Emerging Contaminants in Food and Food Products

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In recent years, a wide variety of new chemicals have continued to be developed as a result of industrial development and associated anthropogenic activities. The microbial contaminants in the environment, more precisely, antibiotic-resistant genes/bacteria produced as a result of mutation due to antibacterial drugs, are also considered emerging contaminants and specifically called emerging microbial contaminants such as sapoviruses, *Waddlia chondrophila* and *Streptococcus parauberis*. Additionally, pharmaceuticals and personal care products are a diverse group of compounds that include ibuprofen, diclofenac, triclosan, antibiotics, anti-inflammatory agents, steroidal hormones and active ingredients in soaps, detergents and perfumes which could find their way into food materials, are tagged as emerging contaminants.

Given this, *Emerging Contaminants in Food and Food Products* discusses issues around the emerging contaminants in food and food products. Different types of contaminants, such as biological, chemical, organic, inorganic and microbial contaminants in foods, ways of detecting them and regulations surrounding global food safety, are all covered.

Key features:

- Discusses all the categories of contaminants in food and food products. Biological, chemical, organic, inorganic and microbial contaminants.
- Provides full information on emerging food contaminants, their effect on human and animal health, and how it affects global food security and emerging technological applications in solving this global problem.
- Gives detection and prevention strategies and guideline policies on emerging contaminants of foods.
- Brings into account global perspectives on food contaminants and health implications.

This volume will serve as an information hub of emerging contaminants for scientists/researchers and professionals globally. This book is a good collection of independent chapters, which presents full insights into the study of emerging contamination in food and the effects of these contaminants in humans and animals.

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Contents

2 Soil-Plant Interaction in Heavy Metal Uptake and Crop Quality

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2.1 INTRODUCTION

Agriculture plays a pivotal role in sustaining global food security and economic prosperity. However, contemporary agricultural practices are not without their challenges, and among the most pressing concerns is the contamination of agricultural soils with heavy metals (Alori *et al.*, 2022). Heavy metals, such as cadmium, lead, mercury, and arsenic, are persistent environmental pollutants known for their toxic effects on human health and the environment (Mitra *et al.*, 2022). These metals enter the soil through various anthropogenic activities, including industrial discharges, mining, and heavy metal-containing fertilizers, leading to their accumulation in agricultural soils (Alori, 2015).

The transfer of heavy metals from contaminated soils to crops is a complex process influenced by many factors. The interaction between soil and plants in the context of heavy metal uptake is a dynamic and multifaceted phenomenon governed by physical, chemical, and biological mechanisms (Cârdei *et al.*, 2021, Aransiola et al., 2022). Understanding this intricate relationship is essential for assessing the risks associated with heavy metal contamination and for developing strategies to mitigate their impact on crop quality and, ultimately, human health (Alengebawy *et al.*, 2021).

Heavy metal contamination of agricultural soils is a global issue, affecting both developed and developing nations. It poses a significant threat to the sustainability of agriculture, as it not only diminishes crop productivity but also compromises the safety and quality of the food supply (Rashid *et al.*, 2023). Furthermore, the global population's increasing demand for food necessitates innovative approaches to ensure that crops can be produced safely and efficiently in contaminated environments. Addressing this challenge requires a comprehensive understanding of the processes governing heavy metal uptake by plants and their subsequent impact on crop quality.

This comprehensive review delves into the intricate interactions between soils and plants, focusing on the uptake of heavy metals and their consequences for crop quality. We will explore the physical and chemical properties of soils that influence heavy metal mobility and availability to plants. Additionally, we will examine the physiological and molecular mechanisms that allow plants to tolerate or accumulate heavy metals. By shedding light on these complex relationships, we aim to contribute to developing sustainable agricultural practices that protect both the environment and human well-being while ensuring a consistent and high-quality food supply.

2.2 DYNAMICS OF SOIL-PLANT INTERACTION

The term soil-plant interaction describes the intricate interaction between soil and plants, in which the earth supplies the water and nutrients needed for plant growth while the plants change

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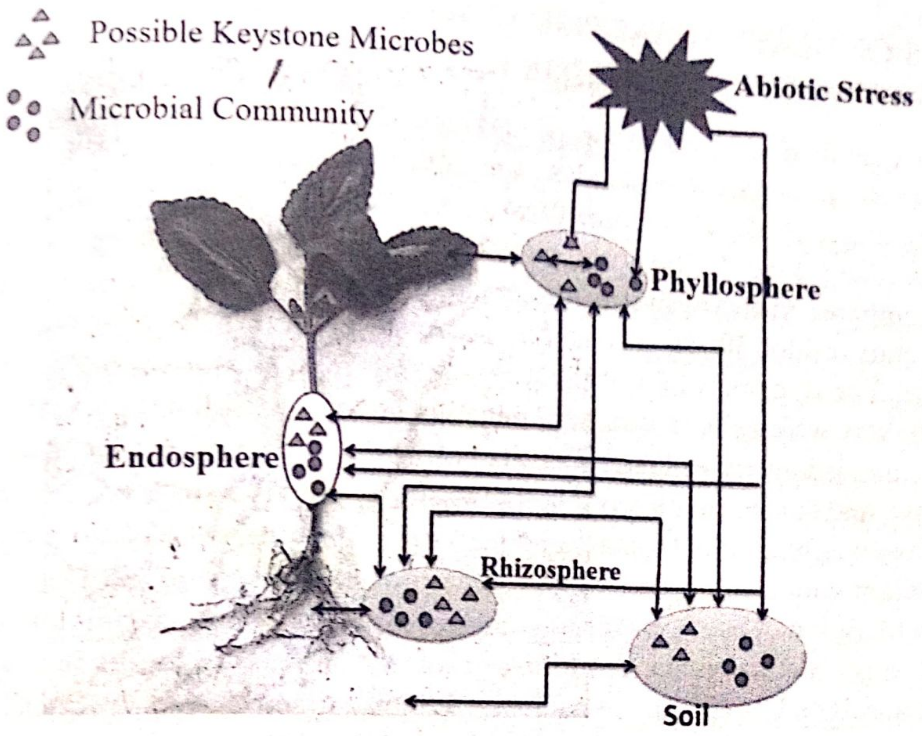

