Heavy Metals Risk Assessment for Potato (*Solanum tuberosum* L.) Grown in Soils at Borg El Arab Region – Egypt

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ABSTRACT

High concentrations of Co, Cd, Cu, Pb, and Zn were found in potatoes sampled collected from overused phosphate fertilizer - soils, which increased the daily intake of metals in food. However, the ingestion of potatoes from soils affected by phosphate fertilizers posed a low health risk when compared with the health risk index of <1 for heavy metals. Nevertheless, the long-term application of phosphate fertilizers, containing high leads of heavy metals, would affect the vegetable production from these fields and raise great concerns about the potential health risks of heavy metal contents of crops grown in such soils. This has been recorded in potatoes grown in Borg El Arab west Alexandria. This study found that long-term phosphate fertilizer use led to a growing accumulation of heavy metals in soils. Thus, heavy metal concentrations should be periodically monitored in vegetables grown in these soils. It would also be beneficial to implement effective remediation technologies to minimize possible impacts on human health.

Keywords: Health risk, Heavy metals, Potato, Borg El Arab, Egypt.

INTRODUCTION

The food safety has stimulated research regarding the risk associated with consumption of foods contaminated by heavy metals and /or toxins (D'Mello, 2003). This is because food consumption is identified as the major pathway for human exposure to environmental contaminants, accounting for >90 % of intake compared to inhalation or dermal routes of exposure (Fries, 1995). About 30 % of human cancers are caused by low exposure to initiating carcinogenic contaminants in the diet (Tricker and Preussmann 1990). Potato plants are cultivated in Egypt in different governments because of their extraordinary capacity to adapt to different climatic and soil conditions, and therefore more people consume potato tubers in Egypt. Potato's agronomic efficiency extends range of soil types that can be used for food production and economic development (Abdelrazek 2014). Various agricultural strategies have been suggested for improving nutrition (Graham *et al.* 2006), including enhancing micronutrient availability through plant breeding, known as bio fortification, and the increased use of fertilizers to improve the nutrient profile of staple foods (Bonierbale *et al.* 2007). The main trace element input sources for agricultural soils are atmospheric deposition and fertilizers such as phosphates, and animal manures (El-Motaium and Badaway 2000). Fertilizers enhance the natural soil fertility and replace chemical elements taken from soil by harvesting, grazing, leaching, or erosion (Tekin et al. 2001). Phosphate fertilizers are essential for agriculture because they supply farmland with the nutrients required by growing plants (Cajuste et al. 2006; Chen *et al*. 2007). Heavy metals can occur as impurities in natural materials and minerals, so heavy metals may be present in phosphorus fertilizers and other chemical fertilizers (Elsokkary and Abukila 2011). Long-term application of phosphate fertilizers could result in the accumulation of heavy metals in the soil (Elsokkary, 2012). Crops cultivated on soil rich in heavy metals could take up toxic metals and accumulate them in their tissues. Vegetables contaminated by heavy metals have been documented (Elgala et al 2003). Potatoes are low in fat and rich in several micronutrients, thus, 150 g potato provides nearly half the daily adult requirement for vitamin C (100 mg). Potatoes are moderate source of iron, and the high vitamin C content promotes iron absorption. Potatoes are also a good source of vitamins B1, B2 (riboflavin), B3, B5 (pantothenic acid), and B6; foliate; and minerals such as potassium, phosphorus, and magnesium. Potatoes also contain dietary antioxidants that may play a part in preventing diseases related to aging, and dietary fiber which benefits the general health (El-Motaium and Badaway 2000). Approximately 80 % of the potato crop is used for human consumption, which is significantly greater than found with cereals such as corn and wheat. Little information is available on the effects of long-term overuse of phosphate fertilizers and any subsequent accumulation of heavy metals from them by crops. Therefore, the aim of the present study was to provide data on contamination levels of heavy metals and its accumulation in potatoes grown in Borg El Arab area in Egypt The obtained results will be compared with the established guidelines for tolerable levels of heavy metals in food in order to evaluate whether such contamination levels may pose risks to human health (Elsokkary, I. H. 1980).

