

**REVIEW OF EDIBLE PLANTS IN DUMPSITES: RISKS OF HEAVY METALS
TOXICITY AND IMPLICATIONS FOR PUBLIC HEALTH**

Abstract

Studies of dumpsite have revealed heavy metals contamination of the soils by anthropogenic inputs. In this review, the uptake and toxicity risks of these heavy metals by habitual edible plants at levels above threshold limit and the implications for public health have been discussed. Edible plants are plants with nutritional and medicinal potentials which salvage numerous human and animal needs when taken. Edible plants like most other underutilized plants in dumpsites have developed mechanisms which enable them to not only survive but accumulate high level of toxic heavy metals due to high environmental metal load in dumpsites. This ultimately could lead to high human and animal exposure to these toxic elements through food-chain/food-web or direct ingestion of soils. The toxic effects caused by excess concentrations of these heavy metals in living organisms vary considerably and present numerous clinical situations ranging from neurological disorder, cellular damage among others and death in extreme cases. This review suggest the urgent need for policy makers to regulate the use of dumpsites for arable farming and the dependence on edible plants in dumpsites to avert heavy metal poisoning in populations.

Key words: Dumpsite soils, Edible plants, Heavy metals, Toxicity, Public health.

1. INTRODUCTION

The use of dumpsites for arable farming and the use of dumpsite compost soils for increasing the fertility of soils for the cultivation of vegetables, fruits and food crops in Nigeria and most developing countries of the world are serious issues of concern to the general public who want to know the safety of such food crops for human and animal consumption (1, 2). The sources of heavy metal to plants are their growth media (soil, air and nutrients) from which heavy metals are taken up by roots or foliage (3-5). Although some heavy metals such as Cu, Zn, Mn, and Fe are essential in plant nutrition, many heavy metals do not play any significant role in the plants physiology (6, 7). The behaviour of heavy metals in soil-plant system is crucial to the understanding of the mobility, bioavailability and toxicity of the heavy metals in an ecosystem (3, 8). Plants growing on dumpsites can accumulate toxic metals at high concentration causing serious risk to human health when consumed (9-13).

The uptake of heavy metals by plants from soil varies due the variation of the soil physicochemical properties (pH, organic matter content, cationic exchange capacity, etc) and the plant species involved (4, 5, 8, 9, 14,15). High load of heavy metals have been reported in crops grown in abandoned heavy metal polluted areas and dumpsites (12-14).

The pollution of the environment with heavy metals from anthropogenic sources especially from domestic and industrial wastes has become a world-wide problem during recent years because they are non-biodegradable and are toxic to flora and fauna in the ecosystem (15-18). In Nigeria as in most African countries, population explosion has led the generation of large quantities of waste which are usually dumped in arable farmlands without recourse to the concomitant risks they may impose in soil and surrounding surface and ground water (19, 20). Poor legislation and the use of such dumpsites for the cultivation of edible vegetables, fruits and food crops for human and animal consumption without routine assessment of the toxicological health risk of such practice is misleading.

This paper, therefore aims to review the studies of the plant-uptake of heavy metals in dumpsites and surrounding environment and point out the risk and health implications posed to humans and animals on consumption of plants cultivated on such soils.

