Original article

Metals in leafy vegetables grown in Addis Ababa and toxicological implications

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Abstract

Background: Vegetables grown at environmentally contaminated sites in Addis Ababa could take up and accumulate metals at concentrations that are toxic to human health.

Objective: To analyze the metal/metalloid contents of some leafy vegetables in Addis Ababa with emphasis on their toxicological implications.

Method: Recently matured leaf samples of cabbage, Swiss chard, and lettuce at early maturity, from Peacock Park and Kera vegetable farms underwent pressurized digestion with HNO_3/H_2O_2 to determine heavy metals.

Results: Cabbage was in general the least accumulator of metals/metalloids. Lettuce and Swiss chard grown at Kera had higher concentrations of metals/metalloids compared to those grown at the Peacock Park. In a few cases, As, Cr, Fe and Pb in these vegetables have surpassed maximum permitted concentrations, while Cu deficiency was observed in cabbage.

Conclusions: Metal uptake differences by the leafy vegetables is attributed to plant differences in tolerance to heavy metals. Vegetables from Kera consisted of higher metal/metalloids than from Peacock Farm because Kera River is more contaminated than Bulbula River. The intake of most of the metals constitutes less than 10% of the TMDI (theoretical maximum daily intake) at present, and hence health risk is minimal. But with increase in vegetable consumption by the community the situation could worsen in the future. Treatment of industrial effluents and phyto-extraction of excess metals from polluted environments could reduce health risk. [*Ethiop.J.Health Dev.* 2002;16(3):295-302]

Introduction

Vegetables constitute an important part of the human diet since they contain carbohydrates, proteins, as well as vitamins, minerals, and trace elements (1). Until recently however, they did not constitute a major part of the Ethiopian diet, except during the fasting period. However, since recent years their consumption is increasing gradually, particularly among the urban community. This is due to increased awareness on the food value of vegetables, as a result of exposure to other cultures and acquiring proper education.

Vegetables grown in the Addis Ababa area include: potato (*Solanum tuberosum* L.) Swiss chard (*Beta vulgaris* L. var. *cicla*), carrot (*Daucus carota* L.), cabbage (*Brassica oleracea* L. var. *capitata*), Ethiopian kale (*Brassica carinata* A. Br.), lettuce (*Lactuca sativa* L.), cauliflower (*Brassica oleracea* L. var. b*otrytis*) and red beet (*Beta vulgaris* L. var. *vulgaris*). These are often grown on the embankments along the major rivers within Addis Ababa town itself and the neighboring towns of Akaki, Alem Gena, and Sebeta.

The vegetable farms at Kera and the Peacock Park are among the biggest farms in the capital, where a substantial amount of vegetables is being produced seasonally. These farms are irrigated with the wastewater from Rivers Kera and Bulbula, respectively. Before several decades, the water from the rivers in the capital was clean. However, with the increase in the urban population and industrialization, the water has now become contaminated with various pollutants, among which are heavy metals.

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Vegetables grown at contaminated sites could take up and accumulate metals at concentrations that are toxic (2). In addition, they could be contaminated as farmers wash them with wastewater before bringing them to market.

The leafy vegetables under this study; namely, cabbage or Swiss chard are usually mixed with potatoes and carrots and cooked to form a special sauce known as "alicha", while lettuce is usually cut in pieces and mixed with pieces of tomato and seasoned well and eaten raw as salad.

Heavy metals are known to pose a variety of health risks such as cancer, mutations, or miscarriages (2). The objective of this study was to analyze the metal and metalloid concentrations of some leafy vegetables (cabbage, Swiss chard and lettuce) grown in Addis Ababa with special emphasis on their toxicological implications.

Methods

Geographic setting of the vegetable farms: The Peacock Park vegetable farm is situated in the central part of the city along the road to Bole International Airport (Fig. 1). A part of this farm extending from the western to eastern side of the city is irrigated with Bulbula River while the farm extending from the northern to the southern side of the city is being irrigated with Kebena River. Bulbula River is more heavily contaminated with heavy metals than Kebena River (Table 2). The vegetable samples in this study were taken from the side irrigated with the Bulbula River. The Kera Farm is situated in the southern part of the city very close to the Addis Ababa Abattoir and is irrigated with Kera River.

Plant sampling, preparation and analysis: Twenty-five recently matured leaves of lettuce, Swiss chard and cabbage from 25 different plants each were sampled at early maturity according to (3), from the Peacock Park and Kera farms in the year 1998. The samples were then brought in plastic bags to ILRI (International Livestock Research Institute) where they were cleaned with de-ionized water repeatedly. These were later dried in an oven at 65 ^{0}C for about 2 days, and were ground there using a Cross-beater Grinding mill (4). The samples were then analyzed at the University of Hohenheim in Germany.

