



A Review on Estimation of Heavy Metals Contamination in Various Food Products

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ABSTRACT

Heavy metals contamination in food products significantly threatens public health globally. This review emphasizes the current understanding of heavy metal pollution in the food supply, with a focus on its prevalence, health risks, and mitigation strategies. The review covers key case studies from different regions, highlighting the concerning levels of toxic heavy metals like cadmium, lead, and chromium detected in commonly consumed fruits, vegetables, and seafood using various analytical techniques. These findings underline the urgent need for comprehensive monitoring, regulation, and remedial measures to safeguard food safety and security. Effective strategies to address heavy metal contamination in the food chain involve a multifaceted approach, including improved farming practices, advanced food processing techniques, and strengthened regulatory frameworks. Public awareness and education also play a crucial role in empowering consumers to make informed choices and advocate for safer food systems. This review critically analyzes the global situation regarding heavy metal pollution in plant-based foods, its implications for public health, its estimation techniques, and the key interventions required to mitigate this pressing environmental and food safety challenge.

Keywords: Toxicity, Heavy metals, Metalloids, Contamination, Analytical Techniques.

INTRODUCTION

Heavy metals are a group of metals and metalloids with relatively high densities, atomic weights, or atomic numbers.¹ They are toxic or poisonous at low concentrations and can accumulate in living organisms, causing various health problems due to their ability to accumulate in biological tissues.² **Heavy metals** are not easily degraded or destroyed so they can persist in the environment for long periods.³ Assuming that toxicity

and heaviness are correlated, metalloids can cause toxicity at low exposure levels, like arsenic.

Examples of heavy metals: lead (Pb), mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), iron (Fe), nickel (Ni), copper (Cu), zinc (Zn), and cobalt (Co).

However, not all heavy metals are toxic, and their effects depend on various factors like the metal type, concentration, exposure duration, and the organism's sensitivity. Here's a differentiation between toxic and non-toxic heavy metals:

Table 1: Types of toxic and non-toxic heavy metals with their health effects.

1. Toxic Heavy Metals	2. Non-Toxic or Less Toxic Heavy Metals
Definition: Toxic heavy metals are those that can cause harm or adverse health effects in living organisms, even at relatively low concentrations. They tend to accumulate in biological systems and can lead to various health problems.	Definition: Non-toxic or less toxic heavy metals are either essential for biological functions or do not cause harm at typical environmental concentrations. However, even these metals can become toxic at very high concentrations.
Mercury (Hg): Highly toxic, especially in its organic form (methyl mercury), and can affect the nervous system, leading to cognitive and motor dysfunction.	Iron (Fe): Essential for oxygen transports in the blood (hemoglobin) but can be toxic in excessive amounts, leading to conditions like hemochromatosis.
Arsenic (As): Although a metalloid, it is often grouped with heavy metals due to its toxic effects, including cancer, skin lesions, and cardiovascular diseases.	Manganese (Mn): Required for bone formation and metabolism, but excessive exposure can lead to neurological problems.
Lead (Pb): Known for causing neurological damage, especially in children, and can also affect kidney function, blood pressure, and reproductive health.	Zinc (Zn): Important for immune function, DNA synthesis, and cellular metabolism, but excess zinc can cause nausea, vomiting, and immune suppression.
Cadmium (Cd): Causes kidney damage, and bone demineralization, and is classified as a human carcinogen.	Copper (Cu): Necessary for enzymatic reactions and the formation of red blood cells, but can cause liver and kidney damage if accumulated excessively.
Chromium (Cr VI): Hexavalent chromium is highly toxic and can cause lung cancer, kidney and liver damage, and skin irritation.	Cobalt (Co): Vital for vitamin B12 function, but high levels can cause cardiomyopathy and thyroid dysfunction.



<p>Health Effects:</p> <ul style="list-style-type: none"> ❖ Neurological disorders ❖ Organ damage (kidneys, liver) ❖ Carcinogenic effects ❖ Cardiovascular issues ❖ Reproductive toxicity ❖ Bioaccumulation leads to long-term effects 	<p>Health Effects (at excessive levels):</p> <ul style="list-style-type: none"> ❖ Gastrointestinal disturbances ❖ Neurological issues ❖ Organ toxicity (liver, kidneys) ❖ Metabolic imbalances
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Toxic heavy metals cause harm at low concentrations, while non-toxic heavy metals are usually safe and even essential at low concentrations. Non-toxic heavy metals often have vital biological roles, whereas toxic heavy metals typically do not. Toxic heavy metals have more severe and widespread health impacts compared to non-toxic heavy metals.

