Original Article

Toxicology Research and Application

Toxicology Research and Application
Volume 5: 1–15

DOI: 10.1177/2397847320985255
journals.sagepub.com/home/tor
SAGE

An analysis of heavy metals contamination and estimating the daily intakes of vegetables from Uganda

Keneth Iceland Kasozi[1,2], Eric Oloya Otim[3], Herbert Izo Ninsiima[2], Gerald Zirintunda[1], Andrew Tamale[4], Justin Ekou[1], Grace Henry Musoke[5], Robert Muyinda[1], Kevin Matama[6], Regan Mujinya[7], Henry Matovu[1], Fred Ssempijja[7], Ejike Daniel Eze[2], Mauryn Atino[6], Bede Udechukwu[6], Ronald Kayima[6], Patrick Etiang[1], Emmanuel Tiyo Ayikobua[8], Stellamaris Kembabazi[7], Ibe Michael Usman[7], Sheu Oluwadare Sulaiman[7,9], Phyllis Candy Natabo[7], Grace Nambatya Kyeyune[10], Gaber El-Saber Batiha[11], and Ochan Otim[12,13]

Abstract

Background: Environmental contamination with elevated levels of copper (Cu), cobalt (Co), iron (Fe), zinc (Zn), lead (Pb), chromium (Cr^{6+}), cadmium (Cd), and nickel (Ni)—all states of which are found in Uganda—raises health risk to the public. Pb, Cr^{6+}, Cd, and Ni for instance are generally considered nonessential to cellular functions, notwithstanding the importance of the oxidative state of the metals in bioavailability. As such, we aimed in this study (i) to evaluate heavy metal concentrations in four vegetables from a typical open-air market in Uganda, (ii) to assess the safety of consuming these vegetables against the World Health Organization (WHO) recommended limits of heavy metals consumption, and (iii) to formulate a model of estimated daily intake (EDI) among consumers in the country. **Methods:** This was a cross-sectional study conducted in five georeferenced markets of Bushenyi district in January 2020. Amaranthus, cabbages, scarlet

[1] Faculty of Agriculture and Animal Sciences, Busitema University Arapai Campus, Soroti, Uganda
[2] School of Medicine, Kabale University, Kabale, Uganda
[3] College of Engineering and Sciences, Purdue University Northwest, Hammond, IN, USA
[4] Department of Wildlife Resources, School of Veterinary Medicine, College of Veterinary Medicine and Biosecurity, Makerere University, Kampala, Uganda
[5] Faculty of Science and Technology, Cavendish University, Kampala, Uganda
[6] School of Pharmacy, Kampala International University Western Campus, Bushenyi, Uganda
[7] Faculty of Biomedical Sciences, Kampala International University Western Campus, Bushenyi, Uganda
[8] School of Health Sciences, Soroti University, Soroti, Uganda
[9] Instituto de Ciências Biológicas, Universidade Federal de Minas Gerais, Minas Gerais, Brazil
[10] Directorate of Research, Natural Chemotherapeutics Research Institute, Ministry of Health, Kampala, Uganda
[11] Department of Pharmacology and Therapeutics, Faculty of Veterinary Medicine, Damanhour University, Damanhour, AlBeheira, Egypt
[12] Department of Humanities and Sciences, University of California – Los Angeles, CA, USA
[13] Department of Chemistry, Faculty of Science, Gulu University, Gulu, Uganda

Corresponding authors:
Keneth Iceland Kasozi, Faculty of Agriculture and Animal Sciences, Busitema University Arapai Campus, Box 206, Soroti, Uganda.
Emails: kicelandy@gmail.com; kicelandy@kab.ac.ug

Eric Oloya Otim, College of Engineering and Sciences, Purdue University Northwest, Hammond, IN, USA.
Email: eotim@pnw.edu

eggplants, and tomatoes were collected from open markets, processed, and analyzed by atomic absorption spectrometry. Modeled EDI, principal component (PCA) and cluster analysis (CA) were conducted to identify relationships in the samples. **Results:** The levels of essential elements in the four vegetables were found to fall from Co > Cu > Fe > Zn. Those of non-essential metals were significantly higher and followed the pattern Cd > Cr > Pb > Ni. The highest EDI values were those of Cu in scarlet eggplants, Zn in amaranthus, Fe in amaranthus, Co in amaranthus, Pb in cabbages, total Cr in scarlet eggplant, Cd in cabbages and tomatoes, and Ni in cabbages. In comparison to international limits, EDIs for Zn, Cu, Co and Fe were low while Ni in cabbages were high. PCA showed high variations in scarlet eggplant and amaranthus. The study vegetables were found to be related with each other, not according to the location of the markets from where they were obtained, but according to their species by CA. **Conclusion:** The presence of non-essential elements above WHO limits raises policy challenges for the consumption and marketing of vegetables in the study area. Furthermore, low EDIs of essential elements in the vegetables create demand for nutritious foods to promote healthy communities.