Samples underwent pressurized digestion with HNO_3/H_2O_2 in an MLS-1200 microwave heated system. 0.5 g of ground plant sample is digested with 5 ml of nitric acid and 3 ml of hydrogen peroxide. The digestion temperature was about 160 ^{0}C. The heating program was conducted in ten steps of different time scale (a total of 61 minutes), and at different power supply for each step ranging between 0 to 750 watts.

Zinc, iron and manganese were determined with echelle-optics, Leeman Labs, PS 1000, ICP-OES (Inductively Coupled Plasma - Optical Emission Spectrometer) with external calibration. Arsenic was measured with a flow injection system using a Perkin Elmer, FIAS 400 (HG-AAS) heated graphite furnace coupled to an AAS equipped with a quartz tube heated to 100 ^{0}C and an EDL (electrodeless discharge lamp), with external calibration. Sodiumborohydride is used as reductant in the flow injection system. All the rest (Cd, Co, Cr, Cu, Ni and Pb) were determined with Perkin Elmer, ELAN 6000 Quadrupol ICP-MS (Inductively coupled plasma -mass spectrometer) with external calibration and Rh used as internal standard.

Guidelines for maximum limit (ML) of metals in vegetables were adopted from FAO/WHO (5), (6), and (2) (Table 1).

Water sampling, handling and analysis: Surface composite samples of water were taken at locations where the rivers are diverted to the Peacock and Kera vegetable farms. About 5ml of HNO_3 acid was added to clean 250ml polyethylene bottles, before adding about 100 ml of river water. The HNO_3 acid was added for the purpose of acidifying and preserving the water samples. The chemical composition of the water was determined at the laboratory of the Geology Department of the University of Saskatchewan using a PE Elan 5000 ICP-MS equipped with regular nebulizer. The elements determined included: arsenic, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, and Zn.

The operating conditions of the ICP-MS (PE Elan 5000) is as follows: Rf forward power (1100 W), Cool gas flow rate (10 L /min), Intermediate gas flow rate (0.8 L/min), Nebulizer gas flow rate (0.76 L/min), Sample uptake rate (1 ml/min), Sampler/ skimmer cones (Ni, 1.1 and

Table 1: **Metal concentrations in leafy vegetables from Kera and Peacock farms, Addis Ababa, Ethiopia, 1998**

Element	Cabbage		Lettuce		Swiss Chard		Recom. Max. L. for Vegetables [a]
mg.kg $^{-1}$	Kera	Peacock	Kera	Peacock	Kera	Peacock	
As	0.13	0.11	1.04	0.31	1.21	0.34	0.43
Cd	0.02	0.01	0.13	0.08	0.08	0.04	0.2[b]
Co	0.06	0.13	0.76	0.17	0.68	0.32	50[c]
Cr	0.89	1.61	9.47	1.21	2.05	1.04	2.30
Cu	3.03	3.30	6.62	6.24	8.06	7.88	73.3
Fe	73.00	173.00	1345.00	351.00	527.00	461.00	425.50
Mn	29.00	25.00	106.00	54.00	37.50	67.00	500[c]
Ni	0.80	0.91	1.86	0.71	2.10	0.89	67.90
Pb	0.21	0.29	1.59	0.39	1.79	0.61	0.3[b]
Zn	31.80	31.81	48.63	47.80	56.19	48.91	99.40

[a]Source: Weight, 1991
[b]Source: FAO/WHO-Codex alimentarius commission, 2001
[c]Source: Pendias and Pendias, 1992

0.89 mm diameter, respectively); Lens settings (v)-Instrument read-back: (P: -69, B: +9.1, S2: -8.3, E1: +), Acquisition (Peak hopping), Dwell time (200 ms/peak), Point/peak (1). Analysis was carried out using external calibration and internal standardization.

FAO (7) and USEPA (8) guidelines for maximum limits of metals in irrigation water were compared here (Table 2).

Soil sampling, processing and analysis: Composite surface soil (0-20cm) samples (from a bulk soil made up of 20 different soil samples per farm) of the Kera and Peacock farms were collected separately and properly labeled. The soil samples were then air-dried, and crushed to pass a 2-mm mesh sieve. The pH of the soils was determined potentiometrically from a 1:2 (soil:0.01M CaCl2) solution occasionally stirred with glass rods, with a PHM standard pH meter. Organic carbon was measured using a LECO CR-12 carbon analyzer.