POSSIBILITIES OF CONTAMINATION:

Contamination of heavy metals in food and food products like fruits and vegetables, nuts, grains and cereals, dairy products, meat and poultry, fish and seafood, legumes and pulses, oils and fats, tea and coffee, herbs and spices, and processed foods can occur through several pathways, posing potential health risks to consumers. Both toxic and non-toxic heavy metals can enter the food chain through soil, water, air, and agricultural practices.⁴

One primary source is **soil contamination**. Industrial pollution from mining, metal processing, and chemical manufacturing can release heavy metals such as lead, cadmium, arsenic, and mercury into the environment.⁵ These metals can then accumulate in agricultural soils, particularly those irrigated with wastewater or treated with metal-containing fertilizers or pesticides.⁶ These metals settle in the soil, where they are absorbed by plant roots. Additionally, agricultural practices contribute to soil contamination through the use of fertilizers, pesticides, and sewage sludge, which can lead to the accumulation of heavy metals in the soil over time.⁷ Irrigation with contaminated water, which may come from industrial discharge or runoff from agricultural lands, can also lead to soil contamination.⁸

Airborne contamination is another pathway. Heavy metals can be released into the atmosphere through industrial emissions, vehicle exhaust, and fossil fuel combustion. These metals can then settle on the surface of fruits and vegetables, causing contamination. Plants grown near highways or urban areas are particularly vulnerable to heavy metal contamination from vehicle emissions.⁹

Water contamination is also a significant factor. Irrigation using water from contaminated sources, such as rivers, lakes, or wells, can lead to the accumulation of heavy metals in fruits vegetables, and other food products. Flooding can exacerbate this issue by bringing contaminated sediments to agricultural fields, which can be absorbed by plants.¹⁰ Anthropogenic activities, such as the use of pesticides, fertilizers, and other agricultural inputs, can also contribute to heavy metal contamination of the food chain.^{7, 11-13}

Processing and handling practices can introduce heavy metals as well. Contaminated machinery or equipment used during the harvesting, processing, or packaging of fruits and vegetables can transfer heavy metals to the produce. Storing fruits and vegetables in containers made from or lined with materials that contain heavy metals can also lead to contamination.¹⁴

Fertilizers and pesticides contribute to contamination as well. Some fertilizers, particularly phosphate fertilizers, may contain traces of heavy metals like cadmium. Similarly, certain pesticides and fungicides used in agriculture may also contain heavy metals, which can accumulate in the soil and plants.¹⁵

Lastly, **genetic uptake** plays a role in heavy metal contamination. Certain plant species, known as hyperaccumulators, have a natural tendency to absorb and concentrate heavy metals from the soil in their tissues. This results in higher levels of heavy metals in the food they produce.^{9, 16}

Mitigating heavy metal contamination involves practices such as soil testing, using clean water sources, implementing proper agricultural techniques, and regularly monitoring environmental pollution.

Toxic heavy metals include lead, mercury, cadmium, arsenic, and chromium.

Lead contamination arises from industrial pollution, past use of lead-based pesticides, and airborne particles that plants absorb. In soil, lead accumulates from industrial activities and old pesticides, while water contamination from industrial discharge leads to its presence in fruits and vegetables. Airborne lead from industrial emissions or leaded gasoline also settles on crops, especially leafy vegetables.¹⁴

Mercury, mainly an aquatic issue, can affect plants through contaminated irrigation water and fish-based fertilizers. Soil contamination occurs from the atmospheric deposition of mercury from coal burning and gold mining. Irrigating crops with mercury-contaminated water, especially methylmercury, leads to plant uptake, though it's more common in aquatic systems. Fish contamination via bioaccumulation is significant, and using fish-based fertilizers can introduce mercury into the food chain.¹⁶

Cadmium from phosphate fertilizers and industrial pollution accumulates in soil and crops, especially leafy and root vegetables. It enters soils through mining, smelting, and battery manufacturing, with irrigation using



contaminated water further contributing. The use of sewage sludge on farmland also introduces cadmium into the soil, increasing its presence in the environment.^{9,14}

Arsenic contamination in soil stems from historical pesticide use and industrial activities like mining and smelting. Water with high natural arsenic levels, especially in regions reliant on contaminated groundwater, affects crops like rice and leafy vegetables. Atmospheric deposition from industrial emissions also contributes to arsenic contamination on crop surfaces.¹⁷

Chromium, specifically hexavalent chromium, contaminates soil through improper industrial waste disposal and can also be present in contaminated water and fertilizers, which affects crops grown in contaminated soils.^{9,18}

Mitigating contamination involves monitoring and managing these pathways to ensure food safety and reduce health risks.