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MATERIALS AND METHODS

Soil sampling and analysis

Soil samples were collected from the surface layer (0– 20 cm) in Borg El Arab, west Alexandria city, in Egypt. Each sampling area was greater than 5000 feden, and a total of 180 soil samples were collected from potato fields. The soils were air - dried and ground, passed through a 2-mm sieve and kept for analysis. Each sample from each treatment received three replicate analyses. Soil samples were digested using aqua regia (HCl / HNO_3, 3:1 solution)-HClO4 (Lu, 2000) and the concentrations of total Co, Cd, Cr, Cu, Ni, Pb, and Zn were determined using inductively coupled plasma atomic emission spectroscopy (ICP-AES).

Crop sampling and analysis

Potatoes (*Solanum tuberosum* L.) were collected from the same sites where the soils were collected. Crop samples were washed three to four times with distilled water to remove foreign materials. Crop samples were digested in triplicate to minimize error, with HNO3 and $HClO_4$ in a 5:1 ratio until a transparent solution was obtained (Allen *et al*. 1986; Markert, 1996).

The heavy metal concentrations were determined using ICP-AES Data analysis for heavy metal transfer factor from soil to potatoes to determine the transfer of metals from the soil to potatoes. The transfer factors (TF) of metals were calculated as follows (Xue *et al.* 2011).

$$TF = C\ potato \div C\ soil \quad (1)$$

Where; C_{potato} and C_{soil} represent the concentrations of heavy metals in potato extracts and soils on a dry weight basis, respectively

Daily intake of metals

The human pathway of exposure to heavy metals by the ingestion of contaminated crop has been studied by many researchers (Arora *et al*. 2008; Chary *et al.* 2008; Qishlaqi *et al.* 2008). The daily intake of metals (DIM) by this exposure pathway was determined using the following equation (Xue *et al.* 2011)

$$DIM = C\ potato \times C\ factor \times D\ food\ intake \div B\ average\ weight \quad (2)$$

Where; C potato, C factor, D food intake, and B average weight represent the heavy metal concentrations in potatoes (milligram/kilogram) on a dry weight basis, the conversion factor from fresh to dry weight of potatoes is 0.085 (Rattan et al. 2005), the daily intake (0.345 and 0.232 kg per person per day for adults and children, respectively), and the average body weight (55.90 kg for adults and 32.70 kg for children), respectively (Ge, 1992; Wang et al. 2005).

Health risk index

A health risk assessment for consumers based on their intake of metal-contaminated crops was characterized using a health risk index (HRI). There was no obvious risk to the exposed population if the HRI is <1, but a risk was present if the HRI is >1. The HRI was calculated using the following equation (Xue et al. 2011)

$$HRI = DIM \div RfD \quad (3)$$

Where; the reference oral doses RfD is for Cu, Zn, Ni, Pb, and Cd which are 0.04, 0. 3, 0.2, 0.0035 and 0.001 mg kg−1 day−1 in this study, respectively (USEPA 2002)

RERSULTS AND DISCUSSION

Heavy metal concentrations in potatoes

The concentrations of Co, Cd, Cu, Ni, Pb, and Zn (μg g^{-1}, DW) in potatoes and in the soil are shown in (Fig: 1). The average concentrations of heavy metals in crop samples were in the descending order: Zn > Ni > Cu > Pb > Co > Cd. Metals, such as Zn and Cu, are essential metals for humans because they play an important role in biological systems. However, essential heavy metals can produce toxic effects when their intake is excessive. Gopalani et al. (2007) showed that the order of trace metal accumulation in potatoes was Al > Fe > Zn > Ni > Mn > Cu > Co > Pb > Cd. The concentrations of heavy metals found in potato tuber samples are presented in Table (1).