FIGURE 2.1 Interaction in the phytobiome between the plant and its surroundings. (Jones et al. (2019)).

the chemical and physical properties of the soil. Because it influences numerous ecological processes like nutrient cycling, carbon sequestration, and water infiltration, this interaction is essential for maintaining life on Earth (Angulo-Bejarano *et al.*, 2021; Ke *et al.*, 2021). On the other hand, various biotic and abiotic variables that affect plant growth and development are involved in the dynamics of soil-plant interaction. Mycorrhizae, bacteria, and other microorganisms that create symbiotic interactions with plants to improve nutrient intake and stimulate growth are examples of biotic factors. Additionally, the improvement of soil structure and nutrient cycling is greatly aided by the presence of soil fauna, including earthworms, termites, and ants. The soil's structure, pH, moisture content, temperature, and nutrient availability fall under the category of abiotic variables, in contrast (Angulo-Bejarano *et al.*, 2021; Ke *et al.*, 2021). By affecting root formation, nutrient uptake effectiveness, water availability, and stress tolerance, these variables impact plant growth (Figure 2.1).

By secreting organic molecules that bind soil particles to one another to create aggregates, plants can change the physical characteristics of the soil. These aggregates increase soil pore space and speed up water penetration to improve soil structure. By producing organic acids that solubilize elements like phosphorus and iron crucial for plant growth, plants also alter the chemical composition of the soil. In turn, the soil provides plants with such vital nutrients as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), and micronutrients, the availability of which is influenced by a number of variables like soil pH, organic matter content, microbial activity, and weathering processes (Sevanto *et al.*, 2020).

Understanding these dynamics is essential for designing sustainable agricultural practices supporting healthy soils and productive crops. Soil-plant interaction is a complicated process that involves several feedback loops between plants and their surroundings. Plants also usually cause changes in the soil microbial community composition, which can consequently affect the growth of neighboring plants or individual plants that ultimately colonize the soil. This process is referred to as plant-soil feedback (PSF) (Bever, 2003; Ikhumetse *et al.*, 2019). The PSF can modify interspecific differences in plant performance, thereby affecting the composition of the plant community as plant species vary in their effects on, and responses to, soil microorganisms (Enni-

2.3 EFFECTS OF HEAVY METAL POLLUTION ON SOIL MICROORGANISMS AND THEIR ROLE IN PLANT UPTAKE

Heavy metals are defined as a sub-group of elements that exhibit metallic properties, includin transition metals, some metals, lanthanides, and actinides, using density as a main distinguish ing factor (Suciu *et al.*, 2008). Heavy metals are metals with a naturally high atomic weight an a density greater than 5 g cm^{-3}. The heavy metals' chemical characteristics are the most practica aspects when compared to their physical properties. An environmental toxicity that exceeds th standard maximum residue limits (MRL) has received extraordinary consideration from think tanks worldwide. The dynamics of soil-plant interaction may be impacted by heavy metal con tamination in the soil, which can in turn have negative impacts on soil microorganisms. Numerou crucial tasks are carried out by soil microbes, including the cycling of nutrients, the breakdown o organic materials, and the stimulation of plant growth. By changing the composition of microbia communities, lowering microbial biomass and activity, and fostering resistant microbial diversity heavy metal contamination can interfere with these processes (Ke *et al.*, 2021). It is important t note that the proliferation of heavy-metal-tolerant (resistant) microbial community could be due t the presence of heavy metals uptake and efflux genes; as a follow-up to this in a study conducte by Ayangbenro and Babalola (2020), heavy metal solubilizing and resistant *Bacillus* sp. obtaine from a gold-contaminated soil contained *cadA*, *PbrA*, and *czcD* genes encoding heavy metal efflu activities. This suggests that the microbial diversity resistant to heavy metal effects could be first partaker in uptake prior to plant uptake. In addition, *Pantoea* sp. and *Pseudomonas koreensi* were able to produce polysaccharides containing protein bioflocculant, which have *cadA*, *czcD* and *chrA*, *czcD* genes, respectively, that biosorp heavy metal through flocculation (Ayangbenr *et al.*, 2019). Also, a study conducted by Fashola *et al.* (2020b) revealed the predominance o Gram-positive bacteria in heavy-metal-contaminated soil. These microbes have thick peptidogly can layers as well as teichoic acid, which sponsors the heavy metal-positive and Gram-positiv bacteria-negative cell wall binding capacity demystified in a review authored by Ayangbenr and Babalola (2017) and Fashola *et al.* (2016). The predominant microbial diversity in heavy metal-contaminated soil is the resilient members of Proteobacteria, Actinobacteria, and Firmicute taxa. Notably, most post-abiotic stress filtering of plant microbial communities always restructur the native microbial community for new taxa. These taxa are mostly the core survival taxa due to their adaptive characteristics, enhancing their key functionalities favorable to plants. In this case of heavy metal stress/contamination aside from being metallophilic, proliferating members of these taxa are also acidophilic (Fashola *et al.*, 2020b). Using heavy-metal-resistant *Bacillus cereus* NWUAB01, which is a member of Firmicutes taxum as a case study, was revealed to contain genes like *ChrA* (chromate transport protein), cadmium-resistant transporter, cadmium efflux sys- tem accessory protein, *CopC* and *CopD* (copper-resistant proteins), cobalt-zinc-cadmium-resistant proteins (CzcD), and arsenic efflux pump protein in its genome, which enhanced its functionality in heavy metal solubilization (Babalola *et al.*, 2019; Ayangbenro and Babalola, 2020). In addition, a study on heavy-metal-resistant bacteria synergistic activity unveiled their ability to immobilize lead, nickel, and zinc (Fashola *et al.*, 2020a).