Heavy metals can accumulate in various parts of a plant depending on the type of metal, the plant species, and environmental conditions. Here's a breakdown of where heavy metals might concentrate:

1. Roots:

Primary Accumulation: The roots are typically the first point of contact with heavy metals present in the soil. They often accumulate the highest concentrations of heavy metals, especially if the plant is a hyperaccumulator species. Some plants may retain most heavy metals in the roots, preventing them from moving to other parts of the plant.¹⁹

2. Leaves:

Translocation from Roots: Heavy metals absorbed by the roots can be transported to the leaves through the vascular system (xylem). This is common for metals like cadmium (Cd), lead (Pb), and mercury (Hg). Heavy metals can also be deposited on leaf surfaces directly from airborne sources (e.g., atmospheric pollution).^{19,20}

3. Stems:

Intermediate Transport: Stems can accumulate heavy metals as they serve as conduits for translocation from roots to other parts of the plant. Metals may accumulate in the vascular tissues (xylem and phloem), but the concentration is usually lower than in roots and leaves.¹⁶

4. Fruits/Seeds:

Lower Accumulation: Generally, fruits and seeds tend to accumulate lower concentrations of heavy metals compared to roots, stems, and leaves. However, certain metals like arsenic (As) can accumulate in grains and seeds. If heavy metals accumulate in fruits or seeds, they pose a significant risk to human health if these parts are consumed.²¹

5. Flowers:

Variable Accumulation: Depending on the plant species, flowers may accumulate some heavy metals, but typically at lower concentrations compared to roots and leaves.²²

6. Bark:

Surface Accumulation: In woody plants, bark can accumulate heavy metals from the environment, especially in polluted areas.¹⁶

IDENTIFICATION METHODS:

Spectroscopic methods are widely used in the determination of metals due to their sensitivity, accuracy, and ability to handle complex matrices. Here are some commonly used spectroscopic techniques: Atomic Absorption Spectroscopy (AAS), Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), Inductively Coupled Plasma Mass Spectroscopy (ICP-MS), X-ray Fluorescence (XRF), Atomic Emission Spectroscopy (AES), Flame Photometry, UV-Visible Spectrophotometry, and Laser-induced breakdown Spectroscopy (LIBS), Anodic Stripping Voltammetry (ASV), Energy Dispersive X-ray Spectroscopy (EDX or EDS).

Each method's limits should be carefully considered when selecting the appropriate technique for metal determination in specific applications.

Atomic absorption spectroscopy:

Atomic Absorption Spectroscopy (AAS) is an analytical technique used to detect and quantify metal elements in various samples, particularly effective for metals and metalloids in solution. It can analyze a wide range of elements, including alkali metals (like lithium and sodium), alkaline earth metals (such as magnesium and calcium), transition metals (like iron and copper), and post-transition metals (including lead and aluminum).²³ However, AAS has limitations with non-metals, noble gases, halogens, light elements, and certain radioactive elements that do not form stable atoms in a gaseous state or lack distinct absorption lines. It measures metal concentrations by detecting the absorption of light at specific wavelengths by free atoms.

Types:

Flame AAS (FAAS): Uses a flame to atomize the sample; suitable for detecting metals like copper, zinc, and iron.

Graphite Furnace AAS (GFAAS): Uses a graphite furnace to atomize the sample, providing higher sensitivity than FAAS; ideal for detecting trace metals such as lead, cadmium, and arsenic.

1. Sample Preparation:

- Dry the plant material in an oven at 60-80°C. Grind the dried plant material into a fine powder. Weigh an appropriate amount (e.g., 0.5-1 g) and transfer it to a digestion vessel. Add concentrated nitric acid (HNO₃) and, if necessary, hydrogen peroxide (H₂O₂) for



digestion. Digest the sample using a hotplate or microwave digestion system until a clear solution is obtained.

- **Dilution:** The digested sample is diluted to bring the analyte concentration within the detectable range i.e. Dilute the digested sample with deionized water to a known volume (e.g., 50 mL).
- **Standard Preparation:** Prepare calibration standards with known concentrations of the target elements.

