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Effect of Bauxite Mineralized Soil on Residual Metal Levels in Some Post Harvest Food Crops in Jamaica

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Abstract The concentrations of nine residual metals in some Jamaican foods were determined using inductively coupled plasma mass spectrometry technique. Cadmium concentration was highest in yellow yam (0.21 mg/kg). Sweet potato had the highest concentrations of lead (0.31 mg/kg), arsenic (0.70 mg/kg) and mercury (0.35 mg/kg). Samples from Grove Place exceeded the regulatory limits of 0.1 mg/kg for cadmium, lead and arsenic and 0.05 mg/kg for mercury. Significant correlations were found between soil and agricultural produce concentrations for cadmium and lead ($r^2 \geq 0.5$). These results suggest that the elements were available in soluble forms in the soil for absorption by food crops.

Keywords Cadmium · Soil · Tubers · Metals

Jamaica has a wide range of soil conditions due to the variability in parent rock materials, topography, and rainfall. The soil of about 70 % of the land area was derived from the weathering of limestone while the remaining 30 % was weathered from conglomerates, shale, igneous and metamorphic rocks. The high concentrations of cadmium in the soils of the parishes of Manchester and St. Elizabeth in Central Jamaica may be due to bauxitization (Jamaica Resource Assessment 1982).

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Chronic consumption of agricultural produce with high levels of cadmium and other metals may lead to their accumulation to toxic levels in organs and tissues of the body (Agency for Toxic Substances and Disease Registry 1988). Cadmium accumulates in plants from the soil in which they are grown and in aquatic animals from water. There is no proven essential metabolic function for cadmium in humans. However, few animal studies suggest that very small quantities may be needed (Schwartz and Spallholz 1978). Human intake of cadmium and other metals are primarily through food consumption, smoking, and occupational (workplace) exposure. The Joint Food and Agricultural Organization/World Health Organization Expert Committee on Food Additives (JECFA) in 1992 established a provisional tolerable weekly intake (PTWI) for cadmium at 7.0 μg/kg of body weight. This PTWI value corresponds to a daily tolerable intake level of 70.0 μg of cadmium for the average 70-kg man and 60.0 μg for the average 60-kg woman. Elemental contents in foods are being increasingly regulated in many countries. Such regulations could be used as non-tariff barriers for many developing countries like Jamaica where agricultural food crops form an essential component of the country's socio-economic development. The present study is aimed at establishing the levels of some metals in food crops relative to the soil in which they were grown in selected areas of Jamaica.

Materials and Methods

The food crops used for this study were obtained from the parishes of Manchester and St. Elizabeth in Central Jamaica. The samples were collected and tested over a period of ten months. Samples were collected from ten farms within the following communities: Comfort Hall (CH) and Balaclava

(BC) – St. Elizabeth; Mile Gully (MG), Grove Place (GP), Maidstone (MS), Williamsfield (WF), Green Vale (GV), Hatfield (HF) and Christiana (CT)-Manchester. Five farms in Eastern section of Jamaica with low metal concentrations were used as the control group. The following food crops: yellow yam (*Dioscorea cayenensis*), sweet potato (*Ipomea batatas*), coco (*Xanthosoma* spp.), cassava (*Manihot esculenta*) and pumpkin (*Cucurbita pepo*) were sampled in triplicates from each farm. Severely diseased or damaged tubers were eliminated. Soil cores were sampled from the same location where the tubers were removed at the surface and a depth of 6, 12 and 18 inches using an auger. The samples were carefully sorted to remove any adhering plant materials including roots and stones so as to create minimum disturbance in the soil. In obtaining a representative sample of soil from the sites, subsamples were taken within a 5 metre radius. These subsamples were composited while ensuring it is thoroughly mixed. Once in the laboratory, the tuber samples were brushed to remove all adhering soil, washed with phosphate free detergent and finally with type 1 water. A stainless steel knife was used to remove the edible portion which was dissected into smaller pieces and placed on a stainless steel tray and dried at 60°C for 4 h. The dried samples were milled with an APEX grinding mill. The soil samples were placed in flat stainless steel trays and dried at 40°C for 1 h, then pulverized with Siebtecnnik Pulveriser. All agricultural produces were stored in an airtight polyethylene container and refrigerated while the soil samples were stored in the same containers at room temperature until required for analysis.