Zero point five gram of finely ground soil samples were placed each in a PFA Teflon 120 ml digestion vessel and digested with 8 ml HNO_3 and 4 ml HF in a microwave digestion system for total elemental soil analysis. To avoid venting of the digestion vessels the reagents were not added all at once but portion by portion over several days. Total soil metals were then determined using a PE Elan 5000 ICP-MS. Analysis was carried out using external calibration and internal standardization. The calibration procedure involves preparation of calibration standards, acid blanks, and spiking samples. For each batch of samples, one standard reference material, one procedural duplicate of the samples, and one procedural blank were prepared.

The guidelines used in this text for maximum levels (ML) of metals in soils was adopted from the reference by (9) and for Fe and Mn from (6) (Table 2).

Results

The major industries from which effluents enter into Kera River are: Addis Ababa Tannery, Tikur Abay Shoe Factory, Gulele Soap Factory, Ethio Marble Industry and Gulele Shirt Factory (10). The daily domestic and industrial wastewater discharge from the above industries (excluding Gulele Shirt Factory) is 305, 200, 62, and 13m^3, respectively. The Ethiopian Metal Tools Factory with a daily domestic and industrial discharge of 21 m^3 is the major source of river pollution of Bulbula River, which is used to irrigate part of the Peacock Park vegetable farm. Additionally, wastes from garages, gas stations, hospitals, etc. are discharged into these rivers.

The pH ($CaCl_2$) of Peacock Park and Kera farms is weakly acidic with values of 6.3 and 6.1, respectively. The organic matter of Peacock Park is 3.4 (medium humic) and that of Kera soil is 4.1 (strongly humic).

Cabbage was generally the least accumulator of metals and metalloids comparing the three leafy vegetables grown in Kera and Peacock Park farms in Addis Ababa, with the exception of Ni and Cr at the Peacock Park (Table 1). Lettuce had generally the highest concentrations of Cd, Co, Cr, Fe, and Mn; while Swiss chard contained the highest concentrations of As, Cu, Ni, Pb and Zn.

Table 2: **Concentrations of some trace elements found in bulbula and Kera rivers and soils of adjacent farms, Ethiopia, Feb. 3, 1998**

Element	Bulbula		Kera		Guidelines for mas. Levels in	
	river (µg/L)	Soil (total) (mg.kg $^{-1}$)	river (µg/L)	Soil (total) (mg.kg $^{-1}$)	Ir rig. Water (µg/L)[b]	Soil (total) (mg.kg $^{-1}$)[c]
As	1.70	5.19	<1.00	6.80	100	20
Cd	0.07	0.71	<1.00	0.44	10	3
Co	2.69	27.95	<5.00	43.00	50	50
Cr	n.d.	81.00	7.40	115.00	550[a]	100
Cu	12.40	38.96	39.00	55.00	17[a]	100
Fe	n.m	163.86	4290.00	79.70	500	50000[d]
Mn	n.m	6587.00	1690.00	3598.00	200	2000[d]
Ni	2.26	74.13	8.90	115.00	1400[a]	50
Pb	14.10	46.74	33.00	110.00	65[a]	100
Se	n.d	0.09	0.08	0.02	20	10
Zn	50.37	2985.50	193.00	263.00	2000	300

n.d.=not detected
n.m.=not measured [a]Source: USEPA, 2001 [b]Source: Ayers and Westcot, FAO 1985 [c]Source: Ewers, 1991 [d]Source: Pendias and Pendias, 1992

Comparing the two contaminated sites, lettuce and Swiss chard accumulated more metals and metalloids at Kera, while on the contrary cabbage accumulated more at the Peacock Farm, with the exception of Mn in both cases (Table 1). Arsenic, Cd and Zn in cabbage grown at both places did not show any difference.

Maximum permitted metal concentrations in leafy vegetables are surpassed by arsenic, chromium, iron and lead (Table 1). This is particularly the case with lettuce grown at Kera (As, Cr, Fe, Pb) and Swiss chard from Kera (As, Fe, Pb) and Peacock Park (Fe, Pb).
Except for Cu, metal levels are generally within normal range in cabbage. The above elements are thus of greater concern in vegetable consumption in Addis Ababa.

