Int. J. Environ. Res., 7(2):403-406, Spring 2013
ISSN: 1735-6865

Industrial Pollution and Food Safety in Kigali, Rwanda

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Received 5 March 2012; Revised 15 July 2012; Accepted 25 July 2012

ABSTRACT: We determined the concentrations of lead and cadmium in edible parts of *Colocasiaesculenta, Amaranthusspp*. and *Ipomoea batata* cultivated on farms in industrially polluted sections of Nyabugogo marsh (Kigali, Rwanda) and quantified metal intake by consumers of these crops. We report that metal concentrations in crops were within EU limits. The highest metal concentrations were found in *Amaranthusspp*. leaves (lead = 0.31 mg/kg and cadmium = 0.03 mg/kg) and the lowestin *I. batata* (lead = 0.02 mg/kg and cadmium = 0.01 mg/kg). Conversely, metal intake through these crops by adults in a surveyed community exceeded thresholds prescribed by the World Health Organization (WHO). Based on crop consumption quantities, dietary lead intake by adults exceeded the recommended maximum by as much as seven and four orders of magnitude through *Amaranthusspp* and *C. esculenta,*respectively. Cadmium intake exceeded the WHO recommended maximum by two (*Amaranthusspp* and *C. esculenta*)and three (*I. batata)* orders of magnitude.

Key words: Health risk, Heavy metals, Colocasiaesculenta, Amaranthus spp., Ipomoea batata, wetlands

INTRODUCTION

The supply of food to an increasingly urban global population represents one of the major challenges associated with urbanization (Satterthwaite *et al.*, 2010). This challenge is compounded in countries where infrastructure such as transport networks and markets is not sufficiently developed. However, even where these exist and food is available to purchase, it is not always accessible to lower income groups (Satterthwaite *et al.*, 2010). Thus, the production of food in urban areas has gained increasing importance within the urbanization framework, both as a source of food for this category of urban dwellers, and also as a means of employment and income (through the sale of surplus produce) (Lado, 1990; KeraitaandDrechsel, 2004). However, the use of waste water in the production of food crops has been reported in diverse locations around the world(Scott *et al.*, 2007). The practice has been reported in cities across India (Sharma *et al.*, 2009), China (Zhuang *et al.*, 2008) and Africa (Bahemuka and Mubofu, 1999; Muchuweti *et al.*, 2006; Scott *et al.*, 2007;Karanja *et al.*, 2010; Mbabazi *et al.*, 2010); with crops being cultivated in soils polluted by industrial and domestic effluent. This happens despite the risks to health presented by the consumption of such produce; as plants growing in such soils and water concentrate contaminants such heavy metals.

In Kigali, where urban agriculture accounts for approximately 80% of the population's nutritional requirements (KCC, 2001), crops are grown in the city's marshes, some of which are fed by rivers polluted with industrial effluent (Rwanda, 2007). Nyabugogo is one such marsh. Situated in the periphery of Kigali's urban precinct (1°56'02.79S, 30°03'22.83E), it is fed by the Rwanzekuma and Kibumba Rivers (having a collective discharge of H"290 L/s) which receive waste water from a textile factory,vehicle repair garages, fuel stations and metal recycling stations in the Gikondo and Gisozi industrial areas (Gasana *et al.*, 1997; Sekomo et al. 2010; Nhapi et al., 2011). The marsh, which begins at the Gikondo industrial area, extends to the confluence of the Nyabugogo and Nyabarongo Rivers. It overlays sandy and clay soils and is dominated by *Cyperus papyrus* in uncultivated sections of approximately 60 ha. This is bordered by a larger area under year-round food crop cultivation by the urban population with vegetable crops such as maize, sugarcane, cassava, lettuce, cabbages, amaranth, taro and sweet potato being produced for sale in the city's markets (Rwanda, 2009).

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Studies in uncultivated sections of Nyabugogomarsh revealed concentrations as high as 23.4 mg/kg of cadmium and 45.2 mg/kg of lead in the umbels of *C. papyrus* plants (Sekomo *et al.*, 2010). While *C. papyrus* is a known hyper accumulator (Rai, 2009) and may not be an appropriate measure for metal accumulation in all plants, the presence of toxic metals in these plants is indicative of the availability of metal ions for plant uptake in this marsh. This subsequently raises questions about concentrations in food plants growing in the same location and of the potential dietary exposure to consumers of these crops. Despite this, we know of no scientific exposition on this matter. The aim of this work was therefore to quantify i) lead and cadmium content in food crops cultivated within the Nyabugogomarsh namely *Colocasiaesculenta* (taro), *Amaranthus spp*.(Amaranth) and *Ipomoea batata* (sweet potato); and ii) dietary metal intake by consumers through these crops.