Keywords
Food safety, heavy metals in vegetables, trade, vegetables, Uganda, vegetable consumption in Africa

Date received: 24 July 2020; accepted: 11 December 2020

Introduction

In Uganda—the subject of this study, heavy metals have been identified in milk, beef, drinking water, and herbal medicines in southwestern Uganda.[1–3] Pb concentrations of between 4 and 18 ppm have been recorded in amaranthus within Uganda.[4] Vegetables grown along Lake Victoria (Uganda) were associated with high cadmium (Cd) and lead (Pb) at concentrations of 0,08–0.76 ppm and 0.003–5.06 ppm respectively above World Health Organization limits.[5] Globalization and increased population growth are associated with an increasing demand for vegetables,[6] and developing countries are no exception[7] demonstrating the importance of this study. Currently, dietary guidelines in 93% of countries (7 African countries in comparison to 17 in Asia and 33 in Europe) encourage the consumption of vegetables and fruits.[8] Vegetables not only contain essential nutrients necessary for maintaining the physiological function of somatic cells and tissues,[9,10] but extracts from various plants may have a role in refining disease management strategies through dietary patterns that may promote health. An amaranthus supplement at 25% and 50% w/w administered for 4 weeks, for example, was shown to mitigate type 2 diabetes mellitus in male Wistar rats,[11,12] with the possible application as a management adjunct in human pathology in diabetes.[13] Scarlet eggplant (*Solanum* spp) and cabbage (*Brasica* spp) extracts (i.e. 1 g in 30 ml of methanol) were shown to inhibit nitric oxide in macrophage cell cultures after 24 h of exposure[14] and to protect a rat cardiomyoblast cell line from oxidative stress i.e. methanol (1:8) extract at least 2 h, treated with 100, 200, and 300 μg/ml cabbage extract for 24 h,[15] thus suggesting the importance of these two vegetables in complementary medicine. This is important since *Brassica campestris* spp (administered at 50 mg/kg orally in mice) effects on obesity were associated with increased expression of lipolysis genes (i.e. *adipose TG lipase, adiponectin*, and *leptin*) and activation of cyclic AMP-dependent kinase.[16] The safety of consuming a plant-based diet, however, is threatened by the increasing presence of heavy metals in the environment from human activities and their subsequent bioaccumulation in vegetables and mutagenic health risks in humans. Furthermore, stress disrupts protein function, metabolic and gene expression.[17] Abiotic stress as a result of soil salinity, reduced rainfall, and high temperatures involve protein kinase activity which modulates energy consumption in the plants.[18] Heavy metal-induced stress has been associated with low growth rate, loss of chlorophyll, and plant death.[19,20]

Compounding the problem of heavy metal contamination are (i) the absence of a robust food safety policy and technical knowledge in most developing countries to carry out routine monitoring of the environment,[1] (ii) the nature of pollution reporting in those countries, particularly in Africa,[15] and (iii) not providing consumers information on the sources and the distribution of contaminants in food products. There was, therefore, a need not only to determine the nature and extent of food contamination by heavy metals in this region but also to encourage the development of technical skills needed to conduct such studies.

Minerals such as copper (Cu), iron (Fe), zinc (Zn), and cobalt (Co) are found naturally in vegetables and in small quantities are essential for cellular function. Copper in the Cu^{2+} state is also insoluble in water, but soluble as Cu^{+}, the form commonly present in naturally unstable copper sulfate. The importance of Cu^{2+}, Fe^{2+}, Zn^{2+}, and Co^{2+} in studies such as this one cannot, therefore, be overemphasized.[21] Fe is abundant on earth; it is insoluble in its Fe^{3+} oxidation state. Iron in oxidation state two (Fe^{2+}) is important to human and plant physiological function.[22] Chromium (Cr^{3+}) is essential in carbohydrate and lipid metabolism and its daily intake of 0.05–0.2 mg has been establisehd.[23,24] In addition, Cr^{3+} is considered safe following its wide safety range of 1 mg/day, although this cannot be said about Cr^{6+}.