Discussions

Differences in metal uptake by vegetables: Genotypical differences in tolerance and cotolerance to heavy metals are well known in some species and ecotypes of natural vegetation (11). Lettuce and Swiss chard have been shown to accumulate relatively high concentrations of heavy metals. An earlier study on metal contents of vegetables from Addis Ababa market showed that lettuce contained the highest Cd and cabbage the least (12). Similar trends of higher accumulation of metals in Swiss chard and low accumulation in cabbage, were observed in vegetables from Akaki farm, which is irrigated with industrial effluent (13).

Metal/metalloid concentrations of Kera and Bulbula river water: Water analyses revealed that Kera River is more contaminated with metals/metalloids than Bulbula River (Table 2). Considerably higher concentrations of particularly Cr, Cd, Ni, Pb and Zn are detected in Kera River. This is consistent with plant content of the same elements in the leafy vegetables grown in farms irrigated with these rivers. Kera Farm is hence more contaminated than Peacock farm primarily because more industrial effluents from various industrial sources enter into Kera River than Bulbula River. Additionally, little or no treatment is applied to the industrial discharges to detoxify the wastewater draining into rivers. Unfortunately, metals/metalloids emitted in such manner are easily transferred to all of the food chain, thereby affecting human and animal health.

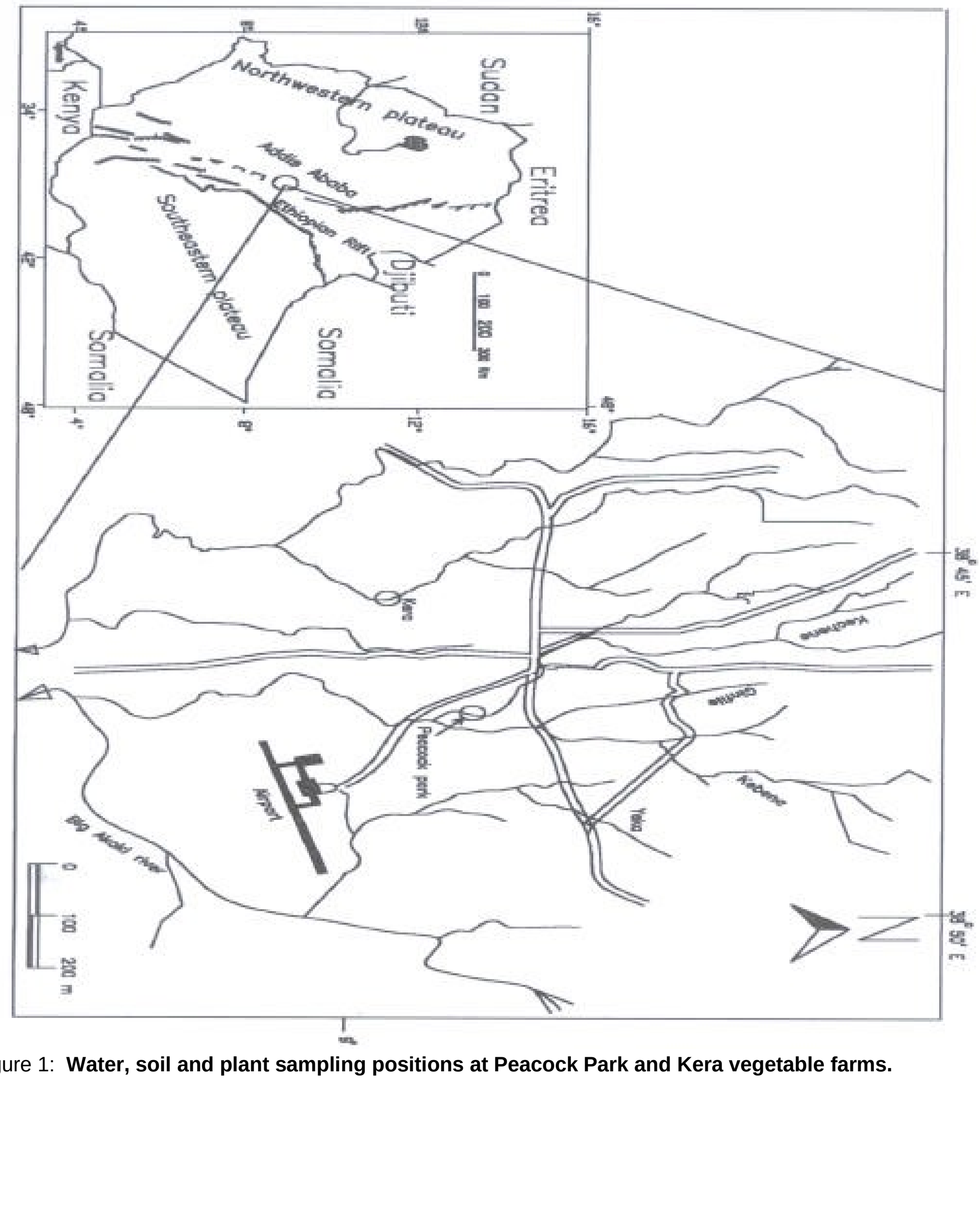

Figure 1: **Water, soil and plant sampling positions at Peacock Park and Kera vegetable farms.**

