Journal of Agricultural Chemistry and Environment, 2019, 8, 23-32
http://www.scirp.org/journal/jacen
ISSN Online: 2325-744X
ISSN Print: 2325-7458

Leafy Vegetables as Potential Pathways to Heavy Metal Hazards

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How to cite this paper: Anarado, C.E., Anarado, C.J.O., Okeke, M.O., Ezeh, C.E., Umedum, N.L. and Okafor, P.C. (2019) Leafy Vegetables as Potential Pathways to Heavy Metal Hazards. *Journal of Agricultural Chemistry and Environment*, **8**, 23-32.
https://doi.org/10.4236/jacen.2019.81003

Received: November 5, 2018
Accepted: January 30, 2019
Published: February 2, 2019

Abstract

The effect of anthropogenic activity relating to industrial and economic development has had a detrimental impact on the environment and human health, and hence the need for continued research. Five common African vegetables—*Murraya koenigii*, *Ocimum gratissimum*, *Amaranthus hybridus*, *Capsicum annuum and Moringa oleifera* were used to study absorption of Lead, Cadmium, Cobalt and Zinc from soils inoculated with metal ions. 0.1 M and 0.5 M solutions of the metal ions were used in the inoculation. Each of the plants was collected in the first instance at 8 weeks, and then at 10 weeks of inoculating. Atomic Absorption spectrophotometer was used to determine the metal ions concentrations absorbed in the plants. Cd^{2+} was most and *Moringa oleifera the least* absorbed of the four metal ions, with a highest value of 34.801 ± 0.805 mg/kg occurring in *Capsicum annuum*. Co^{2+} was the least absorbed of the four metal ions, *Amaranthus hybridus* showed highest absorption of Co^{2+} with mean absorption values of 5.566 ± 0.324 mg/kg and 5.670 ± 0.210 mg/kg for 0.1 M and 0.5 M solution of Co^{2+} respectively. *Ocimum gratissimum* absorbed Pb^{2+} most with the highest mean absorption of 5.290 ± 0.180 mg/kg and 6.354 ± 0.366 mg/kg for 0.1 M and 0.5 M respectively. Absorption increased as the concentration of the inoculant solution increased for all the plants, and decreased on moving from 8 weeks' to 10 weeks' for all the plants except *Moringa oleifera*. This could as a result of Phytovolatilization against the report of Padmavathiamma and Li, 2007 [1] that phytovolatilization occurs in As, Hg and Se. *Ocimum gratissimum* showed highest absorption with the mean value of 9.334 ± 0.312 mg/kg, when the inoculants concentration increased to 0.5 M, *Capsicum annuum* showed highest absorption with mean absorption value of 9.916 ± 0.614 mg/kg at 10th week. Also absorption increased as the concentration of the inoculant solution increased, and also on moving from 8 weeks' to 10 weeks' for all the plants. From the results obtained, all the vegetables absorbed significant amounts of the metal ions. This raises a lot of health concern about the vegetables consumed in most developing countries like Nigeria where vegetables are grown anywhere, without any consideration of the environment.

Keywords

Heavy Metals, *Ocimum gratissimum*, *Murraya koenigii*, *Capsicum annuum*, *Amaranthus hybridus*, *Moringa oleifera*

1. Introduction

During most of its time on Earth, humankind made little impact on the planet, and its small, widely scattered anthrospheric artifacts—simple huts or tents for dwellings, narrow trails worn across the land for movement, clearings in forests to grow some food—rested lightly on the land with virtually no impact. However, with increasing effect as the industrial revolution developed, and especially during the last century, humans have built structures and modified the other environmental spheres, especially the geosphere, such that it is necessary to consider the anthrosphere as a separate area with pronounced, sometimes overwhelming influence on the environment as a whole [2]. One of the greatest problems that the world is facing today is that of environmental pollution, increasing with every passing year and causing grave and irreparable damage to the earth [3]. The decontamination of soil and water polluted with anthropogenic chemical is a global problem that has consumed considerable economic resources [4] [5] [6]. Over the past two decades, pollution prevention and clean-up of contaminated soils have become a worldwide environmental priority [7]. Due to their immutable nature, metals are a group of pollutants of much concern. As a result of human activities such as mining and smelting of metalliferous ores, electroplating, gas exhaust, energy and fuel production, fertilizer and pesticide application, etc., metal pollution has become one of the most serious environmental problems today [8]. Soil, whether in urban or agricultural areas represents a major sink for metals released into the environment from a variety of anthropogenic activities [9]. Unlike organic compounds, metals cannot be degraded by microorganisms and its clean-up requires theirs removal from the site. There are 35 metals that are of concern because of residential or occupational exposure, out of which 23 are heavy metals: antimony, arsenic, bismuth, cadmium, cerium, chromium, cobalt, copper, gallium, gold, iron, lead, manganese, mercury, nickel, platinum, silver, tellurium, thallium, tin, uranium, vanadium, and zinc [10]. Lead and Cadmium are very toxic to humans. They are only tolerated at extremely low concentrations and excesses are associated with many adverse health effects [11]. The ability of plants to accumulate essential metals equally enables them to acquire other nonessential metals. Heavy metals uptake by plants and successive accumulation in human tissues and biomagnifications through the food chain causes both human health and environment concerns.