2. Instrument Setup:

- **Selection of the Element-Specific Lamp:** Choose a hollow cathode lamp (HCL) or electrodeless discharge lamp (EDL) specific to the element you wish to measure. Each lamp emits the specific wavelength of light absorbed by the element of interest.
- **Wavelength Setting:** Set the monochromator to the appropriate wavelength corresponding to the absorption line of the element being analyzed.
- **Slit Width Adjustment:** Adjust the slit width to optimize the resolution of the absorption signal without compromising the intensity.

Flame or Graphite Furnace Setup: Depending on the sensitivity required:

- **Flame AAS:** Use a flame, typically air-acetylene or nitrous oxide-acetylene, to atomize the sample.
- **Graphite Furnace AAS:** Use a graphite furnace for more sensitive analysis, where the sample is atomized in a small graphite tube at high temperatures.

This procedure ensures accurate and reliable detection of metal elements in a variety of sample types using AAS.

Applications and Sensitivity

- **Trace Metals:** AAS detects trace elements like lead, mercury, cadmium, and arsenic.
- **Environmental Analysis:** Used to analyze metal contaminants in soil, water, and air samples.
- **Biological Samples:** Applied in clinical labs to detect metals in blood, urine, and tissues.
- **Industrial Applications:** Used in metallurgy, mining, and materials science to analyze metals in ores, alloys, and products.

The choice of elements that can be detected depends on the specific configuration of the AAS instrument, such as the lamp used (hollow cathode lamp or electrodeless discharge lamp), and the wavelength at which the element absorbs light.²⁴

Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES):

ICP-OES uses inductively coupled plasma to excite atoms and ions in the sample, which then emit light at

characteristic wavelengths. The intensity of this light is measured to determine metal concentrations.²⁵

Also known as ICP-AES (Atomic Emission Spectroscopy), is another powerful analytical technique used to detect and quantify elements in various samples. It is an analytical technique similar to ICP-MS but with different strengths and limitations.

Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) is a versatile technique for detecting a wide range of elements from the periodic table. It effectively detects alkali metals (Li, Na, K, Rb, Cs), alkaline earth metals (Be, Mg, Ca, Sr, Ba), and transition metals (Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Mo, Ag, Cd, W, Hg, Pt, Au). Additionally, it can analyze post-transition metals like Al, Ga, and In, making it a powerful tool for comprehensive elemental analysis in various fields.

Inductively coupled plasma mass spectrometry (ICP-MS)

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is a highly sensitive analytical technique used to detect and quantify trace elements and isotopes across a wide range of concentrations.²⁷ The ICP-MS technique is capable of detecting most elements in the periodic table, including alkali metals, alkaline earth metals, transition metals, actinides, and post-transition metals. Compared to AAS, the ICP-MS technique is generally more sensitive and can detect a wider range of elements.²⁸ Here's how ICP-MS compares in terms of the elements it can and cannot detect, including a brief procedure for its use:

1. Sample Preparation:

- **Digestion:** Prepare the plant sample following the same procedure as for AAS (drying, grinding, digestion, dilution).
- After digestion, dilute the sample with deionized water, typically to a final volume of 50 mL or 100 mL.
- **Internal Standard Addition:** An internal standard (a known concentration of a similar element) is often added to correct for potential variations during analysis.

2. Instrument Setup:

- **Plasma Ignition:** The instrument's plasma torch is ignited using an inert gas like argon, creating a high-temperature plasma.
- **Sample Introduction:** The sample is introduced into the plasma as an aerosol via a nebulizer.
- **Ionization:** The high-temperature plasma ionizes the elements in the sample.
- **Mass Analyzer:** The ions are directed into a mass analyzer, typically a quadrupole, which separates them based on their mass-to-charge ratio.²⁶

Advantages: Extremely sensitive, capable of detecting metals at parts per trillion (ppt) levels with high sensitivity



and precision, and can analyze multiple elements simultaneously.

Applications: Used in environmental monitoring, food safety, pharmaceutical analysis, geochemical studies, metallurgy, food testing, and chemical manufacturing.