A weighed dried milled sample (1.0 g) was digested in 10.0 mL of 1:1 (v/v) Nitric Acid (HNO_3) and water for 30 min at 90.0 ± 5.0°C in a water bath. The solution was cooled and 5 mL of HNO_3 was added until digestion was completed (Association of Official Analytical Chemist 2006). The digest was cooled, filtered and analyzed for chromium (Cr), manganese (Mn), nickel (Ni), copper (Cu), zinc (Zn), arsenic (As), cadmium (Cd), lead (Pb) and mercury (Hg) by Agilent 7500a inductively coupled plasma mass spectrometer (ICP-MS) calibrated with a multi-element standard calibration solution traceable to National Institute of Standards and Technology (NIST) certified reference materials.

Soil samples were analyzed for chromium, manganese, nickel, copper, zinc, arsenic, cadmium, lead and mercury by ICP-MS. Slurry of weighed soil sample (1.0 g) was made with 10 mL of 1:1 (v/v) nitric acid (HNO_3) and water and heated to 95.0 ± 5.0°C and refluxed for 10–15 min. The samples were allowed to cooled, and then 5.0 mL of conc. HNO_3 was added and refluxed for another 30 min until no brown fumes evolved. The solution was subsequently heated at 90.0 ± 5.0°C for 2 h. The samples were again cooled and 5.0 mL of warm water was added followed by 3.0 mL of 30 % hydrogen peroxide (H_2O_2) in 0.5 mL portions. The solutions were heated until effervescence was completed. The volumes were brought to 30.0 mL and centrifuged for 15 min at 2,000 rpm. The samples were filtered and internal standard was added and then diluted to the mark. The solution was then analyzed by ICP-MS.

The detection limits (ppb) for the analytes were 0.06 (Cr), 0.04 (Mn and Cu), 0.9 (Ni), 0.03 (Zn and Cd), 0.05 (As), and 0.001 (Pb and Hg). The recoveries (%) were 93.5 (Cr), 93.2 (Mn), 91.8 (Cu), 104.4 (Ni), 100 (Zn), 92.9 (As), 97 (Cd), 95.6 (Pb), and 93.2 (Hg).

Results are presented as mean ± SD. The data was analysed using SPSS statistical software (version 2010). Correlation and analysis of variance (ANOVA) were used to detect significant differences between or among samples.

Results and Discussion

The results in Table 1 show the mean concentrations of chromium in Jamaican food crops and soil. Chromium is a mineral that humans require in trace amounts but its mechanisms of action in the body and the amounts required for optimal health are not well defined. It is found primarily in two forms: (1) trivalent (chromium 3+), which is biologically active and found in foods and (2) hexavalent (chromium 6+), a toxic form that results from industrial pollution. Chromium is known to enhance the action of insulin (Mertz 1969, 1993, 1998; Bona et al. 2010). In this study, we noted wide variation in the concentration of chromium in Jamaican agricultural produce. The concentrations of chromium in the soils evaluated were below the world mean level of 200 mg/kg (Table 2). There was a weak association between tuber and soil chromium levels for all types of agricultural produce assessed (Table 3). This may be due to poor translocation of chromium (III) from roots to other parts of the plants, thus making the accumulation of chromium in the food chain via plants very unlikely.

Tables 4 and 5 show copper and zinc concentrations in food crops at various locations assessed. The mean distribution of copper among all agricultural produce did not significantly differ from each other. The soil concentration of copper ranged from a low of 12.18 mg/kg in Green Vale to a high of 18.12 mg/kg in Comfort Hall. Copper is one of the seven micronutrients essential for plant nutrition. However, like many other trace elements, it is toxic in excess. The amount of copper present in the agricultural produce was far below the limit of Foods Standards in Australia and New Zealand (10 mg/kg). The dietary intake of copper is reported to be from 1.0 mg to 5.8 mg/day while the recommended daily requirement is 2.0 mg which is met

