codex Alimentarius and WHO guidelines; values vary slightly by commodity and moisture basis (FAO/WHO, 2011; WHO, 2017).

Multiple studies from Africa and Asia report Cd and Pb concentrations in cassava and sweet potato exceeding recommended limits, particularly in areas affected by mining, industrial discharge, and oil exploration (Khan *et al*., 2008; Ogunkunle & Fatoba, 2014). Yam generally exhibits lower accumulation, although exceedances have also been reported near contaminated sites.

5. Human Health Effects of Dietary Exposure

5.1 Non-carcinogenic Effects

Chronic ingestion of Cd-contaminated tubers is associated with renal tubular dysfunction, decreased glomerular filtration rate, and bone demineralization. Pb exposure is strongly linked to neurodevelopmental deficits in children, hypertension, and cardiovascular disease in adults (Jarup, 2003; ATSDR, 2019).

5.2 Carcinogenic Risks

Long-term exposure to As and Cr (VI) through contaminated food has been associated with increased risks of skin, lung, bladder, and gastrointestinal cancers. Several dietary risk assessments report lifetime cancer risk values exceeding the acceptable benchmark of 1×10^{-4} for populations heavily reliant on tuber-based diets (Khan *et al*., 2008; WHO, 2017).

5.3 Summary of Reported Risk Indices by Country

Table 2. Summary of reported hazard quotient (HQ), hazard index (HI), and lifetime cancer risk (LCR) values for heavy metals in edible tubers

Country	Crop	Dominant metal(s)	HQ range	HI range	LCR range	Reference
Nigeria	Cassava	Cd, Pb	0.6–4.8	1.2–6.5	1.1×10^{-4}–4.3×10^{-3}	Ogunkunle & Fatoba, 2014

China	Sweet potato	Cd, As	0.4–3.2	1.1–5.4	8.6×10^{-5}–2.7×10^{-3}	Khan *et al.*, 2008
Ghana	Cassava	Pb	0.7–2.9	1.3–4.1	1.5×10^{-4}–1.9×10^{-3}	Literature synthesis
India	Yam	Cr, Ni	0.3–1.8	0.9–2.6	6.2×10^{-5}–9.4×10^{-4}	Literature synthesis
Bangladesh	Sweet potato	As	0.8–3.6	1.7–5.9	2.1×10^{-4}–4.8×10^{-3}	WHO, 2017

Values above HQ or HI = 1 indicate potential non-carcinogenic risk; LCR values exceeding 1×10^{-4} suggest unacceptable carcinogenic risk.

6. Mitigation and Policy Implications

Mitigation strategies include soil amendments (lime, organic matter, biochar) to reduce metal bioavailability, selection of low-accumulating cultivars, and restriction of food crop cultivation on contaminated lands. Food processing techniques such as peeling, soaking, and boiling can partially reduce metal content but do not eliminate risk. At the policy level, routine surveillance of staple foods, enforcement of environmental regulations, and integration of soil quality criteria into agricultural planning are imperative.

7. Research Gaps and Future Directions

Despite growing evidence, comparative multi-location studies using standardized analytical methods remain limited. Future research should focus on metal bioaccessibility after cooking, interactions between heavy metals and micronutrient status, and long-term epidemiological studies linking tuber consumption patterns with health outcomes.

9. Conclusion

Evidence indicates that cassava, sweet potato, and yam can act as significant vectors for human exposure to heavy metals, particularly Cd and Pb, in contaminated environments. Exceedances of FAO/WHO limits are common in polluted regions, posing tangible non-carcinogenic and carcinogenic health risks. Ensuring the safety of these staple foods requires integrated soil crop human health approaches, strengthened monitoring frameworks, and evidence based policy interventions.

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