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Bioaccumulation of Heavy Metals in Vegetables from Selected Agricultural Areas

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Human activities such as industrial production, mining, agriculture and transportation release a high amounts of heavy metals to the biosphere. Accumulation of heavy metals in crop plants is often of great concern due to the probability of food contamination through the soil-root interface (Cieslinski et al. 1996). As plants acquire necessary nutrients, such as nitrogen, phosphorus and potassium, they also accumulate metals such as lead and cadmium (Wierzbicka 1999; Cobb et al. 2000). Although Cd and Pb are not essential for plant growth they are readily taken up and accumulated by plants in appreciable amounts (Cieslinki et al. 1996; Chlopecka and Adriano 1997; Tatar 1999).

Ingestion of vegetables grown in soils contaminated with heavy metals poses a possible risk to human health and wildlife (Otero et al. 2000). These health risks will depend on the chemical composition of the contaminated soil, its physical characteristics, the vegetables cultivated and their consumption rate (Cobb et al. 2000). The uptake of metals by plants are often influenced by the plant species, growth stages, soil series, metal types and environmental factors (Davies 1992).

Heavy metal concentration in the soil solution plays a critical role in controlling metal availability to plants. Most findings have proved that increasing the heavy metal content in the soil increases the uptake by plants. However, the solubility and availability of heavy metal ions are influenced by various factors, including soil pH, physical and chemical soil properties, clay content and Mn oxide concentration (Xian and Shokohiford 1989; Davies 1992). Sequential extraction is widely used to obtain qualitative information on the form and association of metals and also indirectly it provides information on their availability for plant uptake and migration in the soil (Maiz et al. 2000).

Knowledge on the contamination of vegetables with heavy metals from different areas is not well established especially in Malaysia. Therefore a study was initiated on this aspect in order to avoid possible adverse effects on human health. The study was designed to determine the amount of metals present in vegetable plants from two areas in Malaysia namely Cameron Highlands (highland) and Sepang (lowland). These two areas are well established vegetable growing areas in Malaysia. The purpose of this study was to determine the level of heavy metals

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in selected of vegetables namely brinjal (*Solanum melongena*), sweet potato (*Ipomoea batatas*) and spring onion (*Allium cepa*).

MATERIALS AND METHODS

Three types of vegetables comprising storage roots, leafy and fruit vegetables were selected from Sepang, and Cameron Highlands, which have predominantly peat and sandy loam soils, respectively. The vegetables studied were brinjal (*Solanum melongena*) for the fruit vegetable, sweet potato (*Ipomoea batatas)* for storage roots and spring onion (*Allium cepa*) for the leafy vegetable. Sampling was done randomly at three different times.

The freshly harvested vegetables were brought to the laboratory and washed initially with running water to remove the soil particles, followed by three washings with distilled water. Samples were cut into small pieces before being oven dried at 70°C to constant weight. The samples were then pulverized with a mortar and pestle and weighed samples were subjected to wet digestion in the conical flask with HNO_3: $HClO_4$ (2:1) for 2-3 hrs on sand bath (AOAC 1984). Ten-mL of HCl was added to dissolve inorganic salts and oxides. Digested samples were filtered through 0.45 µm pore size Milipore filter paper and made up to 100 mL with distilled water prior to determination by atomic absorption spectrometry (AAS) Perkin Elmer (model 1100B).

Soil samples were collected from 0 to 30 cm depth randomly from the sampling areas and air dried at room temperature in the laboratory. They were then ground with a mortar and a pestle and sieved through 250 µm mesh. Heavy metals from the easily leachable and ion exchange portions were extracted using 1.0 M NH_4CH_3OO (pH 7). Ten gram soil samples were added to 50 mL of the solute (Badri 1984) and shaken for 1½ hr, followed by centrifugation for 30 min at 3000 rpm before being filtered through 0.45µm pore size filter paper and brought to 50 mL volume with distilled water. Samples were washed by adding 50 mL distilled water, followed by further shaking and centrifugation as before. Carbon organic analysis was determined using the Walkey-Black method (1934). Sequential extraction yielded four fractions, namely: easily leachable and ion exchange fraction (EFLE), acid reducible fraction (AR), oxidation organic fraction (OO), and resistant fraction (RR).