[12]. Uptake of heavy metals by plants and subsequent accumulation along the food chain is a potential threat to human health. Various researchers have found that heavy metals are easily accumulated in various vegetables and fruits through contaminated soil [13] [14] [15] [16] [17]. The consumption of heavy metal contaminated food can seriously deplete some essential nutrients in the body that are further responsible for decreasing immunological defenses, intrauterine growth retardation, disabilities associated with malnutrition and high prevalence of upper gastrointestinal cancer rates [18].

Lead (Pb) is physiological and neurological toxic to humans. Acute Pb poisoning may results in a dysfunction in the kidney, reproduction system, liver and brain resulting in sickness and death [19]. Cadmium occurs in the environment naturally and as a pollutant emanating from industrial and agricultural sources. Food is the main source of cadmium intake in the non-smoking population, Cadmium causes kidney tubular damage and bone damage [20]. Zinc compounds affect the gastrointestinal system [21]. The use of plants for remediation of soils and waters polluted with heavy metals, has gained acceptance in the past two decades as a cost effective and noninvasive method [22]. Phytoremediation is defined as efficient use of naturally occurring or genetically engineered plants to remove, detoxify or immobilize environmental contaminants in a growth matrix (soil, water or sediments) [23]. Leafy vegetables are fresh, edible portion of plant that are either eaten raw or in cooked form [24]. They contain both essential and toxic elements over a wide range of concentrations [25]. In Nigeria, *Amaranthus hybridus* leaves combined with condiments are used to prepare soup [26]. *Moringa oleifera* is considered one of the world's most useful trees, as almost every part of the tree can be put to some beneficial uses. Various parts of the plant act as cardiac and circulatory stimulants, posses antitumor, antiepileptic, anti-inflamatory, antiulcer, cholesterol lowering, antidiabetic, antibacterial and antifungal properties [27]. *Murraya koenigii* is a culinary important plant of Indian origin, and also been a component of many formulations used in the Ayurvedic system of medicine since many centuries. A scrutiny of literature reveals some notable pharmacological activities of the plant. Carbazole alkaloids which are abundantly present in the leaves, fruits, roots and bark of this plant, have been reported for their antidiabetic, anticancer, antibacterial, anti-nociceptive and antioxidant activities. Besides these activities, the plant is described to have a wide array of therapeutic activities [28]. *Ocimum gratissimum* is extensively used throughout West Africa as febrifuge, anti malaria and anti convulsant [27]. *Ocimum gratissimum* is also used in the management of baby's cord and in the treatment of fungal infections, fever and cold [29]. *Capsicum annuum* is considered the second most vegetable in the world after tomato and mainly used as spices in various cuisines [30]. *Capsicum annuum* contains a range of essential nutrients and bioactive compounds which are known to exhibit a range of bioactivities including free radical scavenging (antioxidant), antimicrobial, antiviral, anti inflammatory and anticancer [31].

In developing countries like Nigeria, vegetables are planted anywhere provided they survive and flourish well in that particular environment. The environment where these vegetables are planted is not considered a problem for the local communities. Unfortunately, some of these environments are polluted by heavy metals from industrial effluents discharged from various processing industries, mining, municipal wastes, pesticides etc. the vegetables planted in this type of environment are harvested and sold out to the public for consumption. *Murraya koenigii*, *Ocimum gratissimum*, *Amaranthus hybridus*, *Capsicum annuum and Moringa oleifera* are some of common vegetables grown and consumed as food and medicine in Nigeria.

Lead, Cadmium, Zinc and Cobalt have been used in this work to study the ability of five edible African plants—*Murraya koenigii*, *Ocimum gratissimum*, *Amaranthus hybridus*, *Capsicum annuum and Moringa oleifera*—to phytoremediate soils polluted with the metal ions in their +2 oxidation states.