Flame Photometry:

Flame photometry is an analytical technique primarily used to detect and quantify alkali and alkaline earth metals, such as sodium (Na), potassium (K), lithium (Li), and calcium (Ca). It involves introducing a sample into a flame, where the thermal energy excites the atoms; causing them to emit light at specific wavelengths.²⁹ The intensity of this emitted light is proportional to the element's concentration, enabling detection down to parts per million (ppm) levels. While effective for certain applications like clinical analysis and water testing, flame photometry has limitations: it cannot detect transition metals, heavy metals, or non-metals, as these do not emit detectable light. Additionally, elements with very low atomic numbers, like hydrogen (H) and helium (He), are also undetectable. So in summary, flame photometry is a useful, rapid, and relatively low-cost technique for determining alkali and alkaline earth metal concentrations, but has a more limited analytical scope compared to other atomic spectroscopy methods like atomic absorption spectrometry and inductively coupled plasma techniques.³⁰

1. Sample Preparation:

- **Solution Preparation:** The sample, whether solid or liquid, is typically dissolved or diluted in a suitable solvent, often deionized water or a buffer, to bring the concentration within the detectable range of the instrument.
- **Internal Standard Addition:** An internal standard may be added to the solution to account for potential variations in flame conditions and to improve accuracy.

2. Instrument Setup:

- **Flame Ignition:** The flame, typically produced using a mixture of air or oxygen with a fuel like acetylene, is ignited. The sample is then aspirated into the flame as a fine aerosol.
- **Atomization and Excitation:** The heat from the flame atomizes the sample and excites the atoms of the elements of interest.
- **Detection:** A monochromator isolates the specific wavelength of light emitted by the excited atoms, which is then detected by a photodetector.

Advantages:

Flame photometry is a relatively simple and cost-effective technique, suitable for detecting alkali and alkaline earth metals such as sodium, potassium, calcium, and lithium. It is particularly useful in clinical analysis, water quality testing, and agricultural studies.

Limitations:

Compared to ICP-MS, flame photometry has a limited range of detectable elements and lower sensitivity. It is generally not suitable for detecting transition metals, heavy metals, or non-metals, and it cannot detect elements present in very low concentrations. Additionally, elements like hydrogen, helium, and other light or non-metallic elements cannot be detected by flame photometry due to the absence of characteristic light emissions within the detectable range of the instrument.³¹

Applications:

Flame photometry is used in clinical laboratories for electrolyte analysis, in environmental monitoring for water quality assessment, and in agriculture for soil and fertilizer analysis. It is particularly favored for routine analysis where specific alkali or alkaline earth metals are of interest.

X-Ray Fluorescence (XRF) Spectroscopy

XRF involves bombarding a sample with X-rays, which causes the elements in the sample to emit secondary (fluorescent) X-rays. The energy and intensity of these emitted X-rays are characteristic of specific elements. It is a non-destructive analytical technique used to determine the elemental composition of materials. Here's an overview of the elements XRF can and cannot detect, as well as a brief procedure for XRF:

X-ray Fluorescence (XRF) is a versatile analytical technique effective for detecting a range of elements, though its efficiency varies. Light elements like boron (B), carbon (C), nitrogen (N), and oxygen (O) present challenges due to low fluorescence yields. Transition metals (e.g., Ti, V, Cr, Fe, Co, Cu, Zn) are well-detected, as are post-transition metals (Al, Sn, Pb) and rare earth elements (La, Ce, Nd). XRF also detects heavy metals like Tl, Hg, and Au, along with metalloids (As, Sb). However, light elements (H, He, B, C) and non-metals (F, Cl, S) are harder to analyze due to low emission intensities or overlaps with other elements.³²

1. Sample Preparation:

- **Preparation:** Samples are usually prepared as pressed pellets, thin films, or powders. For solid samples, they may need to be ground and mixed with a binding agent.
- **Homogenization:** Ensure the sample is homogeneous to avoid inconsistencies in results.

2. Instrument Setup:

- **X-ray Source:** The sample is irradiated with X-rays from a high-energy X-ray tube or a radioactive source.
- **Excitation:** X-rays excite the atoms in the sample, causing them to emit secondary (fluorescent) X-rays characteristic of the elements present.
- **Detection:** The emitted X-rays are detected by a detector, typically a silicon drift detector (SDD) or a proportional counter.



Advantages: Non-destructive, rapid analysis, and capable of detecting metals and other elements in solid, liquid, and powdered samples.

Applications: Used in environmental analysis, mining, material science, and quality control in manufacturing.

Laser-Induced Breakdown Spectroscopy (LIBS)

LIBS uses a highly focused laser pulse to create a microplasma on the surface of the sample. This microplasma vaporizes a small portion of the material, causing the atoms in the sample to become excited. As these excited atoms return to their ground state, they emit light at characteristic wavelengths. The emitted light is then analyzed by a spectrometer to determine the elemental composition of the sample.

