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Extent of Heavy Metals Contamination in Leafy Vegetables among Peri-Urban Farmers

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Heavy metals are metalloids of environmental concern, especially in urban and peri-urban small scale farming systems. Plants are contaminated with heavy metals through different pathways, including uptake from soil and from the atmosphere. These pathways need to be distinguished from each other in order to understand where massive contamination comes from and the one suitable for a particular metal. The uptake is affected by various factors, among them are environmental conditions (climatic conditions, soil characteristics, and root system), plant species/morphology and chelating agents. Most vegetables are known to be contaminated by heavy metal like cadmium (Cd), chromium (Cr), lead (Pb), arsenic (As), iron (Fe), zinc (Zn), copper (Cu), with leafy vegetables mostly affected. The contamination levels of these metals have largely exceeded the recommended consumption levels by the world health organization (WHO), thus likely to cause adverse health effects to human beings if regulation measures are not put in place. Research on heavy metal contamination mostly focuses on other vegetables and less has been done with respect to African Indigenous Vegetables (AIVs). On the other hand, plant species, especially AIVs, have different physical, morphological and physiological traits that may affect the movement and accumulation of various heavy metals and thus the extent of contamination and metal affiliation may vary from one vegetable to the other. Since contamination occurs along the value chain, this calls for research that guides farmers to choose the best farming practices, package and transportation measures for reduced heavy metals contamination of vegetables will be vital.

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1. INTRODUCTION

Farming in urban and peri-urban areas has been intensified in Kenya resulting to commercial production of leafy vegetables, among them AIVs. Along the value chain, there are various agronomic and management practices that may result in contamination of vegetables by heavy metals. These metals have been associated with cancer and kidney problems, among other health issues to human beings. This review was documented to unlock the potentials of contaminations in vegetables, in order for the farmers, agriculture extension officers, traders, consumers and decision-makers to better understand the keys sources, likely pathways of heavy metals contamination in leafy vegetables and mitigation measures for a healthy society.

2. MAIN BODY

2.1 Urban and Peri-urban Agriculture

Urban agriculture is the production of crops (both food and horticultural crops) and keeping of livestock in town or cities and its environs, on small pieces of farms acting as a foundation of livelihood [1,2]. The crops and animals products are either for subsistence use or for commercial purpose or both. Across the world, over 800 million farmers have been practicing agriculture in Urban and Peri-urban regions [3], the number is likely to rise due to heavy migration of people, especially youths in African nations, from rural to urban centers. A number of African cities have witnessed a massive number of urban agriculture, in Western Africa, Ghana, and its capital city Accra has about 14% of the households doing agriculture [4], whereas in East Africa, 30 % of the population do urban agriculture in Kampala, Uganda. Due to poor livelihood in rural Kenya, it goes without saying that the country is not an exception from other African nations to continue experiencing increased rural-urban migration [4].

The rise in urban populations, especially in many developing nations has led to an upsurge demand for food. This has led to growing demand for non-staple foods like vegetables [5], which are grown in order to reduce the demand gab. Thus, most peri-urban farmers have taken advantage of rising demand and are supplying consumers in urban areas with fresh vegetables due to closeness to markets [6].

Urban agriculture can play a vital part towards improving the living standards of the urban poor, especially those in the slums, due to diversity in crop production and livestock and eager to learn and adopt technologies. It has been documented that Nairobi City, in Kenya, has farmers producing a wide variety of crops, ranging from legumes (beans, cowpeas), cereals (maize), tubers (arrow roots, sweat and Irish potatoes), bananas, to vegetables (kale, tomatoes), amongst many others [7]. The production of local vegetables, kales and tomatoes have risen in Nairobi, contributing largely to urban market supply [8].

Most urban and peri-urban farming in Kenya, depend heavily on small–scale rain fed mixed farming, with some practicing small scale river irrigation, wetland farming and those keeping animals practicing free-range livestock keeping. In Kisumu, peri urban farming is characterized by small-scale subsistence crops consisting commonly of cereals (maize and sorghum) and legumes (groundnuts and beans) [4]. The issue of food insecurity can easily be addressed in urban centers, since, about 80% of farmers in urban Kenya produce crops entirely for their own consumption although they will be financially unstable as urban agriculture is a sustainable commercial undertaking for the middle and high-income individuals [9].