Table 1. Range and mean values of heavy metals concentrations (μg g^{-1} DW; n=180) in potato tuber of [lants grown in overused phosphate fertilizer soils

Heavy metals	Range	Mean
Co	0.46–12.3	4.0
Cd	0.08–4.4	0.9
Cu	0.58–20.04	11
Ni	0.14–29.6	13.5
Pb	0.21–13.3	4.2
Zn	0.25–55.7	22

However, the mean concentrations of Zn matched those in the published literature (Kumar et al, 2007). Table (2) shows the heavy metal concentrations of the soils, where potatoes were grown. The uptake of heavy metals by potatoes was generally related to the heavy metal levels in the soils (Table 2). Table (3) shows the correlation coefficients for the heavy metal concentrations found in soils and tubers. There were strong correlations among heavy metal concentrations in the potatoes and the metal concentrations in the respective soils where they were cultivated (Abdelrazek, 2014). These results suggest a very simple transfer of heavy metals from soils to plants.

Table 2. Total concentrations of heavy metals (µg g^{-1}) in soils grown with potatoes

Heavy metals	Range	Mean
Co	2.4–17.03	8.6
Cd	0.22–8.1	2.2
Cu	1.46–50.11	26.7
Ni	0.35–54.9	32.9
Pb	0.55–30.1	10.4
Zn	0.64–139.4	55.6

The toxic effect of heavy metals in plants has been studied for many years, but positive and negative results have been reported, depending on the test material and the metal evaluated (White and Claxton 2004). Transfer factors for heavy metals are shown in Table (4). The TF trends for different metals in potatoes grown on overused phosphate-fertilized soils were in the order: Ni > Cd-Cu-Pb >Zn reported by (Ashraf et al., 2004). Thus, Ni had the greatest bioavailability, whereas Zn had the lowest bioavailability for the potatoes in the study, although the concentrations of As and Cd were almost 6.5-fold lower than that of Zn. The results suggest that the uptake of metals by crops was mainly dependent on its bioavailability, rather than its abundance (WHO, 1992).

Risk assessment for crop safety

Potatoes are an important food and the dietary intake may constitute a major source of long-term low level accumulation of heavy metals in the body, so detrimental impacts may only become apparent after several years of exposure. Regular monitoring of heavy metals in crops is essential to prevent excessive accumulation of these metals via the food chain. Long-term daily intake of contaminated crops is likely to be a detrimental health hazard for consumers. Therefore, we estimated the DIM and HRI for adults and children consuming potatoes grown in overused phosphate fertilized soils (Table 5).