2. BIOAVAILABILITY AND MOBILITY OF HEAVY METALS TO PLANTS

Heavy metal content is a critical measure in assessing risk of a refuse dumpsite, however, total heavy metal content alone does not provide predictive insights on the bioavailability, mobility and fate of the heavy metal contaminants (21, 22). It is the chemical form or species of these heavy metals that is important in assessing their impacts on the environment because their chemical forms control their bioavailability or mobility which ultimately influence heavy metal soil-plant transfer (21-26). We have previously reported that there is a strong correlation between the percentage mobile phase of heavy metals in dumpsites and the soil physicochemical properties (3-5). Dumpsites soils have been reported to contain anthropogenic input of heavy metals at levels above threshold limits when compared to soils from uncontaminated area and the bioavailability of these heavy metals in most dumpsites in Nigeria is well documented (3-5, 9-13, 24, 27). Our earlier research experiences in most of the dumpsites in South-East, Nigeria have shown that the available metal in the sequentially extracted fractions followed the general order: residual > reducible > exchangeable > acid soluble > oxidizable for Cd, residual > oxidizable > reducible > acid soluble > exchangeable for Cu, reducible > oxidizable > acid soluble > residual > exchangeable for Mn, residual > exchangeable > reducible > oxidizable > acid soluble for Pb, residual > reducible > oxidizable > exchangeable > acid soluble for Zn, residual > exchangeable > reducible > oxidizable > acid soluble for Fe, residual > oxidizable > acid soluble > reducible > exchangeable for Ni and residual > oxidizable > acid soluble > reducible > exchangeable for Cr (3-5, 8-13, 27). These reports were in line with the reports of other researchers carrying out similar studies (23, 24, 28-33). Consistently, reports have shown that sequential extraction of heavy metals in dumpsites soils indicated higher percentages (%) of the non-residual fraction for most metals except Cu. Our study on numerous dumpsites soils in South-East, Nigeria (as shown Fig 1) implicated higher percentage mobility for metals studied except Cu. Overall, the order of mobility and bioavailability of these metals in most of the dumpsites that we have studied follow this trend: Cd > Fe > Pb > Mn > Zn > Cr > Ni > Cu (3-5, 8-13, 34). Similar findings on dumpsites and heavy metal polluted sites have been reported and well documented (23-

80 26)