Table 1 Concentration of chromium in agricultural produce at various locations

Location	Concentration (mg/kg dry wt.)					
	Coco	Cassava	Pumpkin	Sweet potato	Yellow yam	Soil
Balaclava (BC)	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.03 ± 0.00	134.41 ± 1.17
Christiana (CT)	0.05 ± 0.00	0.02 ± 0.00	0.10 ± 0.02	0.07 ± 0.02	0.02 ± 0.01	102.73 ± 1.13
Comfort Hall (CH)	0.03 ± 0.01	0.03 ± 0.00	0.05 ± 0.02	0.04 ± 0.01	0.03 ± 0.01	163.13 ± 1.73
Green Vale (GV)	0.39 ± 0.00	0.37 ± 0.01	0.39 ± 0.02	0.32 ± 0.01	0.39 ± 0.01	16.98 ± 0.51
Grove Place (GP)	1.72 ± 0.07	1.34 ± 0.35	0.95 ± 0.05	4.17 ± 0.68	0.03 ± 0.00	142.46 ± 1.11
Hatfield (HF)	0.02 ± 0.01	0.05 ± 0.00	0.02 ± 0.00	0.04 ± 0.00	0.12 ± 0.01	27.43 ± 0.69
Maidstone (MS)	0.02 ± 0.01	0.07 ± 0.00	0.05 ± 0.01	0.03 ± 0.01	0.05 ± 0.02	137.43 ± 1.81
Mile Gully (MG)	0.01 ± 0.00	0.02 ± 0.01	0.06 ± 0.02	0.01 ± 0.00	0.01 ± 0.00	123.94 ± 3.08
Williamsfield (WF)	0.39 ± 0.01	0.39 ± 0.00	0.09 ± 0.01	0.36 ± 0.01	0.41 ± 0.02	153.72 ± 3.08
Control Group (CG)	0.17 ± 0.03	0.13 ± 0.04	0.48 ± 0.03	0.11 ± 0.02	0.13 ± 0.00	29.57 ± 0.35

The values are expressed as mean ± SD

Table 2 Comparison of the ranges and mean for Jamaican soil and world soils

Element	Range		Mean	
	Jamaica[a]	World	Jamaica[a]	World
Chromium (Cr)	16.98–163.13	5–1,500	103.18	200
Manganese (Mn)	8.01–230.3	0.01–0.4 (%)	101.18	0.08 (%)
Nickel (Ni)	0[b]–18.4	NA	8.03	NA
Copper (Cu)DST	12.18–18.12	2–250	14.99	20
Zinc (Zn)	12.83–124.85	1–900	126.26	50.0
Arsenic (As)	0[b]–1.68	0.1–40	0.55	5.0
Cadmium (Cd)	0[b]–2.65	0.01–2	1.41	0.5
Lead (Pb)	0[b]–3.16	3–189	1.43	10.0
Mercury (Hg)	0[b]–1.94 (mg/kg)	0.01–4.60 (μg/kg)	0.57 (mg/kg)	0.01 (μg/kg)

Values are expressed in mg/kg unless they are otherwise specified

Compiled from: Kabata-Pendias and Pendias (1984), Alloway (1990)

NA not available

[a] The sample areas were in the parishes of Manchester and St. Elizabeth

[b] Values are below the detection limit

Table 3 Correlation coefficient matrix between the concentrations of tuber and soil metal for different agricultural produce

Metals	Coco	Cassava	Pumpkin	Sweet potato	Yellow yam
Cr_{Tuber}/Cr_{Soil}	0.16	0.17	−0.14	0.23	−0.33
Mn_{Tuber}/Mn_{Soil}	0.65	0.62	0.50	0.60	−0.17
Ni_{Tuber}/Ni_{Soil}	0.32	0.23	0.13	0.30	0.56
Cu_{Tuber}/Cu_{Soil}	0.77	0.50	0.16	0.41	0.57
Zn_{Tuber}/Zn_{Soil}	0.19	0.02	0.08	0.21	0.10
As_{Tuber}/As_{Soil}	0.38	0.23	0.37	0.35	0.19
Cd_{Tuber}/Cd_{Soil}	0.68	0.75	0.61	0.72	0.77
Pb_{Tuber}/Pb_{Soil}	0.64	0.09	0.14	0.10	−0.13
Hg_{Tuber}/Hg_{Soil}	0.46	0.52	0.44	0.44	0.51