Laser-Induced Breakdown Spectroscopy (LIBS) uses a focused laser pulse to create a microplasma, vaporizing a small portion of the sample. As excited atoms return to their ground state, they emit light at characteristic wavelengths, which is analyzed to determine the sample's elemental composition. LIBS can detect a wide range of elements, including metals, metalloids, and non-metals, but faces challenges with noble gases, light elements, and trace elements. It requires minimal sample preparation and offers rapid, non-destructive analysis. A LIBS is applied in materials science, metallurgy, environmental monitoring, and space exploration.³³

Advantages: LIBS is a rapid, non-destructive technique that requires little to no sample preparation and can analyze multiple elements simultaneously. It is also portable, making it suitable for field applications.

Applications: LIBS is widely used in materials science, metallurgy, environmental monitoring, and even in space exploration for in situ analysis of planetary surfaces.

Anodic Stripping Voltammetry (ASV)

Anodic Stripping Voltammetry is an electrochemical technique used for detecting trace levels of metals and other analytes in solution. It involves the deposition of analytes onto an electrode followed by their oxidation and measurement. Here's an overview of what ASV can and cannot detect, as well as a typical procedure for the technique:

Anodic Stripping Voltammetry (ASV) is used to detect and quantify heavy metals like lead, cadmium, mercury, copper, zinc, and trace elements like nickel and cobalt. It involves dissolving the sample in an electrolyte, using a working electrode (often gold, mercury, or carbon), a reference electrode (SCE or Ag/AgCl), and a counter electrode (platinum or graphite). Metal ions are deposited on the working electrode during the deposition step, and in the stripping step, the metals are oxidized and detected by measuring the resulting current, which is proportional to their concentration.³⁴

Advantages of ASV Over Other Techniques

High Sensitivity: ASV can detect trace levels of metals in complex matrices.

Selectivity: The technique is selective for metals that can be deposited and stripped electrochemically.

Rapid Analysis: ASV provides quick analysis and can be used for real-time monitoring.

Energy-Dispersive X-ray Spectroscopy (EDX or EDS):

Energy-dispersive X-ray Spectroscopy (EDX or EDS) is an analytical technique used to determine the elemental composition of a sample by detecting X-rays emitted from the sample when it is excited by a high-energy beam.

Energy-dispersive X-ray Spectroscopy (EDX) detects elements like iron, copper, lead, gold, silver, and non-metals such as silicon, phosphorus, and sulfur. It's effective for analyzing complex materials and trace elements. However, it struggles to detect light elements like hydrogen, helium, and boron due to their low atomic numbers and weak X-ray emissions. The process involves preparing the sample, irradiating it with an electron beam or X-ray source, and using a detector to analyze the emitted X-rays. EDX is often combined with imaging techniques for detailed elemental mapping.³⁵

Advantages of EDX Over Other Techniques

Elemental Analysis: EDX provides detailed information about the elemental composition of the sample.

Non-Destructive: The technique is generally non-destructive, preserving the sample for further analysis.

Spatial Resolution: When used with SEM, EDX can provide spatially resolved elemental analysis.

CASE STUDIES

Case Study-1: "Heavy Metal Accumulation in Fruits and Vegetables and Human Health Risk Assessment: Findings from Maharashtra, India,"

The findings of this study highlight the alarming levels of heavy metal contamination assessed in the soil and its potential accumulation in fruits and vegetables in commonly consumed fruits and vegetables in the Solapur district, Maharashtra region of India. The findings indicated that the levels of heavy metals, including arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb), in the soil were within tolerable limits. Interestingly, the study revealed that the accumulation of these heavy metals in fruits and vegetables did not correlate with the soil concentrations. For instance, while soil samples showed no detectable cadmium, garlic was found to contain cadmium. This suggests that other sources, such as wastewater irrigation, might contribute to the deposition of heavy metals on edible plants. Overall, the majority of fruits and vegetables tested in the Solapur district had heavy metal concentrations within permissible limits; however, some vegetables displayed elevated values for the Metal



Pollution Index (MPI), Health Risk Index (HRI), and Hazard Index (HI). These heightened levels indicate potential health risks if consumption of these vegetables is not controlled. Therefore, regular monitoring of heavy metal content in the area is recommended to safeguard public health, as excessive metal accumulation can lead to various health issues.

Case study-2: “Heavy Metals in Foods and Beverages: Global Situation, Health Risks and Reduction Methods.”