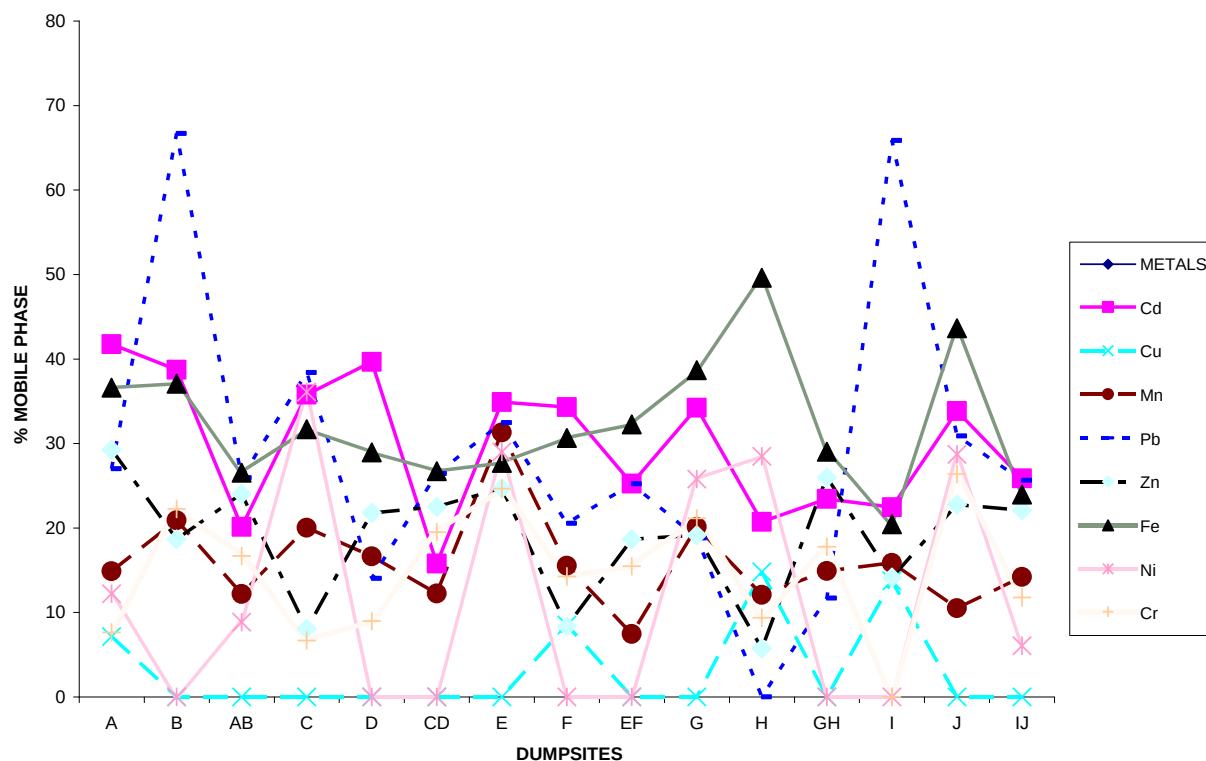


FIGURE 1: PERCENTAGE (%) MOBILE PHASE OF TOTAL EXTRACTABLE METALS

(Where A = Burrow pit-Aba, B = Ntiga-Isiala Ngwa, AB = Control site for Aba, C = Ubakala-Umuahia, D = Abia Tower-Umuahia, CD = Control site for Umuahia, E = Umuka-Okigwe, F = Ubahu-Okigwe, EF = Control site for Okigwe, G = Ishiagu-Enugu Junction, Ishiagu, H = Ntave-Ishiagu, GH = Control site for Ishiagu, I = Four corner-Enugu, J = Amaéchi-Enugu, IJ = Control site for Enugu. (Source: Obasi, 2012; Obasi *et al.*, 2012a;b; Obasi *et al.*, 2013a;b).

3. HEAVY METAL UPTAKE BY PLANTS

Plants (roots, stem and leaves) grown in dumpsites and metal polluted soils have been reported to accumulate heavy metals far beyond the recommended threshold limits when compared to uncontaminated soils. The accumulation of these metals has been shown to vary greatly among plants species and uptake of these metals to the various plant parts has been demonstrated to be primarily dependent on the plant species, its inherent controls and the soil quality (3-5, 8-14, 35 - 42).

Translocation Factors (TF), Biological Concentration Factors (BCF) and Biological Accumulation Coefficient (BAC) values greater than one (>1) had been used to evaluate the potential of plant species for phytoextraction, and phytostabilization (43 -45). Studies in Nigeria have shown that some edible and medicinal plants such as *Amaranthus hybridus*, *Talinum triangulare*, *Carica papaya*, *Ipomea batatas*, *Luffa aegyptica*, *Telferia occidentalis* among others that grows in dumpsites have Translocation Factor (TF), Biological Concentration Factor (BCF) or Biological Accumulation Coefficient (BAC) values greater than one (> 1) for metals such as Cd, Cu, Mn, Pb, Zn, Fe, Ni and Cr among others (3-5, 8-13, 27, 34). For example, our findings from dumpsites in Ibii community, Afikpo North, Ebonyi State, South-East, Nigeria

(Fig 2-4) showed phyto remediation quotient greater than unity (> 1) for some metals. This suggests that these plant species have developed tolerance mechanisms to adapt to the heavy metals stress in their habitual environment and as such have potentials to accumulate these metals in their edible harvestable parts as documented by numerous researchers (8-13, 35-42). The implications are that these metals which have been accumulated by plants might be transferred through food chain and food web within the ecosystem to human and animals where they might pose serious threat to health.