Table 4 Concentration of copper in agricultural produce at various locations

Location	Concentration (mg/kg dry wt.)					
	Coco	Cassava	Pumpkin	Sweet potato	Yellow yam	Soil
BC	2.68 ± 0.10	4.63 ± 0.05	4.78 ± 0.50	2.13 ± 0.14	0.73 ± 0.04	15.82 ± 0.41
CT	0.84 ± 0.04	1.97 ± 0.11	0.99 ± 0.18	1.00 ± 0.00	0.80 ± 0.13	16.39 ± 0.19
CH	3.08 ± 0.35	2.06 ± 0.67	3.59 ± 0.05	0.77 ± 0.08	3.53 ± 0.20	18.12 ± 0.08
GV	0.35 ± 0.01	0.41 ± 0.02	0.36 ± 0.03	0.38 ± 0.02	0.38 ± 0.02	12.18 ± 0.00
GP	2.53 ± 0.13	2.22 ± 0.60	1.50 ± 0.44	5.10 ± 0.44	0.56 ± 0.17	16.15 ± 0.00
HF	1.59 ± 0.12	1.08 ± 0.07	1.20 ± 0.08	0.96 ± 0.14	1.28 ± 0.03	14.47 ± 0.19
MS	2.09 ± 0.01	2.25 ± 0.04	4.53 ± 0.09	0.72 ± 0.10	1.98 ± 0.07	13.41 ± 0.01
MG	1.40 ± 0.01	1.21 ± 0.03	3.14 ± 0.30	0.53 ± 0.05	1.35 ± 0.13	13.89 ± 0.04
WF	0.38 ± 0.01	0.38 ± 0.05	0.36 ± 0.02	0.27 ± 0.04	0.40 ± 0.01	12.23 ± 0.02
CG	2.83 ± 0.10	1.51 ± 0.05	0.72 ± 0.01	1.57 ± 0.06	1.96 ± 0.04	17.32 ± 0.27

The values are expressed as mean ± SD

Table 5 Concentration of zinc in agricultural produce at various locations

Location	Concentration (mg/kg dry wt.)					
	Coco	Cassava	Pumpkin	Sweet potato	Yellow yam	Soil
BC	1.20 ± 0.09	0.70 ± 0.05	1.19 ± 0.15	0.63 ± 0.11	0.55 ± 0.08	114.47 ± 0.21
CT	0.81 ± 0.01	1.33 ± 0.10	1.28 ± 0.37	1.23 ± 0.01	0.57 ± 0.07	116.56 ± 0.48
CH	4.02 ± 0.35	1.50 ± 0.16	1.16 ± 0.02	5.77 ± 0.45	1.12 ± 0.05	115.40 ± 2.50
GV	0.09 ± 0.02	0.27 ± 0.02	0.14 ± 0.01	0.22 ± 0.04	0.12 ± 0.04	124.85 ± 0.42
GP	0.11 ± 0.00	0.21 ± 0.03	0.16 ± 0.02	0.12 ± 0.01	0.08 ± 0.02	118.17 ± 0.93
HF	1.09 ± 0.08	1.27 ± 0.23	0.62 ± 0.05	1.19 ± 0.20	0.61 ± 0.00	117.36 ± 1.05
MS	2.80 ± 0.51	15.77 ± 0.67	17.34 ± 3.28	1.64 ± 0.63	0.92 ± 0.05	110.51 ± 0.40
MG	1.88 ± 0.50	6.95 ± 0.05	2.73 ± 0.61	0.74 ± 0.20	8.74 ± 0.87	110.86 ± 1.62
WF	0.36 ± 0.05	0.44 ± 0.01	0.41 ± 0.03	0.29 ± 0.01	0.51 ± 0.04	121.57 ± 0.81
CG	0.31 ± 0.05	1.45 ± 0.02	0.15 ± 0.01	n.d.	0.02 ± 0.00	12.83 ± 0.24

The values are expressed as mean ± SD, *n.d.* not detected

by most diets (Adriano 1986). The mean soil copper concentration was 14.99 mg/kg compared to the world concentration of 20 mg/kg. We noted a relatively low concentration in Jamaican agricultural produce. The mean concentration of zinc in the food crops assessed ranged between 0.08 mg/kg in yellow yam from Grove Place to 17.34 mg/kg in pumpkin from Maidstone. Zinc is an essential trace element in human and animal metabolism as it is an important constituent of a number of enzymes. The average concentration of zinc was above the world average concentration (50 mg/kg). Of note however, is the weak correlation between the concentrations of zinc in soil and food crops ($r^2 < 0.21$).