This case study examines the existing literature on the levels and distribution of heavy metals in various food categories, including fruits and vegetables, milk and dairy products, meat and meat products, oils and fats, and certain alcoholic beverages such as wines and beers. The concentration of heavy metals in food varies significantly due to numerous factors contributing to biomagnification. In many regions worldwide, the levels of heavy metals present in food do not pose significant health risks. However, certain areas, particularly those with active industrial activities or high pollution levels, exhibit concentrations exceeding the safety limits set by the World Health Organization (WHO). This environmental misuse necessitates careful attention to heavy metal contamination, as it can lead to serious health complications when consumed.

The presence of harmful elements such as lead, cadmium, and arsenic in food sources requires consumers to make informed choices regarding their dietary habits. Research findings reveal alarming statistics; for instance, the highest concentrations of cadmium were detected in lettuce from Romania, while excessive lead accumulation was noted in apples from Ukraine and Kosovo, as well as in lettuce and red potatoes from Romania. Even more concerning, high levels of arsenic were found in lettuce from Florida. Given these findings, it is imperative to address the issue of heavy metal contamination through effective policy measures aimed at reducing these elements in the food supply. The complexity of this topic calls for more in-depth studies across the food chain to ensure food safety and protect public health.

Case study-3: “Presence of heavy metals in fruits and vegetables: Health risk implications in Bangladesh.”

This case study examines heavy metal concentrations in commonly consumed vegetables from the Patuakhali district of Bangladesh, along with the estimated daily intake (EDI) by adults and associated health risks, assessed via Target Hazard Quotient (THQ) and Target Cancer Risk (TR). Soil samples from agricultural fields revealed toxic metals like arsenic (As), cadmium (Cd), and lead (Pb) at levels exceeding the maximum allowable concentration (MAC), indicating potential health risks for consumers. A dietary assessment showed that metal levels in vegetables surpassed the maximum tolerable daily intake (MTDI), highlighting a significant health threat.

The THQ analysis indicated that consuming these vegetables could lead to various health issues beyond

cancer, including organ damage and neurological disorders. The study also noted that arsenic and lead levels in specific vegetables pose a potential lifetime cancer risk to consumers.

This research provides critical insights into food safety and public health in Bangladesh, emphasizing the need for interventions to reduce heavy metal contamination in the food supply. Given the importance of vegetables in the Bangladeshi diet and economy, monitoring and regulating agricultural practices are essential. Further research on arsenic speciation is needed to understand its accumulation in the human body through vegetable consumption and to develop effective mitigation strategies.

Case study-4: “Determination of Heavy Metals in Some Fruits and Vegetables from Selected Market’s in Anambra State.”

This case study examines the levels of heavy metals in fruits and vegetables sourced from three selected markets in Anambra State, Nigeria. The investigation revealed varying concentrations of heavy metals across different produce samples—some with relatively low levels, while others exhibited concentrations exceeding safety thresholds. However, in the present study, the levels of heavy metals such as cadmium (Cd), lead (Pb), chromium (Cr), and nickel (Ni) were found to be above the permissible limits set by the FAO/WHO (Food and Agricultural Organisation and World Health Organisation).

This elevated contamination is likely a result of high pollution density in the area, possibly stemming from industrial activities, improper waste disposal, and the use of contaminated irrigation water. The high levels of these toxic metals in commonly consumed fruits and vegetables pose significant health risks to the local population, including potential organ damage, neurological disorders, and cancer due to the bioaccumulation of these substances in the human body.

Given these findings, health authorities and agricultural ministries in the region must implement strategies to reduce the concentration of heavy metals in the soil used for crop cultivation. Possible interventions include soil remediation techniques, stricter regulations on industrial emissions, and the promotion of safer agricultural practices. Addressing this issue is crucial to safeguarding public health and reducing the long-term risk of heavy metal exposure for consumers.

Case study-5: “Health risk assessment due to heavy metal exposure from commonly consumed fish and vegetables.”

The current research analyzed the concentrations of heavy metals—nickel (Ni), copper (Cu), arsenic (As), cadmium (Cd), and lead (Pb)—in soils from various locations in [Study Area Name]. The findings revealed that metal concentrations in some areas exceeded established soil quality standards, indicating a significant risk at the ecosystem level. Subsequent analysis of vegetables grown in proximity to these contaminated sites showed that all



samples contained elevated levels of the relevant heavy metals, which may pose serious health risks to the local community. Notably, the accumulation factors (AF) for copper and zinc were significantly higher than for other metals, suggesting a more pronounced transfer of these elements from soil to vegetables.