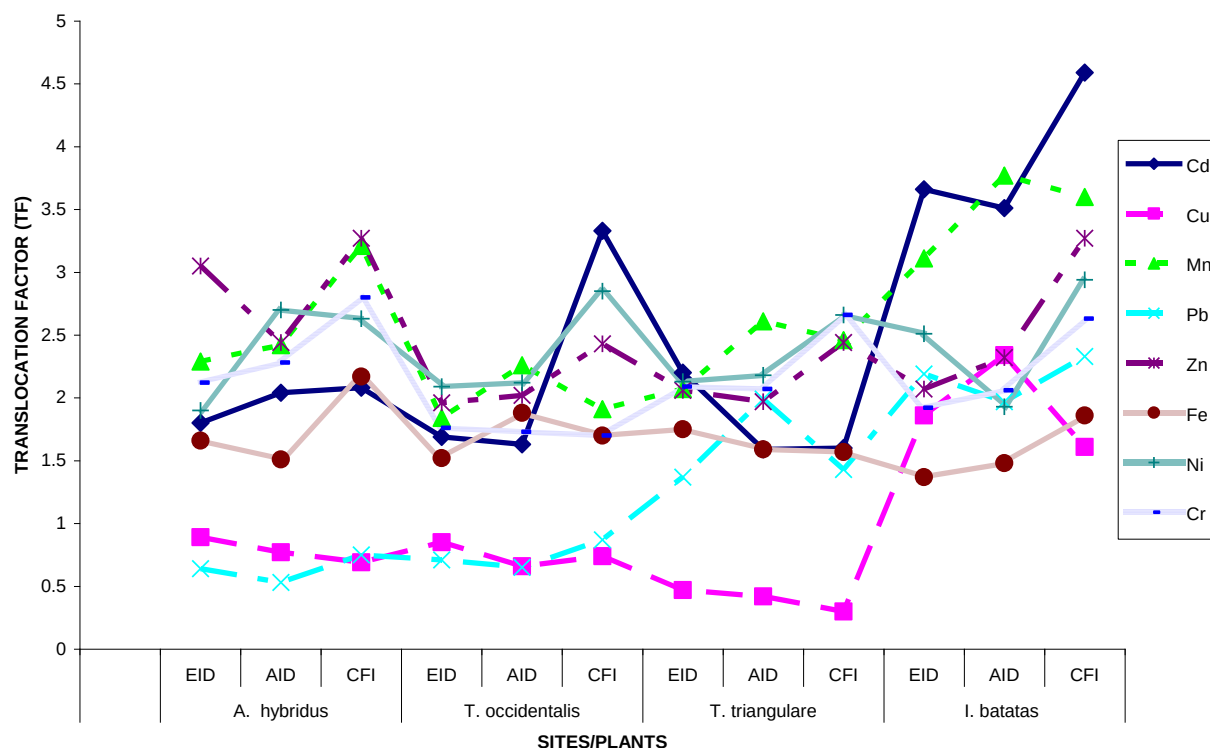


FIG 2: TRANSLOCATION FACTOR (TF) OF PLANTS FOR ALL THE METALS IN THE STUDIED SITES

(EID= Eluuogo Ibii dumpsite, AID = Agboogo Ibii dumpsite, CFI = Control Farmland Ibii, Source: Obasi *et al.*, 2015a)