MATERIALS & METHODS

Soils and crop plants were collected from three transects, two of which were perpendicular to the Ruganwa River and one was perpendicular to the Rwanzekuma River. Transects perpendicular to the Ruganwa River were approximately 0.24 km apart, and 3.00 km from Gikondo industrial area. Plants and soils were collected from 7 x 3m plots, surrounded by water channels. Within each transect, mature plants ready for harvest were collected from three locations chosen by the haphazard placement of 0.75 m^2 quadrats. Five replicate plant samples were collected from each quadrat and composited to one sample for analyses, yielding 3 composited samples of each crop per transect. Thus 15 individuals of each species were collected from each transect, and the total number of composited samples per plant species from all three transects was 12. All crop samples were cleaned with river water on site, as is done by the farmers prior to selling the produce.

Soil samples were collected from within 30 cm of sampled plants used for analysis. Five soil cores (10 cm depth) were collected from each transect using a 55 mm-diameter corer. This yielded a total of 12 composited soil samples, each containing five soil cores. Plant and soil samples were then transported to the laboratory for analyses within 8 hours of collection. Subsamples (~500 g) of each vegetable were prepared and cooked using local preparation methods i.e. taro and sweet potato were peeled, rinsed in tap water and cooked separately, and amaranth leaves were washed and boiled in tap water. The cooked samples were oven-dried at 100^{o}C for 24 hours and ground to powder for analyses.

For metal analyses, 0.1 g of each powdered sample was digested with repeated additions of nitric acid and hydrogen peroxide until the solution was clear. This digest was then refluxed at 95^{o}C for 15 minutes after the addition of concentrated hydrochloric acid, and then diluted to 100ml with deionized water (Jeniss *et al.*, 1997). The resulting solutions were analyzed in triplicate, for lead and cadmium by atomic absorption spectrophotometry (Varian AAS-240, Varian Inc. USA) at the agriculture laboratories of the National University of Rwanda (NUR) in Butare, Rwanda.

Soil samples were weighed, oven dried at 100^{o}C for 72 hours and re-weighed to determine water content and bulk density. Organic matter content was determined by loss-on-ignition at 500^{o}C (Goel 2006). Soil pH was measured with deionized water (1:2.5, soil: solution ratio, dry w/v) and the bioavailable metals were extracted by the diethylenetriaminepentaacetic acid (DTPA) method (Lindsay and Norvell 1978). Total lead and cadmium concentrations in soil were determined as for plant samples.

Crop consumption quantitieswere determined by surveys on residents of Inkingi administrative area where most of the farmers cultivating the Nyabugogo marsh reside. This area alsoborders the Kinamba commercial centre where most of the produce from the marsh is sold to traders and the local population. It is typical of high-density-low-income settlements, with houses comprising one or two rooms constructed out of mud bricks and zinc-coated sheets. The settlement is not connected to the electricity grid, and access to municipality-supplied water is by communal taps. Sanitation facilities are away from houses, and shared between households.

Inkingi administrative area consistsof 198 households, each with at least 6 members, most of them children below the age of 13. One adult from each of the 60 households selected to participate in the survey was interviewed using a prepared questionnaire. Respondents estimatedhouseholds' weekly consumption of taro, amaranth, and sweet potatoes using pre-weighed samples provided by the interviewer. Ages and weights of all household members were also recorded.

The daily metal intake (DMI) of metals for adults living in the Inkingi administrative area was calculated using Equation 1:

$$DMI = \frac{Cmetal * Wfood * 0.085}{Bw} \qquad (1)$$

whereWfood is the average mass of each food crop consumed per day, Cmetal is the amount of lead and cadmium contained in that particular crop and Bw is the average body weight of an adult in the community. A conversion factor of 0.085 (Khan et al. 2008) was used to convert the wet weight of the food crops to dry weight because metal concentrations are expressed on the basis of dry weight (Rattan *et al.*, 2005). Calculated DMIs were then compared with the reference doses (RfDo) prescribed by the WHO (0.0010 and 0.0035 mg $kg^{-1} day^{-1}$ for cadmium and lead, respectively).