2. Methods

Thirty three seedlings each of the five plants—*Murraya koenigii*, *Ocimum gratissimum*, *Amaranthus hybridus*, *Capsicum annuum and Moringa oleifera* were grown on soils isolated in polyethylene pots. 0.1 M solutions of $Co(NO_3)_2{\cdot}6H_2O$, $Zn(NO_3)_2{\cdot}6H_2O$, $Cd(NO_3)_2{\cdot}4H_2O$ and $Pb(NO_3)_2$ were prepared dissolving 29.103 g, 29.748 g, 30.848 g and 33.121 g respectively in 0.7 dm^3 of distilled water and each made up to 1 dm^3 mark with distilled water. 0.5 M solutions of $Co(NO_3)_2{\cdot}6H_2O$, $Zn(NO_3)_2{\cdot}6H_2O$, $Cd(NO_3)_2{\cdot}4H_2O$ and $Pb(NO_3)_2$ were prepared dissolving 145.516 g, 148.74 g, 154.24 g and 165.605 g respectively in 0.7 dm^3 of distilled water and each made up to 1 dm^3 mark with distilled water. Thirty two pots each of the plants were planted in soil inoculated with 20 cm^3 each of 0.1 M and 0.5 M concentrations of solutions of Pb^{2+}, Cd^{2+}, Co^{2+} and Zn^{2+}, while controls were left. The plants were harvested after the eighth and tenth week of inoculation. The harvested plants were washed, dried, and ashed at 450˚C. After digesting with concentrated HNO_3, Varian AA240 spectrophotometer was used to determine the metal ions concentrations absorbed in the plants. The determination of metal ion concentrations absorbed was done in duplicates.

3. Results

Table 1. Concentration of Lead absorbed by *the plants* in 0.1 M solution in mg/kg.

Plant	1ST HARVEST	2ND HARVEST
MK	3.295 ± 0.280	2.155 ± 0.365
OG	5.290 ± 0.180	1.590 ± 0.010
AH	4.571 ± 0.531	1.253 ± 0.147
CA	4.228 ± 0.239	1.458 ± 0.172
MO	0.140 ± 0.048	0.763 ± 0.132

Table 2. Concentration of Lead absorbed by *the plants* in 0.5 M solution in mg/kg.

Plant	1ST HARVEST	2ND HARVEST
MK	3.964 ± 0.304	3.959 ± 0.001
OG	6.354 ± 0.366	1.870 ± 0.528
AH	4.640 ± 0.200	3.134 ± 0.114
CA	3.877 ± 0.123	3.367 ± 0.322
MO	0.680 ± 0.054	0.812 ± 0.172

Table 3. Concentration of Cadmium absorbed by *the plants* in 0.1 M solution in mg/kg.

Plant	1ST HARVEST	2ND HARVEST
MK	1.342 ± 0.375	3.165 ± 0.066
OG	4.125 ± 0.029	3.806 ± 0.436
AH	6.533 ± 0.129	2.243 ± 0.038
CA	10.869 ± 0.031	13.405 ± 0.245
MO	0.023 ± 0.008	0.286 ± 0.005

Table 4. Concentration of Cadmium absorbed by *the plants* in 0.5 M solution in mg/kg.

Plant	1ST HARVEST	2ND HARVEST
MK	1.681 ± 0.012	4.097 ± 0.029
OG	4.200 ± 0.091	0.790 ± 0.031
AH	6.432 ± 0.218	19.007 ± 0.344
CA	9.741 ± 0.321	34.801 ± 0.805
MO	0.819 ± 0.007	0.873 ± 0.006

Table 5. Concentration of Cobalt absorbed by *the plants* in 0.1 M solution in mg/kg.

Plant	1ST HARVEST	2ND HARVEST
MK	0.143 ± 0.037	1.382 ± 0.268
OG	0.073 ± 0.019	0.161 ± 0.035
AH	1.640 ± 0.210	5.566 ± 0.324
CA	1.877 ± 0.227	2.843 ± 0.097
MO	0.090 ± 0.580	0.120 ± 0.013

Table 6. Concentration of Cobalt absorbed by *the plants* in 0.5 M solution in mg/kg.

Plant	1ST HARVEST	2ND HARVEST
MK	0.475 ± 0.550	2.598 ± 0.228
OG	3.392 ± 0.098	1.583 ± 0.990
AH	1.561 ± 0.291	5.670 ± 0.210
CA	1.770 ± 0.050	2.912 ± 0.018
MO	0.340 ± 0.086	0.631 ± 0.131

Table 7. Concentration of Zinc absorbed by *the plants* in 0.1 M solution in mg/kg.

Plant	1ST HARVEST	2ND HARVEST
MK	1.220 ± 0.166	2.124 ± 0.022
OG	4.086 ± 0.086	9.334 ± 0.312
AH	2.415 ± 0.455	3.451 ± 0.109
CA	1.578 ± 0.202	3.932 ± 0.008
MO	0.344 ± 0.026	0.960 ± 0.200

Table 8. Concentration of Zinc absorbed by *the plants* in 0.5 M solution in mg/kg.