Hence, this suggests that most bacterial taxa in a heavy-metal-contaminated soil could have heavy metal uptake, bioflocculation, immobilization, or efflux pumping functionalities and is a potential bioremediation candidate which can be applied in sustainable cleaning of contaminants. This also implies that in the natural environment contaminated with heavy metals, soil biologi- cal sentinel, particularly bacteria, is constantly involved in plant-assisted contaminant uptake (Ojuederie and Babalola, 2017). In line with plant-assisted contaminant removal, these tolerant bac- teria have been applied as bioinoculants with multifunctionalities, including purposeful heavy met- als remediation from the soil, plant growth promotion, and phytoprotection. A typical example is a study involving the application of a continuum of bacteria to extract heavy metals from *Brassica juncea*, which also enhanced the plant growth through phosphate solubilization, indole acetic acid

IAA, hydrogen cyanide, and ammonia production (Ndeddy Aka and Babalola, 2016). Therefore, heavy-metal-contaminated soil has wealthy bioinoculants applicable for sustainable agricultural productivity enhancement in threatened soil.

By attaching to functional groups on microbial cell walls or enzymes, heavy metals can interfere with the activity of soil microorganisms. This may lead to a decrease in the rate of nutrient cycling and a rise in the amount of organic matter in the soil. Furthermore, heavy metals can change the pH of the soil, which has an effect on microbial populations as well.

The dynamics of plant uptake are also significantly impacted by heavy metal contamination. Through their roots, plants absorb heavy metals, and this uptake is controlled by a number of elements, such as the pH of the soil, the amount of organic matter, and the presence of other nutrients. Heavy metals can compete with important minerals for uptake by plants when they are present in the soil, resulting in nutrient deficits and slowed plant growth (Mahmoud *et al.*, 2023). The average concentrations of heavy metals in sediment samples in a study in Iraq took the order, in terms of high concentrations, as follows: Ni>Zn>Cu>Pb>Co>Cd, respectively. Concentrations of heavy metals in the sediment samples were found in ranges as thus: Co (3.88–19.93 mg kg^{-1}), Cu (21.29–40.12 mg kg^{-1}), Cd (0.024–0.721 mg kg^{-1}), Pb (9.02–18.41 mg kg^{-1}), Zn (39.22–133.30 mg kg^{-1}), and Ni (108.41–173.11 mg kg^{-1}).

More so, heavy metals can build up in plant tissues and harm a plant's metabolism. In extreme circumstances, this can result in mortality, chlorosis, and stunted growth. If plants that have accumulated heavy metals are ingested, there may be a consequent risk to human health.

Soil microorganisms and their function in the interactions between soil and plants are significantly impacted by heavy metal contamination (Alengebawy *et al.*, 2021; Ke *et al.*, 2021). Developing methods to reduce the harmful effects of heavy metal contamination on soil health and plant growth requires an understanding of these effects.

2.4 MECHANISMS OF HEAVY METAL TRANSPORT AND ACCUMULATION IN PLANTS

Plants have developed complex mechanisms to enable them to cope with heavy metals present at levels above their threshold concentrations. They are thus classified as hyper-accumulators (>1000 μg^{-1}) and non-hyper-accumulators (<500 μg^{-1}). The accumulation of heavy metals in plant tissues can limit development and yield as they are harmful to plants. Certain plant species have, however, evolved defenses to withstand and even ingest metals. Uptake, translocation, sequestration, and detoxification are only a few of the procedures that are involved in the mechanisms of heavy metal transport and accumulation in plants (Abioye et al., 2013; Angulo-Bejarano *et al.*, 2021).

2.4.1 Uptake

Plants are able to absorb heavy metals from the soil. Soil degradation is one of the many causes of the presence of heavy metals in soils. Transporters that are unique to each metal ion mediate the uptake process. These transporters, which are found on the plasma membrane of root cells, are able to passively or actively transfer metal ions into the cell.