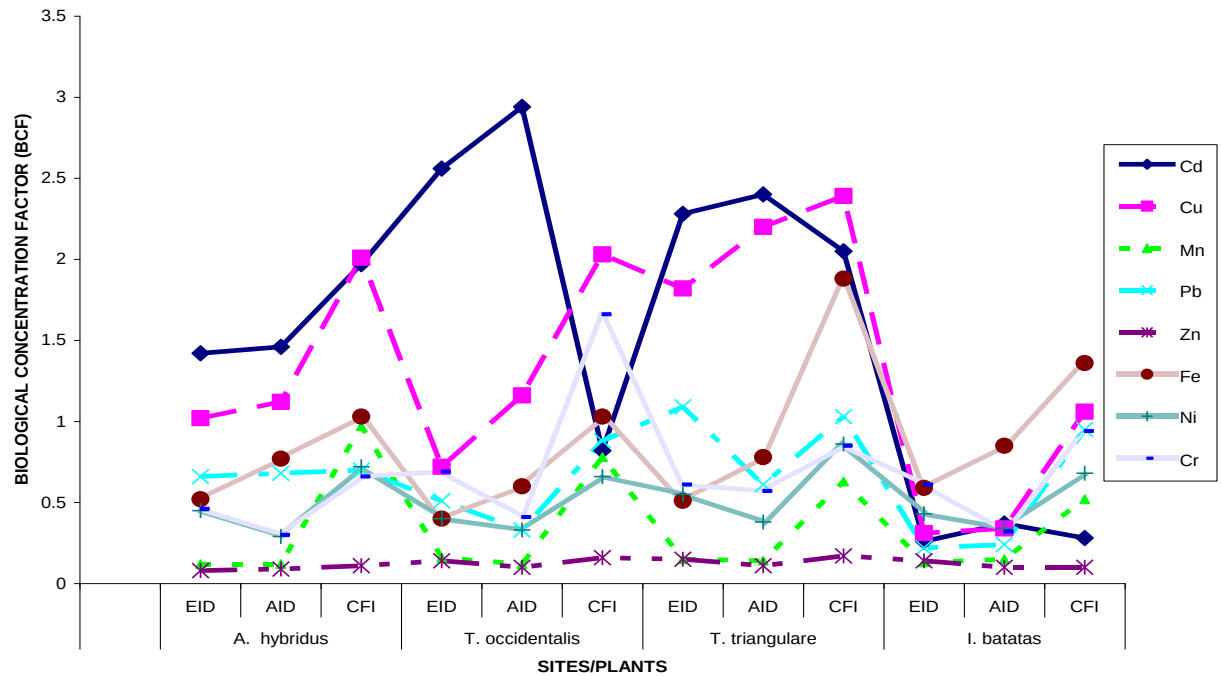


FIG 3: BIOLOGICAL CONCENTRATION FACTOR (BCF) OF PLANTS FOR ALL THE METALS IN THE STUDIED SITES

(EID= Eluuogo Ibii dumpsite, AID = Agboogo Ibii dumpsite, CFI = Control Farmland Ibii, Source: Obasi *et al.*, 2015a)

