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BIOACCUMULATION OF HEAVY METALS BY LEAFY VEGETABLES GROWN WITH INDUSTRIAL EFFLUENTS: A REVIEW

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ABSTRACT

Vegetables are capable of taking up and accumulating heavy metals in their body. The concentrations of the metals increase as the soil available/background concentration increases as a result of human activities including discharge and dumping of industrial waste and effluents into environment. The aim of this review is to highlight the capability of the vegetables to take up and accumulate toxic heavy metals into their body as a result of industrial contamination of the soil and the water used for irrigation purpose and the impact of the metals on human and other organisms in the environment. For this review, available information on current publications, scientific journals, and articles were carefully used. Studies have shown that vegetables grown on a heavy metals contaminated soil accumulate higher amounts of metals than those grown on uncontaminated soils, because in most cases, they absorb the metals through the root. Sometimes, metals may be incorporated with some essential elements required by plants in water and soil. Certain species classified as hyper accumulators are vegetables (mostly leafy vegetables like; spinach, lettuce, and cabbage. Some of the factors that affect metals uptake into plant tissue includes; bioavailability, nature and type of the metal, environmental factors including pH and the plant itself, as some studies have shown some plants to have high uptake capacity than others. High concentrations of Pb, Zn, and Cu were reported for vegetables grown in industrial areas. In most instances, the background concentration of the heavy metals in the soil may not exceed the permissible limit, however, the vegetables have the ability to absorb and accumulate the metals even above the permissible limit. These heavy metals are toxic and pose serious effect on human health and other organisms in the environment. Conclusively, vegetables plays an important role in the body because they provides some essential nutrients to the body as such, any contamination can pose a serious health threat. Moreover, prolonged exposure and consumption of these contaminated vegetables may lead cancer and death.

Key words: Accumulation, Biota, Effluent, Heavy metal, Toxic, and Vegetables.

INTRODUCTION

Vegetable plays a vital role in the body system and are very important for human diet. Despite the fact that vegetables are useful for the human body, they often act as media for carrying poisonous materials such as; heavy metals and other toxicants derived from either irrigation water or from land where the vegetables are grown (Olayiwola and Bernard, 2016). The contamination can be as a result of many factors such as; irrigation water contaminated by effluents or waste, contaminated soil, inorganic fertilizers or pesticides and other sources.

Heavy metals are classified as metallic elements that are relatively denser than water with high specific gravity (5 times more than water). These are referred to as toxic because of their persistent nature and ability to accumulate in a living system. According to Clemens (2006), these metals appear in the environment natural processes or as a result of human activities such as; industrial activities, agricultural activities and mining. The anthropogenic activities posed a more severe environmental problem in some parts of the world because metals contamination metal contamination as a result of

human activities increase daily and may lead to health issues for future generation as a result of persistent nature of metals and ability to accumulate in plants and later gets into the food chain (Clemens 2006). Plants that accumulate toxic metals at high concentration are serious risk to animals and human health when taken into the body either as food or herbal medicine as they contain a significant amount that that may posed a serious effect either at a long run or immediate manifestation (Widowati, 2011). According to Radojevic and Bash kin (1999), health effects related to heavy metal toxicity include; anaemia, kidney damage, lung disease, nervous system disorder, hypereactivity, hypertension, behavioral changes, infertility to male, cancers, and even death in some situations. Some metals are referred to as trace elements as they are essential to the body in minute quantity and they include; Zn, Cu, Fe, Mn, Mo, Co. these essential metals participate in REDOX reaction and act as enzyme cofactors in plants (Sanita di Toppi and Gabbrielli, 1999). Other heavy metals have no function in the biological system and as such are toxic and harmful to the living system and they include; Cd, Hg, Pb, Al, and As (Manju, 2015).

Most of the industries in developing countries tends to discharge their untreated waste including liquid waste (effluent) into the environment. According to Rehman and Anjum (2010), large scale usage of chemical in these days as a result of industrial and other human activities has grown and as a result, some toxic materials (heavy metals) find their way into the soil, rivers, ponds, and lake which pose a significant health risk to both plants, animals (man) and the environment. According to Malarkodi *et al.*, (2007), effluents discharged from industrial areas contained higher concentration of metals especially copper (Cu), Chromium (Cr), and Cadmium (Cd), these effluents were released on the land as well as dumped into the surface water which later infiltrate or leaches to groundwater, therefore, leading to contamination of underground water resources. Ismail *et al.*, (2007) conducted a research on effluents discharged by industries at Sharada industrial area of Kano and found a significant concentration of heavy metals. Farmers in most developing countries engage in irrigation system of farming that involves the use of such contaminated water. Aklilu *et al.*, (2013), reported that the contaminated water from rivers and lakes has been drained to agricultural lands where crops are grown including vegetables. Toxic metals eventually gets into the vegetables through irrigation or when grown on soils contaminated by waste from industries. This paper is aimed at reviewing the literature on vegetable accumulation of toxic heavy metals and the impact of the metals on man and other animals that depends on the vegetables as the source of food and also the effect of growing vegetables around industries.