The health risk assessments, utilizing Target Hazard Quotients (THQ) and Hazard Indices (HI), indicated that consumers of these vegetables could experience toxic and carcinogenic effects, in addition to the health risks associated with malnutrition. The results particularly highlighted that arsenic and lead levels in vegetables may present a lifetime carcinogenic risk to consumers.

Importantly, the estimated heavy metal intakes in this study did not account for other potential sources of contamination from different food items, water, or air. Thus, further research is necessary to establish heavy metal levels in these additional matrices and investigate the incidence of diseases associated with heavy metal exposure in the study area. Such studies are crucial for developing comprehensive strategies to mitigate contamination and protect public health.

Strategies to limit heavy metal contamination:

1. Regulatory Oversight

- **Establishing Standards:** Governments should enforce strict regulations on heavy metal levels in soil, water, and food.³⁶
- **Regular Monitoring:** Conduct ongoing testing of environmental samples to ensure safety compliance.³⁶
- **Public Reporting:** Make test results publicly available to empower consumer choices.³⁷

2. Improved Farming Practices

- **Soil Management:** Use crop rotation, cover cropping, and organic fertilizers to enhance soil health and reduce heavy metal uptake.
- **Irrigation Practices:** Use clean water for irrigation and implement techniques like drip irrigation to minimize soil disturbance.
- **Phytoremediation:** Utilize plants that absorb heavy metals to reduce soil contamination.³⁸
- **Organic Farming:** Promote practices that avoid synthetic fertilizers and pesticides.

3. Innovative Technological Solutions

- **Bioremediation:** Use microorganisms to degrade or immobilize heavy metals in soil.³⁹
- **Advanced Soil Treatment:** Apply amendments like activated carbon and biochar to bind heavy metals.⁴⁰

- **Hydroponics and Aquaponics:** Implement controlled environments for better management of heavy metal levels.⁴¹

4. Effective Processing Methods

- **Washing and Peeling:** Properly wash and peel fruits and vegetables to reduce contamination.
- **Cooking Techniques:** Use boiling to leach out heavy metals from foods.⁴²
- **Food Safety Education:** Inform consumers about safe food preparation methods.

5. Research and Development

- **Conducting Studies:** Continue research to understand heavy metal uptake in plants and develop resistant varieties.
- **Development of Resistant Varieties:** Focus on breeding plants that resist heavy metal absorption.⁴³
- **Innovative Remediation Technologies:** Explore new detection and removal technologies for heavy metals in agriculture.

6. Public Awareness and Education

- **Consumer Education:** Raise awareness about health risks from heavy metal contamination and safe food sources.⁴⁴
- **Community Engagement:** Involve communities in monitoring heavy metal levels.

7. Collaboration and Partnerships

- **Stakeholder Collaboration:** Foster partnerships among government, agricultural organizations, researchers, and the private sector.⁴⁵
- **International Cooperation:** Share best practices and technologies globally to combat heavy metal contamination.⁴⁶

A multifaceted approach combining regulatory oversight, improved farming practices, innovative technologies, effective processing methods, and community engagement can significantly reduce the risks associated with heavy metal contamination in plant-based foods, ensuring food safety, protecting public health, and promoting sustainable agriculture.

CONCLUSION

In conclusion, this article highlights the significant global issue of heavy metal contamination in various food products, which poses a serious threat to food safety and public health. The accumulation of toxic heavy metals, such as cadmium, lead, and arsenic, in agricultural soils, irrigation water, and food crops can lead to the bioaccumulation of these contaminants in the human body, potentially causing a wide range of adverse health effects. This article also emphasizes the estimation of these heavy



metals using various analytical techniques like AAS, ICP-MS, ICP-OES, XRF-Spectroscopy, LIBS, Flame photometry, etc.

To address this pressing challenge, a multifaceted approach is required, involving collaborative efforts from policymakers, regulatory authorities, researchers, farmers, and the general public. Comprehensive strategies must be implemented to monitor and regulate heavy metal levels in the food supply, promote sustainable agricultural practices, and educate consumers on the risks associated with heavy metal exposure through their food.

Effective preventive methods, such as washing, peeling, and cooking, can help to reduce heavy metal levels in the final food products. However, a holistic approach involving multiple strategies is often necessary to ensure the safety of the food supply and mitigate the long-term health consequences of heavy metal contamination.

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