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METAL CONCENTRATIONS OF SOME VEGETABLES IRRIGATED WITH INDUSTRIAL LIQUID WASTE AT AKAKI, ETHIOPIA

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ABSTRACT: Plant analyses of leaves at maturity of some vegetables from Akaki, were conducted to determine their heavy metal concentrations and resulting risk to human life. These vegetables; namely, swiss chard (*Beta vulgaris* var *cicla* L.), onion (*Allium cepa* L.), potato (*Solanum tuberosum* L.), cabbage (*Brassica oleracea* L. var *capitata*), and red beet (*Beta vulgaris* L.) were irrigated with industrial liquid waste from the Akaki Textile Factory, which is directly drained into farmlands. At present, Cd, Cr, Cu, Hg, Ni and Zn contents of potato have surpassed maximum limits expected under normal unpolluted circumstances. The same is true for Cr in onion and red beet. Concentrations of Hg also exceed maximum expected tolerable levels in all vegetables. Copper and chromium are particularly the metals requiring attention. Total chromium and nickel contents of the uncontaminated Akaki soils also are in the toxic range. The bio-availability of most of the metals is restricted because the pH of the soil is in the weakly to medium alkaline range, which normally reduces the activity of most metals. Conclusively, metal concentrations at the moment have not yet reached phytotoxic levels, and hence the condition is now safe for human health, but as long as no measures are taken to avoid irrigating with the industrial liquid waste, the current trend indicates that the hazard to life will definitely rise after a certain period of time.

Key words/phrases: Plant analyses, vegetables, heavy metals, industrial liquid waste, phytotoxic levels

INTRODUCTION

At Akaki, a small industrial town about 20 kms south-east of Addis Ababa, different vegetables are grown along the banks of Akaki River. The vegetables are irrigated with either the river water which is contaminated with toxic substances dumped into it from the close by industries and/or through industrial liquid waste directly applied on the farmlands. Vegetables have been growing in this manner for over three decades, since the establishment of the industries there.

The vegetables grown in this manner at Akaki include, swiss chard (*Beta vulgaris* var *cicla* L.), onion (*Allium cepa*), potato (*Solanum tuberosum*), cabbage (*Brassica oleracea* var. *capitata*) and red beet (*Beta vulgaris* L.), among others.

The quality of these vegetables, particularly in terms of their nutrient composition is of great concern, because they are sold to large number of consumers in and around Addis Ababa. The liquid waste drained into the river or directly applied to the farmlands consists of several toxic metals which can upset the physiological functions of the growing plants, and consequently affect human health.

According to Larcher (1984), major toxic effects to plants include disturbances in photosynthesis, functions of the stomata, respiration and biomass production which eventually lead to growth inhibition.

There are several reviews on different aspects of metal interactions in soils and metal uptake and distribution in plants (Kuo, 1990). Metal interactions at levels of uptake may change the solubility, the valence state and charge and the chemical ligands or chelation of the metals, all of which will influence bioavailability (Beyersmann, 1991). Also, the total quantity of metal present in soils, pH, cation exchange capacity (CEC), clay, organic matter, and Fe-oxide content contribute to plant uptake of metals (Kuo, 1990).

Plants have different patterns of heavy metal uptake and have different degrees of tolerance to metal accumulation in their tissues. Hence, metal taken up by plants depends also on the plant species (Fruechtenicht and Vetter, 1982).

Some plants are very sensitive, while others such as lettuce (*Latuca sativa* L., 'Apollo') are said to be accumulators of heavy metals (Adriano, 1986). Some other plants could even accumulate amounts which are normally phytotoxic to others. A number of reviews are available on heavy-metal-tolerant plant species that are able to hyperaccumulate metals in plant shoots (Baker and Brooks, 1989; Baker *et al.*, 1991). Such species can be used for removing heavy metal pollutants from the soil in phytoremediation technology (Brown *et al.*, 1995).

The objectives of this study are then: to diagnose the extent of metal accumulation in the tissues of the above mentioned vegetable crops which are grown on soils contaminated with industrial wastes, and potential risk to human health based on tissue concentrations.