2.4.2 Translocation

Heavy metals can travel through the xylem or phloem to other plant sections after entering the root cell. Transporters unique to each metal ion mediate the translocation process as well. Some plants can selectively transport hazardous elements like lead and cadmium while rejecting necessary metals like iron and zinc (Angulo-Bejarano *et al.*, 2021).

2.4.3 Sequestration

Plants can store heavy metals in their vacuoles or cell walls to prevent toxicity. Metal ions a actively transported from the cytosol into the vacuole by the process of vacuolar sequestratio where they are then stored in an inactive state (Angulo-Bejarano *et al.*, 2021). Metal ions m attach to pectin or cellulose in the cell wall for cell wall sequestration.

2.4.4 Detoxification

By changing heavy metals into less harmful forms or chelating them with organic ligands, plan can detoxify heavy metals. Chelation is the process of attaching metal ions to organic molecul like phytochelatins or metallothioneins so they can be stored in the vacuole or moved to other pla areas (Jiwan and Kalamdhad, 2011). In conclusion, plants have evolved a number of processe including absorption, translocation, sequestration, and detoxification, to tolerate and ingest hea metals (Angulo-Bejarano *et al.*, 2021).

2.5 IMPACT OF SOIL-PLANT INTERACTION ON HEAVY METAL UPTAKE

Pollution of soils with heavy metals has become a common phenomenon across the globe as a resu of increasing geologic and anthropogenic activities (Wuana and Okieimen, 2011). Plants growin on these soils exhibit a reduction in growth, performance, and yield. Heavy metals are naturall present in the soil but geologic and anthropogenic activities increase the concentration of these ele ments to amounts that can cause harm to both plants and animals.

Physiological and biochemical processes that reduce the growth of plants growing on heav metal-polluted soils have been recorded. Yield reduction, which eventually leads to food insecurity is a result of the continued decline in plant growth. Heavy metals have metallic properties such as ductility, malleability, conductivity, cation stability, and ligand specificity. They are known to have relatively high density and high relative atomic weight with an atomic number greater than 20. Some heavy metals such as Co, Cu, Fe, Mn, Mo, Ni, V, and Zn are required in small quantities by organ- isms (Aransiola *et al.*, 2013). However, excess quantities of these elements can become harmful to organisms. Other heavy metals such as Pb, Cd, Hg, and As (a metalloid but generally referred to as a heavy metal) are not beneficial to organisms and as such referred to as the "main threats" since they are very harmful to both plants and animals.

Metals exist alone or in combination with other soil components, which may include exchange- able ions adsorbed on the surfaces of inorganic solids, nonexchangeable ions and insoluble inor- ganic metallic compounds such as carbonates and phosphates, soluble metal compounds or free metal ions in the soil solution, metal complex of organic materials, and metals attached to silicate minerals. Metals bound to silicate minerals characterize the background soil metal concentration as they do not cause pollution problems when compared with metals that exist as separate entities or those present in high concentration in the other components.

Heavy metals can be conveyed over long distances in gaseous as well as particulate phases, which leads to their quick accumulation in soil, water, and living systems. While certain heavy metals are essential for optimum plant growth, extremely high amounts harm the plants and other organisms in the food chain. Agrochemicals usage and long-term application of urban sewage sludge, industrial waste disposal, waste incineration, and vehicle exhausts are the main sources of these metals in agricultural soils. Soil with high concentrations of heavy metals leads to their absorption and accumulation by plants, which eventually passes into humans through the food chain. Both the underground and aboveground surfaces of plants can absorb heavy metals that directly or indirectly distress plant health. The consequences of these activities are inhibi- tion of cytoplasmic enzymes and damage to cell structures due to oxidative stress (Aransiola *et al.*, 2019).

There are numerous ways soil properties affect heavy metal availability. Research has shown that soil pH is the key factor affecting metal availability in soil. Organic matter and hydrous ferric oxide have been revealed to reduce heavy metal accessibility through the immobilization of these metals. Heavy metals and some soil physical properties, such as moisture content and water-holding capacity, have been shown to be positively correlated.

Density and type of charge in soil colloids are other factors that affect metal availability. There is a large boundary and specific surface area that soil colloids provide by helping in controlling the absorption of heavy metals in natural soils. There are inconsistencies in studies comparing the effect of heavy metals on soil biological properties. Some researchers have recorded adverse effects of heavy metals on soil biological properties, while others have reported no relationship between high heavy metal absorptions and some soil (micro) biological properties. On the contrary, other scientists have reported microbial conversion of heavy metals to stable complexes through increased wettability and reduced surface tension effects of biosurfactant – an extracellular polymer (Ayangbenro and Babalola, 2020). Some of the contradictions may arise from the fact that some of these studies were carried out under laboratory conditions, exhausting artificially contaminated soils while others were carried out using soil samples from polluted fields. The source of the soil samples used in these experiments notwithstanding, the effect of heavy metals on soil biological properties needs to be studied in more extensively to have a broader understanding of the effect of these metals on the soil ecosystem. Heavy metals may transform soil properties, especially soil biological properties. Changes in microbiological and biochemical properties when monitored after contamination can be used to evaluate the intensity of soil pollution because these methods are more delicate and results can be obtained rapidly compared to monitoring soil physical and chemical properties. Heavy metals may influence the number, diversity, and activities of soil microorganisms. The harmfulness of these metals on microorganisms is a result of several factors such as soil temperature, pH, clay minerals, organic matter, inorganic anions and cations, and chemical forms of the metals.