Figures 1 and 2 show the concentrations of manganese and nickel respectively in the food crops analyzed. Manganese is an essential micronutrient for plants and animals. It functions as an enzyme activator and is also a catalyst in oxygen-evolving reaction of photosynthesis. The human requirement for manganese is estimated to be 2–5 mg/day for adults (Recommended Dietary Allowances 1989). The world mean concentration of manganese is 0.08 % compared to the mean of 0.01 % in Jamaica. We noted a strong

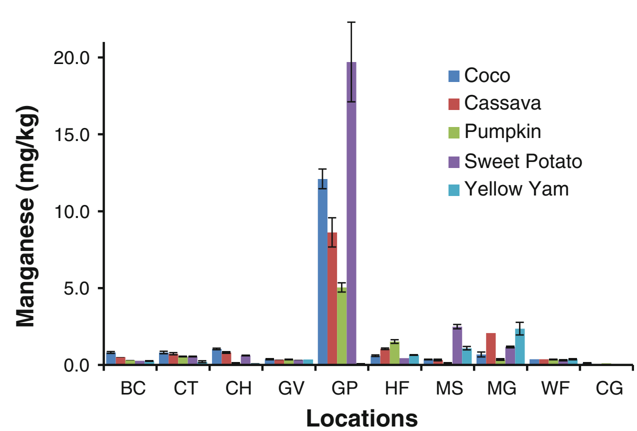

Fig. 1 Concentration of manganese in agricultural produce at various locations

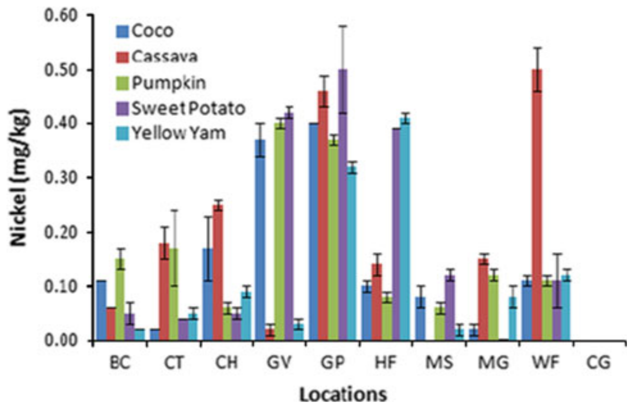

Fig. 2 Concentration of nickel in agricultural produce at various locations

association between the mean soil manganese concentration and mean concentration in most of the agricultural produce assessed. Nickel is an essential trace element in several animal species, plants and prokaryotic organisms. In biological systems it forms complexes with adenosine triphosphate, amino acids, peptides, proteins and deoxyribonucleic acid. The correlation between soil concentration and tuber concentration were relatively weak ($r^2 < 0.5$) with the exception of yellow yam which showed a moderate correlation of $r^2 = 0.56$ (Table 3). The nickel in the soil evaluated may be in the insoluble forms making the absorption by the food crops low.