Due to urgency for massive production of crops in order to meet the growing demand, production has been met with many challenges like use of waste materials like sewage water, sludge that contains heavy metals and other pathogens, lack of policies and guiding principles for urban farming [7], use of contaminated soils/ground due to lack of enough space, among other problems. Some farmers will grow vegetables along the roadside leading to heavy metals contaminations from the traffics. Small scale farmers block sewers in order to tap unhealthy water and nutrients from it, to grow vegetables, causing risks of pathogens, as well as any heavy metals contamination in vegetables [10]. The shortage of water in urban farming has been caused primarily by flower farms that utilize a lot of water making river flow to stagnant [11]. Some farmers have dug boreholes or shallow wells to counter the problem of water supply on their farms and houses, which are largely contaminated by agrochemicals [12].

2.2 African Indigenous Vegetable

African Indigenous Vegetables (AIVs) are native plants, first discovered in Africa and for a long time, they have been regarded as weeds and food for the poor [13]. In recent years, the vegetables have been gaining a lot of demand due to its environmental and nutritional benefits. The crops are said to adopt to harsh environmental conditions with a minimal attack by pests and diseases as compared to other vegetables [14]. AIVs were known to the rural people as home garden crops, intercropped with staples like maize [13]. Due to rise in life-style diseases and nutrition deficiency in children, the crop has gained popularity among all groups of people in Kenya rural and urban dwellers. The demand in the cities has out weight the supply necessitating the vegetables being transported all the way from Western parts of Kenya to major cities like Nairobi, Nakuru and Mombasa. Many communities use AIVs as an accompaniment to starchy foods, particularly the stiff porridge commonly prepared all over Africa, known by such names as ugali, sima (Eastern Africa) [15]. Common and liked AIVs consumed in East Africa are, African nightshade (*Solanum scabrum*), spider plant (*Cleome gynandra*), vegetable amaranth (*Amaranthus hybridus*), slenderleaf (*Crotalaria brevidens*), jutemallow (*Corchorus olitorius*), vegetable cowpea (*Vigna unguiculata*) pumpkin leaves (*Curcurbita muschata*) and African kale (*Brassica carinata*) among many others [16].

The vegetables are known to be rich in minerals, proteins and vitamins [16,17]. The presence of minerals denotes the ability of these vegetables to extract nutrients in the soils up to the edible parts of the plant. For that case, heavy metals being available in the soil, may as well be taken up by these vegetables resulting to high concentration of harmful nutrients in the edible parts. Thus, these vegetables need to be grown in non-contaminated soils or environment free from contaminants.

2.3 Understanding Heavy Metals

Heavy metals are metallic chemical element with a quite great density and are toxic or poisonous at both their high and low concentrations [18], they can neither be destroyed nor degraded while in the soil [19]. These metals cause adverse effects to plants, human beings, animals and the environment [20]. The metals come from different natural (volcanism) and man-made primary sources (mining and metal smelting) [21] and pesticide, harvesting processes, irrigation water, /storage at the point of sale, storage, transportation being the secondary sources [22], thus, get exposed to the natural environment where they last for decades [23]. Heavy metals that have been found to cause problems to biodiversity include, although not limited to, Pb), As, mercury (Hg), C), thallium (Tl) and Cd [24,25]. Some microelements like Cu, Fe and Zn, although essential to plants in low concentration, they may be harmful to human beings when their concentration exceeds a certain level and thus termed as heavy metals [26]. The bioaccumulation nature of these metals in the plants and their ability to last longer before being broken down makes these metal too risky when taken up by plants, especially crops consumed by human beings. The effect on human beings may be worse if locally produced leafy vegetables are grown on contaminated soils [27].

2.4 Effects of Heavy Metals on Leafy Vegetables and Human Beings

Studies have shown that heavy metals have negative effects on plant growth resulting to retardant growth, the inhibition of pollen germination and seed germination, the length and mass of root and shoot and photosynthetic activity [28]. The metals are known to increase nitric oxide levels in the plants which also affect peroxidation of lipids and synthesis of phytochelatins [29,30]. It is only at higher levels that these effects will be manifested in the plants. Despite the effects, AIVs have been able to accumulate heavy metals, beyond the recommended accumulation levels in the plants and thus they become harmful to human beings.