The existence of one heavy metal may affect the availability of another in the soil and even plants. That is to say that hostile and synergistic characteristics exist among heavy metals. For example, an inhibitory effect of Mn on the total amount of mineralized C was antagonized by the presence of Cd in a report likewise; Cu and Zn and Ni and Cd have been reported to compete for the same membrane in plants. Copper (Cu) was stated to increase the toxicity of Zn in spring barley in another research. This suggests that the interaction between heavy metals is quite complex; hence, more study is necessary in this area. Different species of the same metal may also interact with one another. Studies have shown that the presence of arsenite strongly suppressed the uptake of arsenate by rice plants growing on a polluted soil.

Heavy metal contamination is a severe global environmental problem as it poorly affects plant growth and genetic variation. It also changes the structure and activity of soil microbial communities. Plants are sedentary; they do not have the ability to move actively to evade contaminated environments. As such, their only chance to withstand unfavorable conditions is the mobilization of defense mechanisms and evolution of tolerant genotype. Some plants are genetically adjusted to grow and reproduce in soils polluted with heavy metals. However, plants that grow in uncontaminated soils have developed tolerant ecotypes that survive in toxic environments. Furthermore, plant populations growing at polluted sites are often genetically different from those of the same species in adjacent non-contaminated sites. These metal-tolerant populations provide a typical example of microevolution.

The available heavy metals for plant uptake are those that are present as soluble constituents in the soil solution or those that are easily solubilized by plant root exudates. Although plants require certain heavy metals for their growth and upkeep, excessive amounts of these metals can become toxic to plants. The capacity of plants to store essential metals similarly enables them to gain other nonessential metals. Since metals cannot be broken down, when absorptions within the plant surpass optimal levels, they badly affect the plant both directly and indirectly.

One of the direct noxious effects caused by heavy metal pollution in the soil includes inhib of cytoplasmic enzymes and cell structure damage due to oxidative stress. And the indirect to effect is the substitution of essential nutrients at the cation exchange sites of plants. Furtherm the negative influence heavy metals have on the growth and activities of soil microorganisms m also indirectly affect the growth of plants. For instance, a reduction in the number of beneficial microorganisms due to high metal concentration may lead to a decrease in organic matter decom sition, leading to a decline in soil nutrients. Enzyme activities useful for plant metabolism may a be hampered due to heavy metal interference with the activities of soil microorganisms. These to effects (both direct and indirect) hinder plant growth, occasionally leading to plant death.

The extent to which heavy metal toxicity will affect plant growth will depend largely on particular heavy metal involved in the process. Specific metals have toxic effects on the growth, b chemistry, and physiology of various plants. Low concentrations of heavy metals may also inhi the physiological metabolism of plants. For instance, Pb, Cd, Hg, and As are not beneficial in pl growth yet adversely affect plant growth at very low concentrations. Significant decrease has be reported in the height of rice plants growing on soil contaminated with 1-mg Hg/kg. Oftentim decreases in growth parameters of plants growing on polluted soils can be linked to reduced pho synthetic activities, plant mineral nutrition, and reduced activity of some enzymes.

2.5.1 Factors Influencing Heavy Metal Uptake By Plants

Solubility of the metal associated with the solid phase is the major factor overseeing metal avai ability to plants in soils. In order for root uptake to occur, a soluble species must exist closest the root membrane for some predictable period (Cataldo and Wildung, 1978). Although partial understood, it is essential to break down the translocation tool of metal throughout the plant, whic takes place after the foliar absorption of heavy metals by plant leaves Wuana and Okieimen (2011 Different authors proposed different tools for metal/nutrient entrance to plants through foliar tran fer. Shahid *et al.* (2016) mentioned that foliar uptake in general enhances metal content in leaf tis sues but is difficult to differentiate between the processes of foliar uptake and metal transfer withi the plants and that adsorption and internalization through the cuticle and penetration of metal through the stomata are the two major steps involve in foliar metal uptake. There are several factor that can affect the heavy metals uptake processes by plants. Being acquainted with these factors ca enhance and greatly improve uptake performance by plants (Cataldo and Wildung, 1978).

2.6 SOIL FACTORS

Soil Metal Concentration; Soils signify the major source of trace elements over geologic time. On a universal basis, soils display an average arrangement close to the earth's crust but the near-surface parent material from which soils are derived is not constant, and soil-forming processes differ evi- dently from one climatic area to another, giving rise to considerable overall inconsistency in trace metal concentrations (Krishna and Ahuja, 2023). Rise in average trace element levels projected to arise from the deposition of metal from a coal combustion plant; operating with electrostatic precip- itators over a 40-year period is relatively low, amounting to less than 1% rise in most of the elements amount to less than 0.1% of the total with only Cd, Ge, Hg, Mo, Se, and W meeting or surpassing this value (Cataldo and Wildung, 1978). However, the increases in soil concentration estimated from studies are generally unpredictable. Therefore, the extent of changes in the total concentration of these elements in the soil would be an unclear indicator of increases in environmental levels due to coal combustion. Therefore, there is a need to develop other chemical or biological measures of increased levels and plant availability of trace metals in soil from this source (Cataldo and Wildung, 1978). In addition to fossil fuel combustion, trace elements may enter the soil indirectly as a result of industrial activity and directly from municipal wastes, fertilizers, or other soil extracts. Several of these sources, disposal of wastes, may also result in locally higher concentrations of trace elements in soils than estimated to arise from releases to the atmosphere, and increases may be detectable by chemical analysis. However, a key consideration in the use of plants as monitors of these increases will be the availability of the elements for plant uptake Wuana and Okieimen (2011).