Heavy Metals in Vegetables

Studies have shown that vegetables are capable of accumulating high levels of metals from the soil as some of them are classified as hyper accumulators (Cobb *et al.*, 2000). Vegetables tends to absorb and accumulate higher concentration of heavy metals when grown on metal contaminated soils than those grown on uncontaminated soil. This is because vegetables absorb these metals through their roots (Al Jassir *et al.*, 2005). The heavy metals are absorbed by vegetables along with other essential plant nutrients and contamination of soils and crops with these metals may have adverse effects on soil, plants, animals and human beings (Varalakshmi and Ganeshamurthy, 2010). Certain species of *Brassica* (Cabbage) have been classified as hyper-accumulators of heavy metals into the edible tissues of plant (Xiong, 1998). Lettuce and Spinach grown within the catchment area of River Jakara shows high concentration of heavy metals beyond the permissible limit and soil was asserted as the major source of the elements (Dike and Odunze, 2016).

Heavy metals levels in vegetables increase as soil background concentration increases as a result of irrigation of vegetables with wastewater/water contaminated by effluents, sewage sludge application as well as increased in fertilizer and pesticides application. This has narrowed especially the use of sewage sludge land application although there is abundant nutrition for plants. Demirezen and Ahmet

(2006) reported high concentration of Lead above the safe limit in vegetables grown in soil irrigated with wastewater from industrial areas. Al Jassir *et al.* (2005) reported the levels of Zn to be higher in the vegetable species for both washed and unwashed samples. Tandi *et al.* (2005) also reported a higher uptake of Cu in lettuce and mustard rape and pointed out that leafy vegetables produced around industrial sites pose a health risk to poor communities, especially to children.

Levels of metals in background concentration may not exceed the safe limits but vegetables uptake of metals in such areas can exceed their acceptable limits. Awasthi (2000) reported levels of heavy metals in soil under study were within safe limits as per the standards but the levels in vegetables exceeded official Indian standards by many folds. This shows that even when the concentration in the soil does not surpass the standard permissible limits, plants have the ability to take up and accumulate the metals to even exceed the permissible limit.

Study has shown that vegetables bio-accumulate heavy metals differently and this has been attributed to plant differences in tolerance to these metals and within the plant, there is accumulative partitioning of the metals in the leaves, fruit or roots (Itanna, 2002; Fitzgerald). Demirezen and Ahmet, (2006) analyzed various vegetables (cucumber, tomato, green pepper, lettuce, parsley, onion, bean, eggplant, pepper mint, pumpkin and okra) and reported that the Zn concentration (3.56–4.592 mg kg⁻¹) was within the recommended international standards as compared to Lead levels. Analysis of the vegetables from an industrial area in some studies demonstrated the concentration of Zn to be within the set limits of international standards (5.00 mg kg⁻¹, WHO, 2006) (Fytianos *et al.*, 2001). Sharma *et al.*, (2006) reported the concentration of Cu (2.25-5.42 mg kg⁻¹) in vegetables grown in wastewater areas of Varanasi, India to be within the safe limit.

It was observed that heavy metals accumulated more in roots and leaves than those in other parts because both are the entry points of heavy metals from soils and air, respectively. Research work of Demirezen and Ahmet (2006) indicated that levels of Cu (22.19-76.50 mg kg⁻¹) were higher in the leafy species than the non-leafy vegetable species from Turkey. Some metals levels in soil have been correlated with their uptake by plant. The edible portions of five varieties of green vegetables, viz. Amaranth, Chinese Cabbage, Cowpea leaves, Leafy Cabbage and Pumpkin leaves collected from several areas in Dar Es Salaam, Africa, were analyzed for Lead, Cadmium, Chromium, Zinc, Nickel and Copper. There was a direct positive correlation between Zn and Lead levels in soils with the levels in vegetables. The relation was absent for other heavy metals (Othman, 2001). Olayiwola and Bernard, (2016) reported high concentration of heavy metals in vegetables irrigated with industrial streams in Kano state, Nigeria. Also, Dan azumi and Bichi in (2010) reported high concentration of heavy metals (exceeds the WHO permissible limit) in Challawa which is one of the major industrial areas where irrigation is prominent.