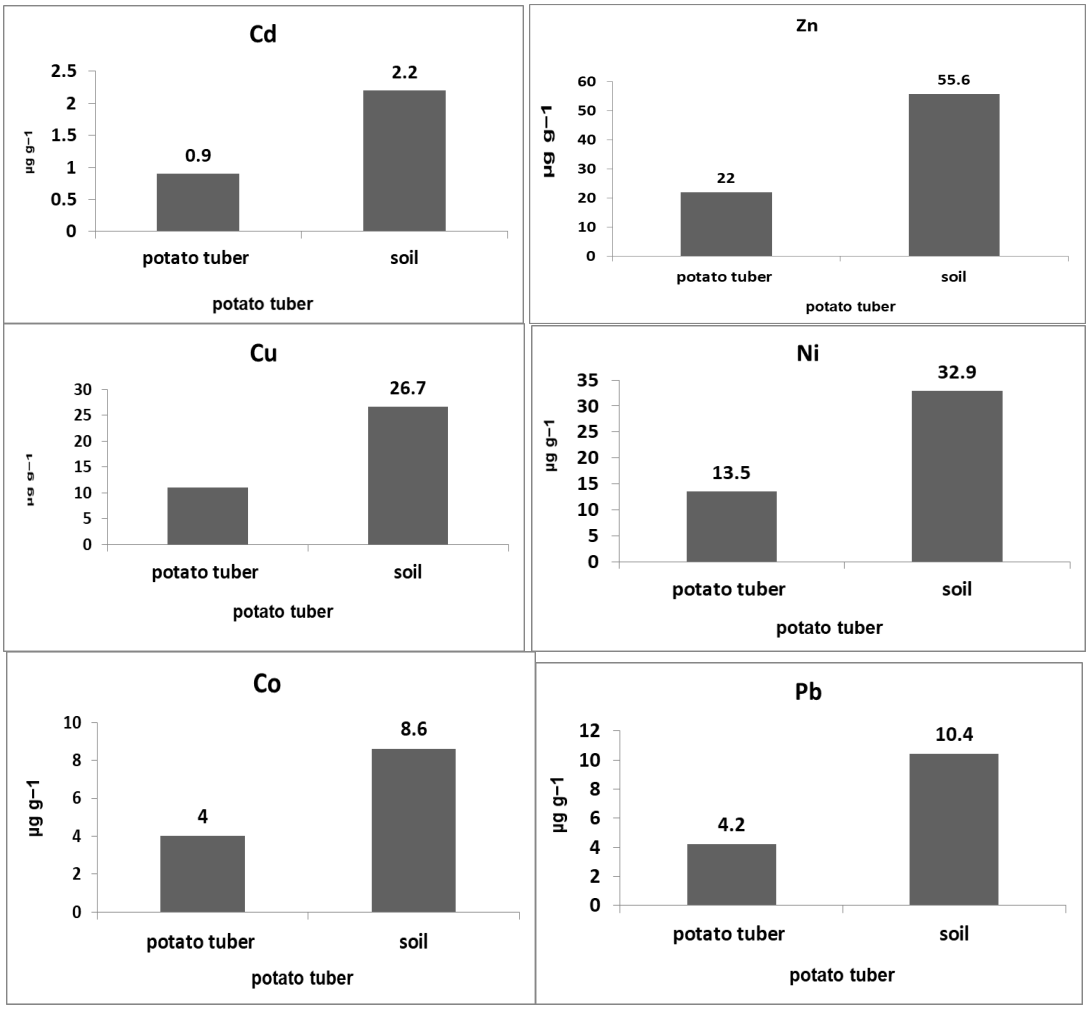

Fig. 1. Range and mean of heavy metals concentration (µg g^{-1} DW; n=180) in potato tuber and soil samples

Table 3. Pearson correlation between the heavy metals contents in soils and tubers*

Heavy metals	Heavy metals in soils (μg g^{-1})					
	Co	Cd	Cu	Ni	Pb	Zn
	(mg kg^{-1})					
Co	0.91	0.74	0.32	0.94	0.85	0.83
Cd	0.90	0.75	0.91	0.93	0.35	0.81
Cu	0.79	0.58	0.87	0.90	0.76	0.71
Ni	0.79	0.58	0.88	0.90	0.76	0.70
Pb	0.90	0.73	0.91	0.93	0.35	0.80
Zn	0.80	0.62	0.86	0.87	0.76	0.80

*All values are significant at 1 % level of significance Co> Ni> Cu> Zn> Cd> Pb

Table 4. Transfer factors of heavy metals for potatoes grown in overused phosphate fertilizer soils (on dry weight basis)

Transfer factor	Range	Mean
Co	0.19–0.72	0.46
Cd	0.36–0.54	0.40
Cu	0.39–0.40	0.40
Ni	0.40–0.53	0.41
Pb	0.02–0.44	0.40
Zn	0.37–0.39	0.39

Table 5. DIM* and HRI (on dry weight) for individual heavy metals caused by the consumption of potatoes grown in overused phosphate fertilizer soils**