Among all the AIVs, cowpea being a legume is known to accumulate less toxic substances [30]. The amount of heavy metals accumulation in the AIVs varies with the vegetable species and genotype, the plant external morphology (i.e. leaf size, leaf orientation and presence of hair on the shoot, root orientation), physiological characteristics of the crop, soil characteristics/ agricultural site, levels of contaminants in the growth media and method of contamination [31,21]. Abdu et al. [62], showed that zinc uptake and accumulation by shoots and roots varied with Zn levels in growth media and vegetable types. For instance, Ethiopian kale accumulates heavy metals in order of Zn>Mn>Cu>Ni>Cr>Co>Cd>Pb, of which the highest levels also differed according to location/site [32]. Cabbage has the ability to accumulate low levels of heavy metals due to its genetic behaviors [33]. The concentration of heavy metals may also differ among those species grown in tropical and temperate regions with tropical vegetables likely to show higher concentrations [21]. For instance, plant leaves of *Thlaspi caerulescens* and *Minuartia verna* accumulated the highest amount of Zn and in contrast, *Minuartia verna* accumulated high concentrations of Cd unlike *T. caerulescens* [34]. Vegetables in urban area have shown high heavy metals contamination compared to those grown in the rural areas. With the movement from small plots owned by urban dwellers to large plots owned by the rich [17], may change the trend. In reference, the study done in the North Eastern of Iran, at Shahroud, North Eastern of Iran, showed most of the leafy vegetables were contaminated with heavy metals exceeding the recommended levels by WHO, posing a health risk to humans [22].

In humans, heavy metals accumulate in the vital organs such as the kidneys, bones and liver and each metal is associated with specific health conditions [35]. Accumulation of these metals are also associated with stomatitis, tremor, diarrhea, paralysis, vomiting and convulsion, depression, and pneumonia [36]. The effects may either be carcinogenic, teratogenic, neurotoxic or mutagenic [37].

The channel of contamination in humans is through drinking contaminated water (e.g. lead pipes), inhalation of high ambient contaminated air/dust. Most people have reported heavy metal intake through the food they eat [38].

2.5 Key Pathways of Heavy Metal Contamination in Vegetables and Their Mitigation Measures

2.5.1 Surface contamination

Surface contamination involves contaminants getting attached on the surface of the plant parts and with time they may penetrate beneath the internal plant organs or just adhere to the plant surface. As alluded before, heavy metals contamination can originate from anthropogenic and natural sources. [18]. In urban agriculture, vegetables are grown near mining sites, metal industries, or along the road or places with fossil fuel combustion (for the case of urban gardens) are prone to surface contamination [39]. Heavy Metals discharged from these sources are directly deposited on vegetable surfaces at the time of production, transportation, and marketing [40,29].

Other sources of atmospheric pollution are power plants, usually located within or at the margins of the urban areas. In addition, incineration of industrial, hospital and laboratory solid wastes is also a major mode of waste disposal that results to surface contamination [41]. Aerial depositions is also caused by chimneys that releases vapor streams, gas, dust and air and discharged as particulates and finally ends up on vegetables and soils [29]. The contaminants may partially adhere on the surface or penetrate inside the plant systems through the openings on the plant surface. This depends largely with the surface area to volume ration of the surface, the harboring organs like hairy surface. A sprinkling of contaminated water on the harvested vegetables in the market or at storage point may also contribute to surface contamination. It has been revealed that, washing of vegetables, has eliminated a massive amount of some heavy metals, signifying surface contamination as the main pathway of contamination [42]. Surface contaminations can never be avoided in leafy vegetables and thus drastic measures need to be taken by farmers to avoid it.

Surface contamination can be reduced or avoided altogether by growing vegetables in protected areas like the greenhouse [43], avoid harvesting crops and placing them on wet contaminated grounds or soils before packing. Also applying appropriate post-harvest measures like dusting or washing the vegetables with clean water, adhere to proper packaging and handling of products during transportation and while at the market.

2.5.2 Systemic contamination and their mitigation measures

Systemic contamination mostly occurs via root uptake of heavy metals. Heavy metals that are transferred from the roots to other organs should be soluble in water as it is the only media that transfers nutrients in plants. Heavy metals can reach non-contaminated soils, if they are next to dumpsites through leaching and surface runoffs/erosion [44]. Other soil fertility enrichment like cattle manure, composts, and municipal waste leads to a build-up of heavy metals in soil media [45]. These lead to the uptake of toxic elements into the vegetables via roots and internal distribution into the edible plant organs [46]. Furthermore, high exposure can be due to plant uptake in the abandoned waste dump site, irrigate soils with sewage water or any other form of polluted soils [47]. Systemic contaminations may also result from use of pesticides containing heavy metals, use of mineral fertilizer with phosphates element, medical or laboratory waste incineration [48].