Influence of some soil parameters on metal availability and solubility: Solubility of metals is known to increase with a decrease in soil pH, and hence plant metal uptake is higher in acidic soils than in calcareous soils (14). Metal uptake due to soil pH under the present state is thus limited in both soils, but any reduction in soil pH in these farms could raise metal availability and metal uptake by plants, which also could increase health risk. It is also known that there is a linear relationship between metal availability and organic matter content (15).

Kera farm contains slightly higher organic matter that could have partially contributed to the relatively higher metal uptake by plants grown there. Both farms have alluvial soils deposited as a result of sediments carried by rivers. Contaminated sediments are one of the several means through which soils are enriched with heavy metals (16).

Anticipated health risk from metal/metalloid status in the leafy vegetables: The Codex Committee on Food Additives and Contaminants of the Joint FAO/WHO Food Standards Programme, has proposed draft levels for typical daily exposure and theoretical maximum daily intake (TMDI) for some of these metals in vegetables (5). Accordingly, the intake of most of the metals constitutes less than 10% of the TMDI.

Arsenic, chromium, iron and lead are at present of greater concern of health risk than the other metals. Arsenic could be added into Kera River from effluents of the glass and ceramic industries in the northern part of the city, while Cr is added from effluents of a tannery. The other probable arsenic sources could have been insecticides and herbicides. Elevated iron content in plants could be due to iron in effluents from metal industries, which enters the river. One likely source of the high Pb concentration in the vegetables is the gas emissions from the traffic in Addis Ababa. Some injured leaves have been witnessed and on some plants necrotic spots were observed.
This is usually attributed to Fe toxicity (6). Chlorosis of leaves has also been observed on some plants, due to metal toxicity. Cu is found in deficient ranges in cabbage at both sites. One possible deficiency of Cu in plant tops is due to its preferential accumulation in roots (17). This remains to be studied in the future to make a definite conclusion.

Metal concentrations in the vegetables studied would not suffice for determining health implications. This depends also on the dietary pattern of the consumers. The average amount of vegetables consumed per day by a person in Addis Ababa is 5g in contrast to the international daily average of 50g for leafy vegetables (18). It is because of this, that the intake of metals from the studied vegetables constitutes much less than the theoretical maximum daily intake (TMDI) or the provisional tolerable weekly intake (PWTI), which are used to express the exposure of consumers and associated health risk. A recent study on leafy vegetables bought from Addis Ababa market also confirms this (12).

Hence, the situation at this moment does not seem to pose a great threat. However, with increase in vegetable consumption this situation could easily change. For instance, it has been reported that through the introduction of biointensive gardening in some households in Addis Ababa the daily vegetable intake per person has risen from 5g to 161g (18). Periodical monitoring of rate of contamination and consumption is thus necessary to assess the overall exposure level in the community.

Conclusions and recommendations Since cabbage is the least accumulator of metals and metalloids, it may be less risky to eat cabbage from Kera and Peacock Park farms, than eating lettuce or Swiss chard, from health standpoint. On the other hand, lettuce and Swiss chard could further be used to investigate whether they could accumulate much higher concentrations of metals and metalloids for possible phytoremediation of vegetable farms.

To avoid entrance of metals into the food chain, municipal or industrial waste should not be drained into rivers and farmlands without prior treatment. Apart from treating the discharge that enters into the farms, it is also imperative to utilize alternative measures of cleaning up the already contaminated substrates.

Although there is a general tolerable level of metals and metalloids in vegetables from Addis Ababa at the moment, there are exceptional cases of metal/metalloid build up such as arsenic in Swiss chard and Cr in lettuce at Kera.

Iron and lead happen to be of concern as well. The daily intake of these metals at present is much less than concentrations that affect health, the situation could however change in the future depending on the dietary pattern of the community and the volume of contaminants added to the ecosystems.

Since copper is one of the essential micronutrients, its adequate supply for growing vegetables should be ensured through artificial or organic fertilizers.

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