Individuals	Co	Cd	Cu	Ni	Pb	Zn
Adults						
DIM	2E-2	4.5E-4	5.6E-3	6.8E-3	2E-3	1.1E-2
HRI	-	0.45	0.14	0.034	0.57	0.036
Children						
DIM	2E-2	5.3E-4	6.5E-3	7.9E-3	2E-3	1.3E-2
HRI	-	0.53	0.16	0.039	0.57	0.043

*DIM: Daily intake of metals **HRI: Health risk index

The highest DIMs for the metals Zn, Cr, Ni, and Cu, both in adults and children, came from the consumption of potatoes. This indicated that adults and children consuming potatoes grown on overused phosphate-fertilized soils ingested high amounts of the metals studied (Sharma et al., 2007).

However, the HRI value of <1 indicated a relative absence of health risk from the ingestion of contaminated potatoes. In addition, it was apparent that the intake of a single metal via the consumption of potatoes posed a relatively higher potential health risk for children, when compared with adults. The contamination of crops grown in heavy metal contaminated soils has led to an increased public awareness of health hazards resulting from the consumption of contaminated crops Chary et al., 2008) Heavy metals can accumulate in human bodies and produce toxic, neurotoxic, carcinogenic, mutagenic, or teratogenic diseases (El-Gendi, et al 1997). Higher concentrations of metals in crops with higher HRIs or health quotients (HQ) were reported by Agrawal (Agrawal 1999). The HRI values of all tested potatoes were <1 in the study area (Table 2), which indicated a relative absence

CONCLUSIONS

Monitoring of the contaminants of heavy metals contributes to improve food safety and warning of actual and potential food scares and facilitates evaluation of possible health hazards by providing information on levels of environmental pollution in the society. Furthermore, this study focused on the analysis of the heavy metal content and its accumulation in potatoes grown in Borg El Arab area in Egypt. According to our results, long-term phosphate fertilizer use led to moderate accumulation of As, Cu, Pb, and Zn and a significant buildup of Cd in the soils of the Borg El Arab Area. Potatoes grown in these soils were contaminated with heavy metals and there were strong correlations among heavy metal concentrations in the potatoes and the metal concentrations in the respective soils where they were cultivated. These results suggest a very simple transfer of heavy metals from soils to potatoes and that they were not safe for human consumption. However, the HRI values of <1 indicated

a relative absence of health risks associated with ingestion of the contaminated potatoes.

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الملخص العربي

تقييم مخاطر المعادن الثقيلة على درنة البطاطس التي تزرع في برج العرب

سعد عبد الصمد السيد عبد الرازق

وجدت تركيزات عالية من الكوبلت، والكادميوم، والنحاس، والرصاص، والزنك في عينات البطاطس التى تم جمعها من تربة غنية بالاسمدة الفوسفاتية نتيجة الاسراف فى التسميد بها والمحتوية على كميات من العناصر الثقيلة. ونتيجة الاستهلاك المتزايد للبطاطس فى الغذاء، فإن تناول البطاطس من التربة المتضررة من الأسمدة الفوسفاتية يشكل خطرا صحيا على الانسان، مما يشكل خطرا صحيا عند مقارنته بمؤشر المخاطر الصحية بنسبة (١%) واحد في المائة بالنسبة للمعادن الثقيلة، والتسميد بالأسمدة الفوسفاتية المحتوى على المعادن الثقيلة على المدى الطويل سيؤثر على انتاجية الخضروات وجودة الثمار الناتجة من هذه الحقول، ويثير مخاوف كبيرة بشأن المخاطر الصحية المحتملة نتيجة وجود المعادن الثقيلة من المحاصيل التي تزرع في هذه التربة، وبناءا عليه ينبغي رصد تركيزات المعادن الثقيلة بشكل دوري في الخضروات التي تزرع في هذه التربة. ولابد من تنفيذ تكنولوجيات معالجة فعالة للتقليل إلى أدنى حد ممكن من الآثار الضارة المحتملة على صحة الإنسان.