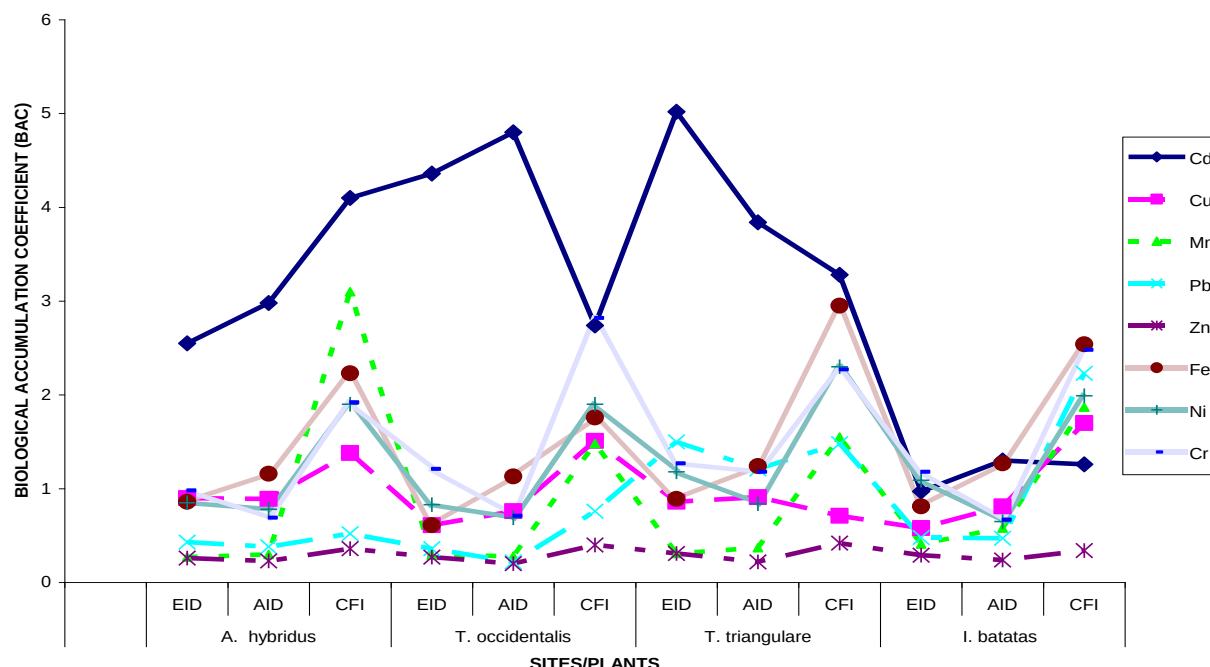


FIG 4: BIOLOGICAL ACCUMULATION COEFFICIENT (BAC) OF PLANTS FOR ALL THE METALS IN THE STUDIED SITES

(EID= Eluuogo Ibii dumpsite, AID = Agboogo Ibii dumpsite, CFI = Control Farmland Ibii, Source: Obasi *et al.*, 2015a)

4. HEAVY METALS AND PUBLIC HEALTH

Heavy metals are crucial to the maintenance of various biochemical and physiological functions in living organisms when in very low concentrations; however they become noxious when they exceed certain threshold limits. The toxicity of heavy metals arise from the fact that sometimes their chemical coordination and oxidation-reduction properties enable them to escape control mechanisms such as homeostasis, transport, compartmentalization and binding of required cell constituents. Thus, they bind with protein sites which are not made for them by displacing original metals from their natural binding sites causing malfunctioning of cells and ultimately toxicity. Heavy metal toxicity is a major threat in the world today and reports have shown that there are several health risks such as oxidative deterioration of biological macromolecules caused by binding of heavy metals to the DNA and nuclear proteins associated with it (46). Metal toxicity depends upon the absorbed dose, the route of exposure and duration of exposure, *i.e.* acute or chronic and their effects manifest in various disorders. This can also result in excessive damage due to oxidative stress induced by free radical formation. Heavy metals are significant environmental pollutants and their toxicity is a problem of increasing significance for ecological, evolutionary, nutritional and environmental reasons (47, 48). The most commonly found heavy metals from edible plants parts include arsenic, cadmium, chromium, copper, lead, nickel, iron, manganese and zinc among others, all of which cause risks for human health and the environment (49-51).

The toxicity of heavy metals to humans and animals arise from various mechanisms involving binding to important proteins causing cellular damage and generation of reactive species. Inorganic arsenic compounds get methylated by bacteria, algae, fungi and humans to give monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA) which are intermediate highly

toxic product that account for arsenic-induced carcinogenesis (52). Lead metal causes toxicity in living cells by following ionic mechanism which occurs mainly due to the ability of lead metal ions to replace other bivalent cations like Ca^{2+} , Mg^{2+} , Fe^{2+} and monovalent cations like Na^+ , which ultimately disturbs the biological metabolism of the cell. This ionic mechanism of lead toxicity causes significant changes in various biological processes such as cell adhesion, intra- and inter-cellular signaling, protein folding, maturation, apoptosis, ionic transportation, enzyme regulation, and release of neurotransmitters (49). Lead can substitute calcium even in picomolar concentration affecting protein kinase C, which regulates neural excitation and memory storage (46).

Methylmercury is a neurotoxic compound which is responsible for microtubule destruction, mitochondrial damage, lipid peroxidation and accumulation of neurotoxic molecules such as serotonin, aspartate, and glutamate (53). Reports have shown that cadmium concentration increases 3,000 fold when it binds to cystein-rich protein such as metallothionein. In the liver, the cystein-metallothionein complex causes hepatotoxicity and then circulates to the kidney and gets accumulated in the renal tissue causing nephrotoxicity. Also, reports have shown that cadmium can bind with cysteine, glutamate, histidine and aspartate ligands causing iron deficiency (54). Cadmium and zinc have the same oxidation states and as such cadmium can replace zinc in metallothionein, thereby inhibiting it from acting as a free radical scavenger within the cell.