2.7 PROCESSES AND PROPERTIES OF SOIL

The major factor responsible for the availability of plants in soils is likely to be the solubility and the thermodynamic activity of the uncomplicated ion since, in order for root uptake to occur, a soluble species must exist adjacent to the root membrane for a period of time (Rieuwerts *et al.*, 1998). The form of this soluble species will have a strong effect on its prolonged existence in soil solution, mobility in soils, and the rate and extent of uptake, and maybe, mobility and toxicity in the plant (Abdullahi *et al.*, 2021). Once dropped, metal-containing materials are subject to chemical and microbial alteration, with metal solubility eventually approaching thermodynamic equilibrium with inherent soil minerals and organic matter (Zhou *et al.*, 2023).

The rate and extent of solubilization are overseen by the physicochemical properties of the deposited material, soil processes, and soil properties. The major sources of metals in the soil may be sorted according to anticipated initial solubility in the soil. Particulate oxides such as those arising from fossil fuel combustion or nuclear fuel recycling initially may be expected to be largely insoluble in the soil solution (Adnan *et al.*, 2022). Eventually, solubility should be a function of the composition, configuration, and equivalent diameter of the particle as well as soil properties and processes. Oxide particles containing the highest concentrations of impurities in the crystal lattice may exhibit the greatest solubility. The blending of configuration and equivalent diameter as reflected in the surface area open to solution will be the other main factors influencing oxide solubility. Cataldo and Wildung (1978) Once solubilized, the metals will be subject to the chemical reactions influencing soluble salts. Hydrolyzable metals (e.g., Ni, Cd) or metals forming insoluble precipitates with S or P on entering the soil in soluble forms may be expected to be rapidly insolubilized at the near neutral pH of most soils due to hydrolysis on dilution and subsequent precipitation on, or reaction with, particle surfaces (Jung, 2008). Certain elements (e.g., Fe) may also form precipitates with S or P. Equally, metals not subject to marked hydrolysis (e.g., TI) may be initially more soluble. Metals with low ionic potentials tend to form mostly simple soluble ions, while metals with intermediate and high ionic potentials tend to form soluble complexes (Cataldo and Wildung, 1978). Current indications show that soil microorganisms may play an important role in this process by producing soluble ligands with a high affinity for metals. Metals entering the soil as stable organic complexes, such as those used in fertilization to appropriate micronutrient deficiencies or those possibly present in discharge from a nuclear fuel separation facility, may originally be highly soluble (Manikant and Rajeeva, 2021). The period of solubility and mobility in the soil will be a result of how stable the complex will be in replacing major competing ions, such as Ca and H and the stability of the organic ligand to microbial decomposition. The interference of the complex may lead to a striking reduction in metal solubility through hydrolysis, precipitation, or exchange reactions, as explained above (McGowen *et al.*, 2001). A portion of the ion released may react with another, possibly more stable, ligands in the soil. The mobility of the stable, intact complexes, in turn, will be primarily a function of the charge on the complex, which will govern the degree of sorption on soil particulates. Additional simplifications of metal activities on the basis of origin are complicated by the tremendous importance of soil properties and processes in motivating metal behavior on a regional and local basis (Opeyemi *et al.*, 2020). Soil physic-chemical properties may be expected to have complex, dependent effects on metal solubility. Investigations have shown trace metals exhibiting a range chemistries, and it may be concluded that the soil physicochemical parameters are the most significant in influencing the solubility of metals including solution composition (inorganic and organic soluble), Eh, and pH; type and density of charge on soil colloids; and reactive surface area (Cataldo and Wildung, 1978). These occurrences will be dependent upon soil properties, including metal concentration and form, particle size distribution, quantity and reactivity of hydrous oxides, mineralogy, degree of aeration, and microbial activity. These soil prope highly movable geographically and will be a function of the joint effects of parent materia raphy, climate, biological processes, time, and activities of man. It is well-defined that the tors influencing the concentration, form, and plant availability of metals are highly comp the use of plants as checks of increased metal levels arising from pollutant sources is rela detailed awareness of influential phenomena for specific pollutants, soils, and geographical l (Hashim *et al.*, 2011).

2.8 PLANT SPECIES CHARACTERISTIC

The uptake of various kinds of compounds can be affected by the type of plant species. T cess of the phyto-extraction technique depends upon the identification of suitable plant that hyper-accumulate heavy metals and produce large amounts of biomass using establish production and management practices (Nedelkoska and Doran, 2000).