The level of arsenic in sweet potato from Grove Place was 0.70 mg/kg (Fig. 3). Arsenic is a known poison. The soluble species are easily absorbed and are known to cause acute gastrointestinal irritations, loss of peripheral response and ultimately cardiovascular failure. The estimated lethal

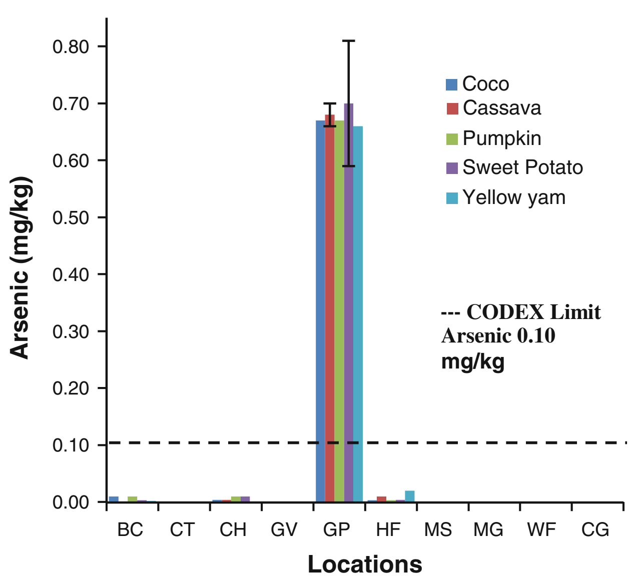

Fig. 3 Concentration of arsenic in agricultural produce at various locations

dose for adults is 70–180 mg (Fergusson 1990). The arsenic contents in Jamaican agricultural produce varied from 0.01 to 0.70 mg/kg. The world limit for arsenic in soil varied between 0.1 and 40 mg/kg compared to 0–1.68 mg/kg in Jamaica. Of note however, is the weak correlation between soil and agricultural produce arsenic concentrations ($r^2 \leq 0.38$). However, close monitoring of arsenic level in agricultural produce from these locations in Jamaica may be necessary to avoid the deleterious effects that may accrue from large consumption of these staple foods. The distribution of cadmium was below the detection limit [(0.03 μg/kg) Table 6] in all types of agricultural produce in most localities. However, in Green Vale and Grove Place the lowest concentrations were 0.30 mg/kg and 0.57 mg/kg respectively. Chronic exposure to cadmium is associated with kidney damage, bone damage, cancer, low birth weight, spontaneous abortion, and many other ailments (Agency for Toxic Substances and Disease Registry 1988; Godt et al. 2006; Hwangbo et al. 2011). We found that cadmium content in all the agricultural produce from Green Vale and Grove Place were above the allowable CODEX limit of 0.1 mg/kg in food stuffs. Similarly, the mean soil concentration of cadmium in the two parishes evaluated was 1.41 mg/kg, which is higher than the world mean level (0.5 mg/kg). We also noted a strong correlation between soil and agricultural produce cadmium concentrations, with yellow yam demonstrating the strongest correlation ($r^2 \geq 0.61$; Table 3). The findings above even become more critical to health with the report that iron-deficient individuals have higher uptake of cadmium than those with balanced iron reserve (Flanagan et al. 1978). Thus, menstruating women and children with low iron stores will be at higher risk because of increased expression of DCT-1, a metal ion transporter (Gunshin et al. 1997).

The highest concentration of lead was seen in sweet potato from Grove Place [(1.39 mg/kg) Fig. 4]. The lead content varied from below the detection limit of 0.001–1.39 mg/kg which is beyond the CODEX safety limit of 0.1 mg/kg. Lead has no known beneficial physiological function in animals. Accumulation of lead above tolerable level has been shown to cause neurological disorders, reproductive problems, diminished intelligence and a host of other diseases (Pearce 2007; Brunton et al. 2007). The correlation between soil and agricultural produce lead concentrations was weak for cassava, pumpkin, sweet potato and yellow yam but a strong correlation was noted for coco ($r^2 = 0.64$; Table 3). Our data on lead combined with high level of cadmium in some agricultural produce from some areas assessed in this study may be of great concern since exposure to these toxic metals has been shown to negatively impact human health globally. Figure 5 shows mercury concentration in food crops from various locations assessed. The regulatory limit of mercury