The reactions between $\text{Cr}(\text{vi})$ and biological reductants like thiols and ascorbate result in the production of reactive oxygen species such as superoxide ion, hydrogen peroxide, and hydroxyl radical which like most heavy metals ultimately lead to oxidative stress in the cell causing damage to DNA and proteins (55). Free iron can also lead to lipid peroxidation, which may results to severe damage in mitochondria, microsomes and other cellular organelles (56). The attack of heavy metals on a cell and the balance between reactive oxygen species (ROS) production and their subsequent defense by antioxidants is shown in Fig 5 (49). The toxicity of iron on cells has led to iron mediated tissue damage involving cellular oxidizing and reducing mechanisms and their toxicity towards intracellular organelles such as mitochondria and lysosomes. Also, a wide range of free radicals believed to cause potential cellular damage have been reported to be produced by excess intake of iron. The iron produced hydrogen free radicals attack DNA, resulting in cellular damage, mutation and malignant transformations which in turn cause an array of diseases (57).

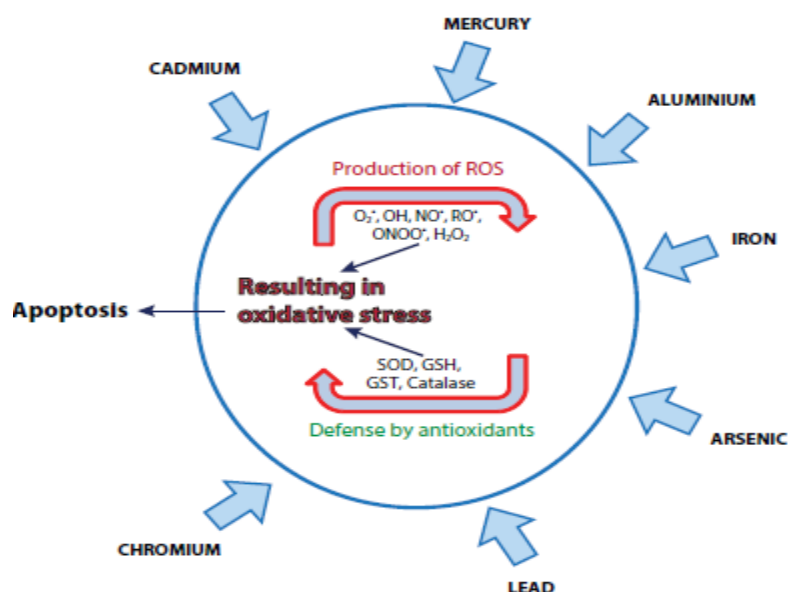
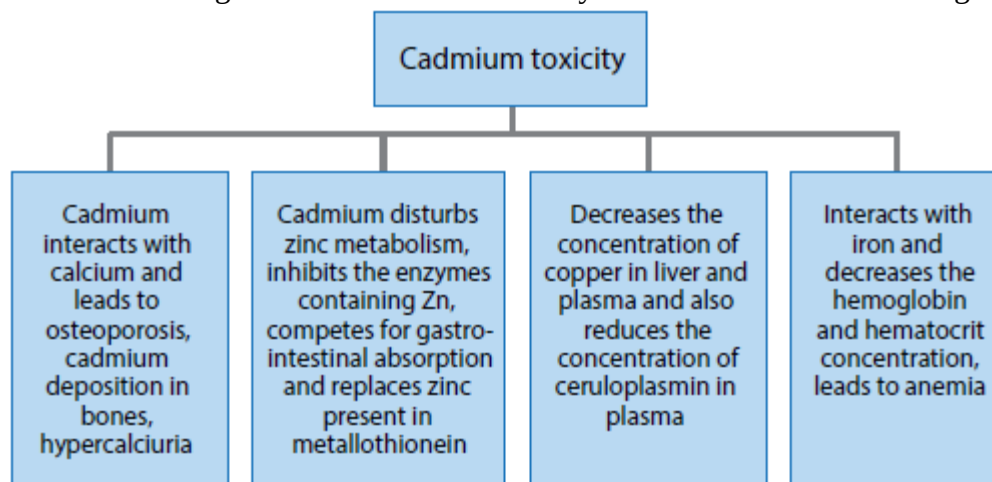