The plant uptake of chemical species in soil solution is also supported by a number factors. These comprise the physical processes such as root intrusion, water, and ion flu their relationship to the kinetics of metal solubilization in soils; biological parameters, in the kinetics of membrane transport, ion interactions, and metabolic fate of absorbed ions; ability of plants to adapt metabolically to changing metal stresses in the environment (Catal Wildung, 1978).

2.8.1 Ion Replenishment in the Rhizosphere

The effectiveness with which plants gather essential nutrients and non-nutrients from the supported by the interrelationships between plant and soil physical factors (Shaji *et al.*, 202 process of plant root interference within the soil profile provides a vast rhizosphere for ion a tion. Studies have shown that after a few months of plant growth, the roots of some plan an increased surface area and an increased combined length. This actually provides an eff absorptive surface in contact with soil particles and associated soil solution (Griffiths and 2020). Plant uptake can rapidly deplete the concentration of individual ions in solution. Deple ions in the rhizosphere is eased to some degree by diffusion of ions and by mass flow of both and ions from immediate soil induced by the transpirational requirement of the plant. Even the supply of ions within the rhizosphere is ordered by the kinetics of solubilization of ions ads to the solid phase of soil (Griffiths and York, 2020).

2.8.2 Kinetic Parameters Controlling Plant Absorption of Metals

Several years ago, authors studied 15 trace metals in plants and their behavior, and from their ies, there are indications that abiotic and biotic soil processes control the solubility and availab metals for plant uptake. Plants take up metals at different rates, and metals, once absorbed, are ified as to their mobility within the plant, implying a second point of metabolic regulation (El and Elhassan, 2014). There are complications in retaining plants as pointers of environmental tion. When the bioavailability of a number of endogenous soil elements and soluble amended were compared, it is noteworthy that the reported concentration ratios (CR) were based on the original soil concentration of each element and on the total metal amended. Only a small of the original metal is soluble and therefore available; similarly, although amended metal supplied in soluble forms, non-volatile metals' solubility increased after incubation. This that these elements remain as stable, soluble species within the soil solution and are more for plant uptake. This may result from disparities in the nature of metal in association with phase or in soluble species, which affect the type and kinetics of exchange between origin and added metals. It is evident that, as discussed earlier, the origin or source of metals play major roles in affecting plant availability in soil (Chojnacka *et al.*, 2005). The presumption in terms of the use of plants as checks of metal pollution is clear. For example, the uptake may not accurately exhibit recent invasions of metals into the environment. Essential nutrients show two types of distribution in shoot tissues: relatively uniform distribution with leaves being the primary site of deposition and transport within the plant through passive movement in the xylem and initial uniform shoot distribution, with remobilization of specific elements from leaves through phloem transport during senescence, to either developing leaves and/or seeds (Pilon-Smits and Freeman, 2006). The circulation of Cd, Hg, Sn, and Tl is similar to nutrient species such as Mg, K, Cu, and Mo, reflecting the potential for remobilization from senescing tissues. Complexation may provide a basis for holding the solubility and mobility of chemically reactive species, warrant the conservation of substrates by permitting remobilization, and delivering a means of compartmentalization. Complexation of non-nutrients may also characterize a tool for detoxification (Michaud *et al.*, 2021). This aspect will be tackled in combination with accumulator or indicator species. Although it is generally agreed that nutrient uptake by plants is metabolically regulated (Legendre, 2013). There is a question as to the mechanisms controlling the absorption of non-nutrient species. The evidence is essential to understand the behavior of metal pollutants in plants can be inferred from a broad database obtainable for nutrient species. Unusual to higher plants is a form of ion uptake referred to as multiphasic uptake (Sahu and Basti, 2021). Principally, as the concentration of an ion surrounding the root is increased, uptake or absorption by the plant exhibits a series of distinct isotherms, each of which has different kinetic characteristics. Kinetic constants Km and Vmax describe the affinity of the transport mechanism for a given ion and the rate of uptake at half-saturating ion concentrations. Aside from providing insight into directing mechanisms, uptake potential, and ion associations, a kinetic approach to the behavior of heavy metals in soils and plants is beneficial in deducing and recognizing some of the present complications related to the environmental distribution of heavy metals from anthropogenic activities (de Mello Prado, 2021). For example, it is clear that the use of urban waste amendments for agricultural soils will result in higher plant concentrations of numerous heavy metals. However, modifications may also reduce the uptake of essential nutrient analogs; similarly, the concentration of nutrient analogs in soil solution will affect the rate of absorption of non-nutrients (Escobedo-Monge *et al.*, 2020).