MATERIALS AND METHODS

Leaf samples of swiss chard (*Beta vulgaris* var *cicla* L.), onion (*Allium cepa*), potato (*Solanum tuberosum*), cabbage (*B. oleracea*), and red beet (*Beta vulgaris* L.), were sampled at maturity in Akaki. These crops were grown on farmers' fields irrigated with liquid waste from the Akaki textile factory.

Recently matured leaves (15 to 20) were collected per sample, and placed separately in plastic bags and transported to International Livestock Research Institute (ILRI) soil laboratory. At ILRI, the samples were cleaned successively with distilled water, to remove dust or any surface contamination. Afterwards, they were dried at 65° C for 48 hours. The samples were later ground using a Crossbeater grinding mill with a 1.0 mm mesh sieve. The ground samples were later taken to the Institute of Plant Nutrition laboratory at Hohenheim in Germany, for tissue analysis of the various metals.

At Hohenheim, the plant samples were weighed and placed in special paper bags and let to stand in a desiccator for 24 hrs. Later on, 0.5 g of each of the samples was weighed in duplicates and placed in 20 ml volumetric flasks. Three batches of blank samples were also arranged. To each sample 8 ml of concentrated reagent grade HNO_3 was added. This was let to stand for sometime and then 4 ml of H_2O_2 was added to the mixture very gently making sure that all plant samples on the walls of the flasks were carefully driven below.

Afterwards, the mixture was heated in a microwave digestion apparatus for 22 minutes. The digestion was performed in six steps: 2 minutes with 250 W power at 40° C, followed by 1 minute pause, then 3 minutes with 250 W power at 55° C, followed by 5 minutes with 450 W power at 75° C, then 3 minutes with 550 W power at 90° C and finally 8 minutes with 300 W power at 100° C. The digest was let to cool for about 30 minutes. This was later filled to 20 ml mark with deionized water.

After preparation of the known standards, Cd, Cr, Cu, Ni, and Zn were determined using flame atomic absorption spectrophotometer. As, Co and Hg on the other hand, were determined using an inductively coupled plasma spectrophotometer.

Weigert (1991) provides normal ranges of heavy metal concentrations (minimum to maximum) expected in different vegetables used as food crops (Table 3). Bergmann (1993) also reviews average contents of heavy metals in leafy vegetables from unpolluted field as well as maximum tolerable concentrations of heavy metals in vegetables, deemed safe for human consumption (Tables 3 and 4). These values are used to compare the contaminated vegetables considered in this experiment.

RESULTS AND DISCUSSION

Site properties of polluted soil

The vegetables are grown dominantly on Pellic Vertisol and along the river bank on Eutric Fluvisol. The pH of the contaminated surface soil samples ranges between weakly alkaline (7.1) to medium alkaline (8.3). The organic matter content ranges between medium (3.2%) and strong (4.6%). Carbonate content ranges between very poor (0.07%) to weakly carbonated (2.8%) (Fisseha Itanna, 1997, unpublished report).

Of the nine toxic metals determined from the contaminated Akaki soils; namely, As, Cd, Co, Cr, Cu, Hg, Ni, Pb and Zn (Table 2), total chromium (Cr) and total nickel (Ni) contents have reached the "toxic levels", according to critical limits set by Hein and Schwedt (1991).

Although the plant available forms of the metals have not been determined, the weakly alkaline to medium alkaline soil pH is indicative of reduced plant uptake of these metals. Several studies show decreased availability of many of these metals with increasing pH (Heckmann *et al.*, 1987; Basta and Tabatabai, 1992).

Metal uptake due to differences in plant species

According to concentrations in leaf samples, heavy metal contents of the different vegetables considered, have not reached phytotoxic levels. One major reason why tissue concentration of these metals have not reached phytotoxic levels may be because, the mobility of these metals and their availability in the plant have been reduced due to the soil pH, which is in the alkaline range (weakly to medium).

Generally, potato was found to be the highest accumulator of heavy metals followed by swiss chard, whereas onion was the least accumulator from the vegetables considered (Table 1). Metal accumulation generally decreased in the order of potato, swiss chard, red beet, cabbage and onion. Similar trend of metal accumulation is reported by Kloke *et al.* (1984), with a slight difference in that swiss chard was considered as a high accumulator and potato and beets as medium accumulators of metals. Cabbage was low accumulator of metals, its maximum contents of Pb, Cd and Zn being slightly higher than that of onion (Bergmann, 1993).