Bioavailability

Bioavailability is the proportions of total metals that are available for incorporation into biota (Davis *et al.*, 2001). Total metal concentrations do not necessarily correspond with metal bioavailability. For example, sulfide minerals may be encapsulated in quartz or other chemically inert minerals, and despite high total concentrations of metals in sediment and soil containing these minerals, metals are not readily available for incorporation in the biota; associated environmental effects may be low (Davis *et al.*, 2001). Metals of major interest in bioavailability studies, as listed by the U.S. Environmental Protection Agency (EPA), are Al, As, Be, Cd, Cr, Cu, Hg, Ni, Pb, Se, and Sb. Other metals that are presently of lesser interest to the EPA are Ag, Ba, Co, Mn, Mo, Na, Tl, V, and Zn. These metals were selected because of their potential for human exposure and increased health risk (McKinney and Rogers, 1992).

Factors Affecting Heavy Metals Mobility and Bioavailability in Plants

Plant uptake of trace elements is generally the first step of their entry into the agricultural food chain. Plant uptake is dependent on Comerford, (2005);

- Movement of elements from the soil to the plant root,
- Elements crossing the membrane of epidermal cells of the root,
- Transport of elements from the epidermal cells to the xylem, in which a solution of elements is transported from roots to shoots, and
- Possible mobilization, from leaves to storage tissues used as food (seeds, tubers, and fruit), in the phloem transport system.

After plant uptake, metals are available to herbivores and humans both directly and through the food chain. The limiting step for elemental entry to the food chain is usually from the soil to the root. Plant species and relative abundance and availability of necessary elements also control metal uptake rates. Abundant bioavailable amounts of essential nutrients, including phosphorous and calcium, can decrease plant uptake of non-essential but chemically similar elements, including arsenic and cadmium, respectively. Bioavailability may also be related to the availability of other elements. For example, copper toxicity is related to low abundances of zinc, iron, molybdenum and (or) sulfate (Chaney, 1989).

The bioavailability of elements to plants is also controlled by many factors associated with soil and climatic conditions, plant genotype and agronomic management, including: total concentration and speciation (physical-chemical forms) of metals, mineralogy, pH, redox potential, temperature, total organic content, and suspended particulate content, the type of plant root system and the response of plants to elements in relation to seasonal cycles (Kabata-Pendias and Pendias, 1984). Many of these factors vary seasonally and temporally, and most factors are interrelated. Consequently, changing one factor may affect several others. In addition, other poorly understood biological factors seem to strongly influence bioaccumulation of metals and severely

inhibit prediction of metal bioavailability (Clemens, 2006).

Mechanism of Toxicity

The ability of some vegetables to remove and accumulate heavy metals may cause a serious health risk to human health when plants based food stuff are consumed (Wenzel *et al.*, 1999), but may also have the potential in the remediation (phytoremediation) of heavy metals contaminated soils. The tolerance characteristics of plants to heavy metal ions are diverse among the metal ions involved (Inouhe *et al.*, 2012). Especially a group of metals called "Borderline class" metals including Mn, Zn, Fe, Ni, Cd, Pb and Cu etc. are capable of binding to multiple types of naturally occurring chemicals or components in plants, although "Class A" metals, such as K, Ca, Na, Mg, Al, and Cs prefer the O-donor ligands, all of which bind through oxygen, rather than the S or N bond ligands preferred by "Class B" metals (Inouhe *et al.*, 2012). Nevertheless, the tolerance against those toxic ions can be expressed in a highly specific manner for each metal in general in plants, and co-tolerance appears relatively rare (Inouhe 2005). One of the fundamental bases of the mechanisms can be addressed to either the alteration of the metal-sensitive metabolism and structure or the development of new metal-sequestering principles within some cellular compartments (Inouhe *et al.*, 2012). As for the latter detoxification mechanism, various types of metal-binding complexes have been identified from plants. Among them the best characterized are phytochelatins (PCs) and the related thiol-peptides. Furthermore, a variety of other organic ligands capable of conjugating to various metals *in vivo* have been reported with their possible roles similar to or distinct from those of PCs in plants (Callahan *et al.*, 2006; Sharma and Dietz 2006; Haydon and Cobbett 2007).