2.8.3 Performance of Metals in Plants as Linked to Tolerance

The possibility of engaging higher plants as checks of metal pollution is supported by knowledge of the metabolic activities that enable plants to gain needed nutrients and tolerate increasing levels of toxic elements (Rodríguez-Eugenio *et al.*, 2018). Studies involving plant breeding have caused authors to realize that many sides of mineral nutrition are under genetic regulation and hence directed by selection. Genetic control has been revealed to govern the initial absorption of ions, the oxidation-reduction of Fe, compartmentalization of ions within the root, transfer from root to xylem, and metabolic utilization. The tolerance of plants to high levels of both nutrient and non-nutrient elements appears to be genetically controlled in the same way. Plants' tolerance to individual metals, while making the functional basis for the manner of indicator or accumulator plants, is often misunderstood (Cataldo and Wildung, 1978). Obvious plant tolerance can result from the elimination of toxic elements or metabolic tolerance to specific elements; the specific element appears to be the more prevalent instrument. Instruments for elimination have been revealed to include low root cation exchange capacities restraining uptake of Al and Mn, sorption of Zn to cell walls, and precipitation of Al by hydroxyl ions at the root surface. Metabolic acclimatization as a tool of metal tolerance in plants appears to be the rule rather than the exception (Rahman and Upadhyaya, 2020). An assessment of a specific grass species such as (*Agrostis tenuis*) collected from old mine dumps and adjacent pasture lands and stressed 12 under laboratory circumstances, followed, and identification of vital traits of tolerant species. Populations of plants developed from environments containing raised levels of lead were tolerant to lead but no other metals; results obtained for other plants tolerant to other metals were the same, implying that tolerance is peculiar. The noticed tolera adapted plants and the sensitivities of plants growing in adjacent areas of low metal weight we lost on cultivation, although individuals did differ and seeds collected from the tolerant popu had the same tolerances as the parent and asexually grown plants (Anguilano *et al.*, 2022).

2.9 POLICY AND REGULATORY FRAMEWORK FOR MANAGING HEAVY METAL POLLUTION IN AGRICULTURE

Several lines of evidence suggest that the levels of heavy metals in foodstuffs of most countri higher than the acceptable limits set by the World Health Organization (WHO) and the Foo Agriculture Organization. There are numerous literature revealing that the sources of tra pathways of heavy metals in the ecosystem and the abundance of heavy metals in food and products are potential threats to food safety (Kacholi and Sahu, 2018).

The conceptual policy frameworks for sustainable management of heavy metal contamina most countries are used for fostering food safety and environmental sustainability. These incl

- Studying the current trend of heavy metal in various countries.
- Studying the heavy metal concentrations in foodstuffs, associated environmental matri such as water, waste, and farmlands.
- Acute and chronic risks assessment of heavy metals in food, water, and land.
- Examining the co-exposure to the toxicity of heavy metals and their associated pollutan

There are other sources that policy should cover, and these are the ecotoxicology profile of metals and their trophic transfer.

The policy should also include the study of bioaccumulation, biotransformation, human to ogy, and marine food web toxicity determination.

Sustainable remediation should be conducted using phytoremediation, wastewater treatmen potential microbes should be studied (Hou *et al.*, 2020).

There are national and global regulatory bodies involved in regulating acts and legislative r toring, and safety regulations of heavy metal contamination in various countries, and these inc

The Food and Safety for Heavy Metal Management Act, 2013
The Food Safety (Contaminants, Toxins and Harmful) Residue Regulations, 2017
Food and Agricultural Organization (FAO/WHO), 2006, 2011
Joint FAO/WHO Expert Committee on Food Additives (IECFA), 2003
WHO 1985, 1996, 2004

2.10 UNITED STATES ENVIRONMENTAL PROTECTION AGENCY (USEPA) 2010, 2015

Agricultural soil pollution by heavy metals is one of the most significant methods of soil degr tion. Soil pollution by heavy metals causes many problems for soil functions, the environm agriculture production, food chains, or even human health. The preservation of a fit soil loa heavy metals should be of concern to every society and government. The assessment of soil by heavy metals must be supported by the awareness of heavy metals' initial rates, their inputs soils, their conduct and fate in the soil environment, and their transfer into the plants or groun ter (Vácha, 2021). The procedures and approaches for the evaluation of soil load by heavy m can vary from country to country in the world. Natural or anthropogenic sources are caus increased soil content of heavy metals. These methods of approaches, technical keys, legis kits, or remediation procedures decreasing heavy metals inputs into th consequences in the soil and environment or reducing direct risks to human health on contaminated soils are developed. The efficiency of these methodologies depends strongly on how much of the knowledge of the field of interest is at one's disposal (Hou *et al.*, 2020). The agricultural sector is dominant in most developing countries' economies. There are relevant issues in this sector that are essential to be structured for the sector to be well directed. The guideline in the agricultural sector commences with land management and then deals with the unique legal matters related to the sector. Directives of land for agriculture purposes, soil authority, livestock management, crop production and management, regulation of water for agriculture, pesticide control, fertilizer management, regulation of investment in the agriculture sector, and taxation are all included (Meijerink and Roza, 2007).

Different countries have regulatory standards for heavy metals in agricultural soils (mg/kg), and this is used in managing soil health for sustainable agriculture. Labor Contract; Labor Law; Environmental and Social Safeguard, Environmental and Social Impact, Land Acquisition and Resettlement; social and economic development; legal and regulatory framework; heavy metal; control of crop pest; monitoring and evaluation method; safety of drinking water; ambient air quality standard; heavy metal pollution; law and regulation; industrial solid waste; agricultural land; land expropriation; environmental noise pollution; food safety standard; crops and soil; grievance redress mechanism; hazardous waste storage; agricultural land management; irrigation water quality; Integrated Pest Management and agricultural product. These are the environmental and social management frameworks. The policy and the regulation should be strictly enforced by the existing legislation. There should be contemporary amendments to ensure local food safety. The implementing authorities should include government bodies and non-governmental bodies, NGOs, food retailers, and food industries.

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