According to Weigert (1991) and Bergmann (1993), some of these metals have surpassed the expected mean and maximum contents under normal unpolluted conditions for some of these vegetables (Table 3).

Comparing the heavy metal contents (As, Cd, Cr, Cu, Hg, Ni and Zn) of potato grown under contaminated condition at Akaki with that of the tolerable minimum, mean and maximum values on (Table 3), it can be noted that the potato grown at Akaki contains values exceeding the maximum contents tolerable for all elements except arsenic.

Table 1. Leaf concentrations of arsenic and some heavy metals of different vegetables at maturity stage, grown with industrial liquid waste at Akaki.

Vegetables	Metal content (mg kg^{-1})						
	As	Cd	Cr	Cu	Hg	Ni	Zn
Cabbage	0.105	0.030	1.80	3.28	0.218	0.64	29.7
Onion	0.105	0.018	2.81	5.24	0.201	0.44	15.4
Potato	0.113	0.076	2.26	8.72	0.355	1.75	47.4
Red Beet	0.170	0.057	2.87	8.92	0.142	1.47	27.3
Swiss chard	0.038	0.044	1.25	8.96	0.218	0.79	38.1

Table 2. Metal concentrations (total) of treated and untreated soils at Akaki.

Sample	Description	Total metal concentrations (mg kg^{-1})								
		As	Cd	Co	Cr	Cu	Hg	Ni	Pb	Zn
1	untreated	3.62	0.104	26.40	81.83	31.19	0.017	46.41	9.11	115.23
2	treated*	3.82	0.188	35.25	108.51	40.74	0.082	69.61	9.10	132.84
3	"	3.55	0.183	34.61	111.87	39.88	0.060	62.20	8.43	142.20
4	"	4.30	0.173	44.37	116.01	34.83	0.08	53.23	13.06	137.14
5	"	4.41	0.163	43.92	81.02	33.02	0.091	48.74	17.02	153.16
Toxic limits**		>20	>3	>50	>100	>100	>2	>50	>100	>300

* Treated samples are taken at 25 m interval downslope.

** According to Hein and Schwedt (1991) and Pendias and Pendias (1984).

The arsenic value is also still higher than the mean tolerable value. Similar conclusion can be drawn when comparing these results with the maximum tolerable contents of heavy metals allowed in vegetables as enacted by Law in former GDR (Table 4) (Bergmann, 1993). Here again, arsenic contents only fall below the maximum values.

Table 3. Metal loads of food of vegetable origin (mg kg^{-1}) (Weigert, 1991).

Food	Value (mg kg^{-1})	Metal						
		As	Cd	Cr	Cu	Hg	Ni	Zn
Potatoes	Mean	0.070	0.03-0.05	0.05-0.30	1.57	0.006	0.05-0.26	3.50
	Minimum	0.001	0.001	ND	0.55	ND	ND	1.10
	Maximum	0.200	0.320	0.65	5.30	0.020	0.56	17.90
Vegetables	Mean	0.040		0.11	1.00		0.05	4.31
	Minimum	0.001		ND	0.01		ND	ND
	Maximum	0.430		2.30	73.70		67.90	99.40
Lettuce, cabbage and tomato	Mean	0.030						
	Minimum	0.010						
	Maximum	0.140						
Lettuce, cabbage	Mean					0.005		
	Minimum					ND		
	Maximum					0.040		
Cabbage**	Mean	-	1.10	4.60	12.40		6.30	75.50

ND, Not Detectable.
** Source Bergmann (1993).

Table 4. Maximum tolerable contents of trace metals (mg kg^{-1}) in vegetables (according to rules regulating amount of foreign material in foodstuffs in the former GDR (Bergmann, 1993)).