Plant	1ST HARVEST	2ND HARVEST
MK	2.025 ± 0.025	8.978 ± 0.010
OG	4.120 ± 0.088	9.520 ± 0.180
AH	2.312 ± 0.325	9.000 ± 0.468
CA	3.021 ± 0.011	9.916 ± 0.614
MO	0.167 ± 0.005	1.373 ± 0.351

4. Discussions

The result of the analysis showed that the absorption of the metal ions generally followed the trend; *Capsicum annuum* > *Amaranthus hybridus* > *Ocimum gratissimum* > *Murraya koenigii* > *Moringa oleifera*. On inoculation of the plants with 0.1 M and 0.5 M Pb^{2+} (**Table 1** and **Table 2**), *Ocimum gratissimum* showed highest mean absorption (5.290 ± 0.180 mg/kg and 6.354 ± 0.366 mg/kg respectively, which are above the FAO/WHO, 2011 and EU Pb limit for leafy vegetables, 2006-0.3 mg/kg) [32] at 10th week, *Moringa oleifera* absorbed least amount of Pb^{2+} [0.140 ± 0.048 mg/kg (which is below EU commission regulation, 2006) and 0.763 ± 0.132 mg/kg (above EU commission regulation, 2006)] [33] at the 8th week. Absorption increased as the concentration of the inoculant solution increased, and also on moving from 8 weeks' to 10 weeks' for all the plants. On inoculation of the plants with 0.1 M and 0.5 M solution of Cd^{2+} (**Table 3** and **Table 4**), *Capsicum annuum* showed highest absorption of the metal ion with mean absorption values of 13.405 ± 0.245 mg/kg and 34.801 ± 0.805 mg/kg respectively at 10th week. *Moringa oleifera* also showed least absorption of the metal ion at both concentrations. Absorption increased as the concentration of the inoculant solution increased, and also on moving from 8 weeks' to 10 weeks' for *Capsicum annuum*, *Murraya koenigii*, *Moringa oleifera* while absorption decreased moving from 8 weeks' to 10 weeks for *Amaranthus hybridus* and *Ocimum gratissimum*. All the plants absorbed Cd^{2+} above the FAO/WHO, 2011 and EU Cd Maximum limit of 0.2 mg/kg, 2006 [32] [33] except *Moringa oleifera when inoculated with* 0.1 *M during the first harvest*. *Amaranthus hybridus* showed highest absorption of Co^{2+} with mean absorption values of 5.566 ± 0.324 mg/kg and 5.670 ± 0.210 mg/kg for 0.1 M and 0.5 M solution of Co^{2+} respectively (**Table 5** and **Table 6**). *Moringa oleifera* still absorbed least metal ion. Absorption increased as the concentration of the inoculant solution increased, and also on moving from 8 weeks' to 10 weeks' for all the plants. On inoculation of the plants with 0.1 M solution of Zn^{2+} (**Table 7**), *Ocimum gratissimum* showed highest absorption with the mean value of 9.334 ± 0.312 mg/kg, when the inoculants concentration was increased to 0.5 M (**Table 8**), *Capsicum annuum* showed highest absorption with mean absorption value of 9.916 ± 0.614 mg/kg at 10^{th} week. Also absorption increased as the concentration of the inoculant solution increased, and also on moving from 8 weeks' to 10 weeks' for all the plants. All the plants absorbed Zn^{2+} below the FAO/WHO limit 2011-20 mg/kg [32]. Co^{2+} was the least absorbed while Cd^{2+} was most absorbed, and they followed the trend; $Cd^{2+} > Zn^{2+} > Pb^{2+} > Co^{2+}$. From the results, *Moringa oleifera* showed least absorption of all the metal ions. The results indicated that all the absorbed significant amounts of the four metal ions. Some researchers have reported the presence of Pb, and Cd, in vegetables grown in polluted soil, waste dumpsite and waste water in concentrations above the permissible level [17] [18] [34] [35] [36]. This shows that people in most developing countries might be at the risk of these heavy metals poisoning, considering that these leafy vegetables sometimes are grown near refuse dumps, waste water, industries etc.

5. Conclusion

Industrialization is considered vital to the nation's socio-economic development as well as its standing in the international community. Ideally, the sitting of industries should achieve a balance between socio-economic and environment considerations [36]. The plants, *Murraya koenigii*, *Ocimum gratissimum*, *Capsicum annuum*, *Amaranthus hybridus and Moringa oleifera* absorbed all the metal ions—Pb^{2+}, Cd^{2+}, above the standard based on EU commission regulation 2006, except *Moringa oleifera which absorbed below the limit when inoculated with* 0.1 *M solutions of* Pb^{2+} *and* Cd^{2+}. Since these metal ions are bioaccumulating, it can be safely concluded that the consumption of these leafy vegetables grown in soils polluted with Pb^{2+}, Cd^{2+} is a potential source of health hazard due to the metals.

Conflicts of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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