RESULTS & DISCUSSION

The concentrations of lead and cadmium in sampled soils were within EU limits for crop production (Table 1). Metal concentrations in plants werehighest in amaranth leaves and lowest in sweet potato tubers. Concentrations of cadmium in all three crops were well below EU thresholds. In contrast, with the exception of sweet potato, lead concentrations were right at the stipulated thresholds (Table 2).

The average surveyed household in Inkingi administrative area consisted of two adults and four children under the age of 13. The average weight of adult residents was 57 kg. All respondents reported that the taro, amaranth and sweet potatoes they consumed were sourced directly from the marsh or indirectly (bought from grocers who sourced it from the marsh). Adults consumed, on average, 50 g amaranth, 120 g taro and 210 g sweet potato per day.

Based on these intake quantities and the plant metal concentrations, adults in the surveyed community were exposed to excessive concentrations of lead and cadmium through the consumption of these three staple crops (Table 3; WHO, 1993). Amaranth and taro supplied the highest concentrations of lead to consumers, approximately seven and four orders of magnitude, respectively, in excess of stipulated guidelines. The greater cadmium contribution was derived from sweet potatoes (3 orders of magnitude higher than WHO stipulations).

Table 1. Defined physical and chemical descriptors of soils from the Nyabugogo marsh (average of 5 samples ± SE), and EU-stipulated upper limits

	pH ± SE	OM (%) ± SE	Bulk density (g cm^{-3}) ± SE	Total soil Pb (mg/kg dw)	Bioavailable Pb (mg/kg)	Total soil Cd (mg/kg dw)	Bioavailable Cd (mg/kg^{1})
Transect 1	7.69 ± 0.29	6.31 ± 0.41	0.91 ± 0.12	116.51 ± 97.53	5.46 ±2.58 (16.33%)	0.92 ± 0.40	0.07 ±0.05 (8.88%)
Transect 2	7.25 ± 1.79	6.04 ± 1.54	1.17 ± 0.27	182.75 ± 77.91	4.29 ± 2.06 (2.42%)	1.88 ± 0.60	0.09 ±0.05 (4.62%)
Transect 3	5.38 ± 1.87	11.83 ± 3.34	0.82 ± 0.25	88.22 ± 89.87	2.43 ± 2.01 (16.69%)	0.63 ± 0.55	0.09 ± 0.07 (11.81%)
EU Standards*				**300**		**3**	

* European Commission (EC), 2001

Table 2. Lead and cadmium concentrations in sampled plants and EU-stipulated upper limits

	Lead (mg/kg)	Cadmium (mg/kg)
Amaranth	0.31 ± 0.108	0.03 ± 0.015
Taro	0.08 ± 0.030	0.01 ± 0.003
Sweet potatoes	0.02 ± 0.006	0.01 ± 0.002
EU Standards**	**Leafy vegetables: 0.3; Root vegetables: 0.1**	**Leafy vegetables: 0.2; Root vegetables: 0.1**

** European Commission (EC), 2001

Table 3. Daily mean intake of metals by adults in the study area from each of the food crops

	Lead DMI (mg/kg/day)	Cadmium DMI (mg/kg/day)
Amaranth	0.023	0.002
Taro	0.014	0.002
Sweet potatoes	0.006	0.003
WHO Standards***	**0.0035**	**0.001**

*** World Health Organisation (WHO), 1993

CONCLUSION

This study revealed that although the concentrations of lead and cadmium in Nyabugogo Marsh soils were within EU limits for crop production, the picture was varied amongst plants. Lead in amaranth and taro was at threshold concentrations while cadmium concentrations in all three crops were orders of magnitude below stipulated concentrations. With respect to dietary metal exposure to the surveyed community, adult members were exposed to metal concentrations in excess of those stipulated in the WHO guidelines.

ACKNOWLEDGEMENT

We thank, from the National University of Rwanda, Mr. Chiragaga, and from the University of the Witwatersrand, Dr. Tutu, colleagues at the School of Animal, Plant and Environmental Science, and two anonymous reviewers for valuable contributions during the preparation of this manuscript. This work was partially funded by the School of Animal, Plant and Environmental Science and approved by the Human Ethics Research Committee of the University of the Witwatersrand.

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