Table 6 Concentration of cadmium in agricultural produce at various locations

Location	Concentration (mg/kg dry wt.)					
	Coco	Cassava	Pumpkin	Sweet potato	Yellow yam	Soil
BC	n.d.	n.d.	n.d.	n.d.	n.d.	2.05 ± 0.38
CT	n.d.	n.d.	n.d.	n.d.	n.d.	0.41 ± 0.00
CH	n.d.	0.01 ± 0.00	0.55 ± 0.02	n.d.	0.54 ± 0.02	1.92 ± 0.04
GV	0.33 ± 0.00	0.30 ± 0.01	0.33 ± 0.00	0.36 ± 0.02	0.33 ± 0.00	2.37 ± 0.01
GP	0.61 ± 0.01	0.58 ± 0.01	0.57 ± 0.00	0.61 ± 0.02	0.57 ± 0.00	2.65 ± 0.04
HF	n.d.	0.03 ± 0.00	n.d.	n.d.	0.02 ± 0.00	0.52 ± 0.02
MS	0.10 ± 0.00	n.d.	n.d.	n.d.	n.d.	0.47 ± 0.04
MG		0.14 ± 0.00	0.14 ± 0.03	n.d.	0.12 ± 0.00	1.30 ± 0.02
WF	0.32 ± 0.00	0.33 ± 0.00	n.d.	0.29 ± 0.03	0.33 ± 0.02	2.38 ± 0.05
CG	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

The values are expressed as mean ± SD, *n.d.* not detected

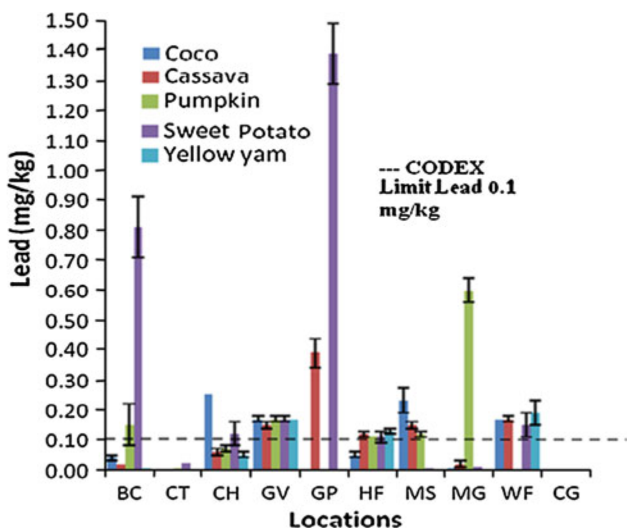

Fig. 4 Concentration of lead in agricultural produce at various locations

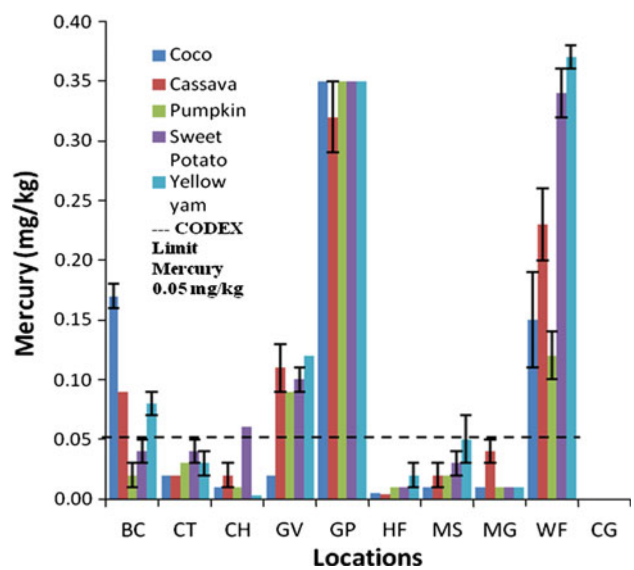

Fig. 5 Concentration of mercury in agricultural produce at various locations

outlined by WHO in the CODEX standards is 0.05 mg/kg. This limit was exceeded by all the crops grown in Grove Place and Williamsfield. Mercury is a contaminant that is toxic in all its compounds. The correlation between soil and agricultural produce mercury concentration was however moderate ($r^2 \leq 0.52$; Table 3).

In conclusion, this exploratory study has shown that selection of land and food crops along with suitable sustainable agricultural practices may be necessary to mitigate the metal content in the various types of Jamaican agricultural produce assessed in this study. This is important because chronic consumption of these food crops with high levels of toxic metals, especially cadmium, lead, arsenic and mercury may be deleterious to human and animal health.

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