Vegetables	As	Cd	Cu	Hg	Pb	Zn
	0.5	0.10	5.0	0.05	0.5	15.0

Considering the other vegetables (namely; swiss chard, cabbage, red beet, and onion); all consist of higher heavy metal contents of As, Cu, Cd, Cr, Ni and Zn than the mean value given for vegetables (Weigert, 1991), but lower values than the maximum tolerable contents allowed in these vegetables (Table 3). The exception to these are: onion has lower nickel content than tolerable mean values and onion and red beet contain Cr contents above tolerable maximum values. All these vegetables on the other hand, contain much higher Hg content than the maximum tolerable level found in foodstuffs. Weigert (1991), explains that plants grown in polluted areas absorb only a small amount of Hg through their roots; however, most mercury in plants results from surface contamination from mercury containing aerosols.

Although swiss chard is said to be a cadmium-accumulator (Mortvedt, 1987), the content of this metal in swiss chard is exceeded by that of potato and red beet on the contaminated Akaki soils (Table 1). Possible explanation may be the generally low levels of Cd in soils and competition by the other metals.

Behaviour of metals in plants

Comparing plant tissue concentrations versus critical levels of these metals and plant requirement for them, Cu contents are relatively higher in most of these vegetables (Tables 1 and 3).

Brams and Fiskell (1971) reported that if Cu is accumulated in plant roots, it can hinder the uptake of the other essential nutrients. These authors explain that accumulation of Cu in the roots leads to decreased root length and to suppressed formation of lateral roots. Similarly, one reason why the contents of the essential elements Zn and Co and that of the other heavy metals in the vegetables is low may be due to depressed root development which might have been caused by high uptake of Cu.

Zinc levels are generally low (Table 1). Zinc levels are almost close to bottom critical limit (20 mg kg^{-1}), based on the report of Amberger (1979). One possible cause for low levels of Zn may be that the phosphate fertilizer that the farmers apply on their farms could have reduced Zn availability. This is mainly because of Zn-phosphate interactions in soils (Fisseha Itanna, 1992). Additionally, Vertisols generally contain plant deficient levels of Zn (Fisseha Itana, 1992).

Moreover, the total Cd and Zn contents of Akaki contaminated soils are lower or comparable to that of Awassa contaminated soils although pollution due to industrial waste in Akaki began about two and half decades earlier than in Awassa (Fisseha Itana, 1997, unpublished report). This shows that little if ever

Zn and Cd are added to the soil from the industrial waste water. Therefore, plant uptake may also be correspondingly low.

Cd concentrations in all vegetables are generally low (Table 1). Apart from the low levels in soil, the weak to slightly alkaline soil pH could have likely reduced plant uptake of Cd. Soil pH is an extremely important factor in controlling metal uptake in crops (Lindsay, 1972). Page (1981), also concluded that the total soil Cd content and soil pH are the most important soil factors that affect the concentrations of Cd in food crops.

Cd accumulation in plant tissue is also gradual. Mortvedt (1987), reports that addition of Cd up to 450 g Ha^{-1} over a period of time did not significantly increase Cd concentration in different plant parts of potato and onion. Co was found in trace quantities in all vegetables.

CONCLUSIONS

Although all of these metals have not reached the phytotoxic levels, some of the metals in some of the vegetables have surpassed the normal maximum limits expected in these vegetables. This is particularly true for Cd, Cr, Cu, Hg, Ni and Zn in potato and Cr in onion and red beet. Since toxic concentrations of these metals in food are already known to increase health hazard (Pendias and Pendias, 1984), the increasing trend of heavy metals at the treated farmlands in Akaki, need serious consideration and timely correction before such levels are reached. Hg levels also exceed maximum tolerable levels expected in all vegetables.

The fact that the total chromium content in soils exceeds the toxic limit agrees well with the condition here that chromium has passed the maximum limits expected normally in three out of the five crops (potato, onion, and red beet) in the experiment. Improper handling of chromium products can cause respiratory injury and cancer while dumping of wastes on land and streams results in ground water contamination and damage to aquatic ecosystems.

The present study attempts to diagnose the status of metals taken up by the vegetables through leaf analysis. Mineral nutrient content of leaves generally reflects the nutritional status of the overall plant than the other plant organs (Marschner, 1986). In future studies, specific analyses of the edible organs will be made to find out the direct effect of the metal uptake on health.

In future studies, it will also be seen how different soil management practices affect heavy metal build up. Moreover, metal build up will be studied considering soil type differences.

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