Fig 5: The Effects of heavy metals on a cell and the balance between ROS production and the subsequent defense presented by antioxidants (Source: Jaishankar *et al.*, 2014)

Heavy metal toxicity can lower energy levels and damage the functioning of the brain, lungs, kidney, liver, blood composition and other important organs. Reports have shown that long-term exposure to heavy metals and their compounds can lead to gradually progressing physical, muscular, and neurological degenerative processes that imitate diseases such as multiple sclerosis, Parkinson's disease, Alzheimer's disease and muscular dystrophy while repeated long-term exposure may even cause cancer (58). Lower levels of arsenic exposure has been implicated in nausea and vomiting, reduced production of erythrocytes and leukocytes, abnormal heart beat, pricking sensation in hands and legs, and damage to blood vessels while long-term exposure can lead to formation of skin lesions, internal cancers, neurological problems, pulmonary disease, peripheral vascular disease, hypertension and cardiovascular disease and diabetes mellitus (59). Chronic arsenicosis results in many irreversible changes in the vital organs with no effective treatment for this disease and Mazumder (60) reported that the mortality rate is high. Toxicity of lead (lead poisoning) can be either acute or chronic. Acute exposure to lead has been implicated in loss of appetite, headache, hypertension, abdominal pain, renal dysfunction, fatigue, sleeplessness, arthritis, hallucinations and vertigo while chronic exposure can result in mental retardation, birth defects, psychosis, autism, allergies, dyslexia, weight loss, hyperactivity, paralysis, muscular weakness, brain damage, kidney damage and may even cause death (61). Exposure to metallic mercury vapors at higher levels for shorter periods of time can lead to lung damage, vomiting, diarrhea, nausea, skin rashes, increased heart rate or blood pressure. Symptoms of organic mercury poisoning include depression, memory problems, tremors, fatigue, headache, hair loss, etc. Exposure to higher amounts of chromium compounds in humans has been implicated in the inhibition of erythrocyte glutathione reductase, which in turn lowers the capacity to reduce methemoglobin to hemoglobin (62, 63). Chromate compounds has been reported to induce DNA damage in many different ways such as formation of DNA adducts, chromosomal aberrations, sister chromatid exchanges, alterations in replication and transcription of DNA leading to various forms of mutation with manifestations in cancer and abnormal cells

207 formation (O'Brien *et al.*, 2001; Matsumoto *et al.*, 2006). Excess iron uptake is a serious
 208 problem as it increases the risk of cancer while reports have shown that cadmium interacts with
 209 essential nutrients through which it causes its toxicity effects as summarized in Fig 6 (46).



210
 211 **Fig 6: Values of cadmium toxicity (source: Flora *et al.*, 2008)**
 212

213 Conclusion

214 In this review, the effects of some heavy metals accumulation by edible plants grown on
 215 dumpsites soils on public health were discussed. It was shown that plants grown on dumpsites
 216 accumulate heavy metals at levels beyond the threshold limit partly due to the high levels of
 217 heavy metals in the dumpsite soils and the ability of these plants to develop tolerance
 218 mechanisms in this habitual environment. These heavy metals can be transferred through feeding
 219 relationship (food chain and food web) to humans and animals where they exert numerous
 220 toxicities in humans and as such calls for public health concern. Effective legislation, guidelines
 221 and routine assessment of heavy metals in dumpsite plants are necessary as failure to control the
 222 exposure will result in severe public health complications in the future because of the adverse
 223 effects imposed by these heavy metals. National as well as international co-operation is vital for
 224 framing appropriate tactics to prevent heavy metal toxicity arising from the use of dumpsites for
 225 arable farming and the use of dumpsites habitual plants for nutritional and medicinal purposes.
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227 Conflicts of Interest Statement

228 We, the authors declare that no competing interests exist.
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