High accumulation of heavy metals in soils where vegetables are grown, will results in large amounts of heavy metal uptake by crops and the vice versa is also true. In most plant species, accumulation of these vegetables has been witnessed in roots, steam and leaves [43]. Morphological, biochemical and physiological changes play a major role in heavy metals translocation, removal and buildup [49] in plants. Factors such as, amount of heavy metals, contact period, soil and environmental temperature, soil pH, redox reaction can regulate mobility and concentrations of soluble heavy metals in soil [50]. Different organs of plants will accumulate a given concentration of heavy metals which differs among the plant species [51].

In the soil rhizosphere, the absorption of heavy metals and its utilization by the plants, depends on the plant's availability in the media. The presence of lupins in the soils will result to citric acid release, which is likely to intensify Cd availability [51]. The biological processes of the plants have provided them with natural ability to remove metals from soil and allot them between roots and shoot [52].

Plant roots take up heavy metals contaminants from growth media by rhizofiltration process, which enables adsorption/precipitation of solution adjacent to the root zone [53]. Plants therefore oxidize the residues in the root area or the soil rhizosphere or facilitates downward movement of oxygen along the parenchyma tissue [54]. In the process, carboxylates (mainly citrate and malate) are released by the roots, as well as phosphates and other compounds like protons and phenolic. At the senescent stage of most vegetable species, exudation of carboxylates and phenolic lead to mineral/ heavy metals solubility and their uptake [52]. The roots (mature clusters) also secret citrate which help in the solubilization of heavy metals in the growth substrate [55]. After which, metals get into the plant cells through cation transporters. It is noted that, at the cellular level, the process is facilitated by the presence of metal transporters on the plasma membrane [56]. These transporters or proton pumps include ATPase, the NRAMP, the CDF that utilize energy and in the process produce electrochemical gradients [57], alongside the ZIP family transporters [58], proficient of transporting cations like Mn, Zn, Fe and Cd. Ion uptake and translocation will at the same time require co-transporters and anti-transporters, that will work together with channels like proteins that enables ions to travel into the cells. In the plant system, metal ions are transported to the shoot through the xylem as complexes alongside numerous chelators [59].

At some point, metal remobilization may occur leading to acidification of the rhizosphere by plant exudates [54]. With some crops, neither leaves or shoots are consumed but specific storage organs (e.g. tubers, grains, fruits), thus heavy metals are remobilized from other plant organs to sink tissue through the phloem [56]. As translocation and uptake completes, the trend or heavy metal accumulation in the plant organs is likely to follow the order of roots > shoots > leaves > fruits > seeds [60].

Several factors have contributed to a decrease or increase of heavy metals uptake in plants. The use of lime is known to address acidity in the soils and may also limit heavy metals uptake by crops (Knox et al., 2001). Lime address the issue since cationic metals like Pb and Cd are highly soluble and mobile in acidic soils, therefore, raising the soil pH immobilizes the metals (Knox et al., 2001). On the other hand, the presence of organic matter and aeration state of the soil plays a vital role in metal uptake [19]. Improved drainage aids soil aeration and allows oxidation of all heavy metals except Cr, making heavy metals less soluble and vise versa. Increasing soil organic matter improves the soil cation exchange capacity (CEC) leading to trapping of heavy metals. Organic matter also improves water retention capacity that reduces irrigation rates, and hence low heavy metal addition in the soil and plants [61]. The presence of high content of clay particles reduces the availability and uptake of heavy metals [62]. Secretion of exudates at the root zone may enhance microbial activities which help in the breakdown of contaminants in the soil, among other roles they play [63]. Heavy metal uptake by plants is also affected by climatic conditions like precipitation and temperature [64], the temperature affects growth substances and consequently roots length that are the primary contact point of the metals [65,66]. Systemic pathway need to be thoroughly understood across different species in order to limit the level of contamination in vegetables which are now widely consumed in the world.

3. CONCLUSION

Leafy vegetables, like other crop species, are prone to heavy metal contaminations if the contamination pathways are not well known and discovered despite knowing the sources of contaminants. It is a high time that researchers should work on the methods that will completely limit the contamination of vegetables by heavy metals in order to meet the quality standards of vegetables for export and local consumption to avoid future health effects like cancer. Many studies have been done on exotic vegetables and their ability to be contaminated with heavy metals but little information exists on AIVs, especially those grown in urban and peri-urban areas and this calls for extensive research on the matter. AIVs are now a valuable source of nutrients to millions of people and their imminent contamination sources and plant traits regulating their uptake need to be understood. With the expansion and growth of towns and cities, urban and Peri-urban farming is likely to expand calling on farmers to use crude farming methods, wastewater and be non-considerate of the production site, this calls for proper guideline to be formulated by policymakers which may be achieved through extensive research.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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