As a result of physical and chemical properties of heavy metals, there exist three molecular mechanisms for metals toxicity which include;

- Production of reactive oxygen species (ROS) by autoxidation and Fenton reactions,
- Blocking essential functional groups in biomolecules, and
- Displacement of essential metal ions from biomolecules (Cuypers *et al.* 2002; Schutzendubel and Polle, 2002).

Reactive oxygen species (ROS) production is the most common outcome of this abiotic stress which may lead to the nonspecific attack of vital molecules such as; proteins, lipids, and nucleic acids, that can result into detrimental effect causing structural, metabolic, and physiological disorders in cells and may result in cell death (Bray *et al.*, 2000).

Oxidative Stress and Cell Defenses

Reactive oxygen species are highly reactive atoms or molecules found in all aerobic biological organisms. They are naturally produced in plants and are predominantly formed in the electron transport chain of chloroplasts (cellular respiration) and in photo reactivation.

The main reactive species formed from these processes are superoxide radicals ($O_2^{\cdot-}$), hydroxyl radicals (OH^{\cdot}), which are highly reactive molecules with a short half-life, and hydrogen peroxide (H_2O_2), a signaling molecule that can cross membranes and accumulate within cells (Apel and Hirt 2004; Giampaoli 2010; Pinto *et al.*, 2003). Plants have developed a variety of strategies to prevent excessive accumulation of nonessential metals within cells and/or transform these metals into less toxic forms (Cobbett 2000). Some plants produce metabolites that bind to heavy metals in the cytosol, such as glutathione (GSH), polypeptides and proteins (example; metallothioneins and phytochelatins) and proline (Hall, 2002). However, when these defense mechanisms are not sufficient, ROS overproduction occurs, which causes oxidative stress and activates other mechanisms (Patra *et al.* 2004). The defense system includes enzymatic and nonenzymatic antioxidants.

Effects of Heavy Metals on Human Health

Small amounts of heavy metals are needed in our environment and diet and are actually necessary for good health. However, large amount of any of them may cause acute or chronic toxicity (poisoning) Duruibe et al. (2007). Heavy metal toxicity can result in damaged or reduced mental and central nervous function, lower energy levels and damage to blood composition, lungs, kidneys, liver, and other vital organs. Long term exposure may result in slowly progressing physical, muscular, and neurological degenerative processes, allergies are not uncommon, and repeated long-term contact with some metals (or their compounds) may cause cancer (WHO, 2006). For some heavy metals, toxic levels can be just above the background concentrations naturally found in nature. Therefore, it is important to learn about heavy metals and take protective measures against excessive exposure. The association of symptoms indicative of acute toxicity is not difficult to recognize because they are usually severe, rapid in onset, and associated with a known ingestion or exposure. Symptoms include: cramping, nausea and vomiting;

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pain; sweating; headache difficulty in breathing impaired cognitive motor, and language skills, mania and convulsions symptoms of chronic exposure (impaired cognitive and language skills, learning difficulties; nervousness and emotional instability; and insomnia, nausea, lethargy, and feeling ill) are also usually recognized; however, they are much more difficult to associate with their cause (Jarup, 2003). Symptoms resulting from chronic exposure are very similar to symptoms of other health conditions and often develop slowly over months or even years. Sometimes, symptoms of chronic exposure subside; thinking the symptoms are related to something else people postpone seeking treatment. (Khillare *et al.*, 2004).

In cooperation with the U.S. Environmental Protection Agency, the ATSDR has compiled a Priority List for 2001 called the "Top 20 Hazardous Substances." The heavy metals arsenic (1), lead (2), mercury (3), and cadmium (7) appear on the list.

CONCLUSION

Vegetables plays a vital role in human body as they provide essential nutrients to the body. Any form of contamination to vegetables can pose a serious health issue and a prolonged exposure and consumption of these contaminated vegetables may lead to health problems of different kind and even causes cancer in some instances and death in others. Farmers need to be conscious about the farming activities and the water their use for irrigation purposes which is one of the major sources of heavy metal contamination of vegetables. It is therefore recommended to conduct more researches on the heavy metals contamination of vegetables. There is also a need to enlighten farmers on the effects of growing vegetables using contaminated water from industrial discharge.

Contribution of Authors

All the authors contribute equally in the development of this paper.

Conflict of Interest

The authors declare no conflict of interest in this article.

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