Concentration of metals in the plants and soils were determined by AAS (Perkin Elmer model 1100B) following the standard methods (AOAC 1984). All analyses were replicated three times. Data were subjected to an analysis of variance and means were compared by the Tukey test at the 5% level of significance.

RESULTS AND DISCUSSION

The metals content in spring onion, sweet potato and brinjal from the two areas namely, Cameron Highlands and Sepang are shown in Tables 1. It was observed that Fe followed by Zn were found to be highest in spring onion from Cameron

Highlands as compared to the other metals. Spring onion samples from Sepang contained high levels of Zn followed by Mn and Fe. The results also indicated that Zn was mostly accumulated in spring onion from Sepang. Spring onion seemed to tolerate higher concentrations of Zn in the soil compared to the other vegetables studied. Sweet potato collected from Cameron Highlands (and Sepang) contained a high concentration of Fe followed by Zn, at 0.549 and 0.219 $\mu g\ g^{-1}$ respectively. The highest metal concentration in sweet potato from Sepang was Fe followed by Mn and Zn. In brinjal, the highest accumulation of metal in samples from both Cameron Highlands and Sepang were Fe and Zn. In general, Fe, Zn and Mn were the common metals detected in the three vegetable samples from Cameron Highlands and Sepang. Other metals such as Pb, Cr, Cu and Cd were detected at lower concentrations in the 3 vegetable types collected from the two areas studied.

Differences in metal concentration in vegetables seem to imply that different types of vegetables have different abilities to accumulate the metals. In spite of the mechanisms involved in the elemental uptake by roots (non-metabolic or metabolic), plants are known to respond to the amounts of readily mobile type of metals in soils (Li and Shumas 1996; Madrid et al. 2002).

Concentration levels found in the study areas were comparable to those previously found and at lower concentrations than those reported in vegetables from other areas (Khairiah et al. 2002). High concentration of Zn and Fe and Mn in the vegetables indicate that Zn is an essential element and an activator of many enzymes involved in photosynthesis (Berg 1997) and hence is important in the early stages of seedling growth (Berg 1997; Grewal 1997).

These results explain that the type of metals accumulated in plants correlated to the leachable amounts of the metals in the soil solution. It was shown also by Khairiah et al. (2002) that the availability of metals, and thus the uptake by plants, is related both to their total concentration and their form and association in the soil, especially metals in the EFLE fraction. But most important, the chemical composition in plants reflects the soil media composition (Vousta et al. 1997).

Table 2 shows the concentration of heavy metals in soil grown with sweet potato from Sepang and Cameron Highlands. Both soils showed high levels of Mn in the EFLE and AR fraction. Zn was found to be the highest metal accumulated in both soils in the OO and RR fractions.

Table 3 shows the concentration of heavy metals in soil grown with onion from Cameron Highlands and Sepang. Mn was found to be higher in soils from both locations in the EFLE and AR fraction. In the OO fraction, Mn and Fe were found to be higher in soils from Cameron Highlands and Sepang, respectively, while in the RR fraction, it was found that Fe was markedly high in soils from Cameron Highlands and Sepang.

Table 4 shows the concentration of heavy metals in soil grown with brinjal from Cameron Highlands and Sepang. Mn was found to be higher in the EFLE and AR

Table 1. Concentration of heavy metals ($\mu g\ g^{-1}$) in spring onion and sweet potato from Cameron Highlands and Sepang.

Vegetable - Location	Fe	Zn	Pb	Mn	Cr	Cd	Cu
Spring onion							
- Cameron	0.133a	0.112b	0.002f	0.082c	0.005e	0.009e	0.033d
- Sepang	0.675b	1.207a	0.010f	0.863c	0.023f	0.098e	0.138d
Sweet potato							
- Cameron	0.549a	0.219b	0.010f	0.099d	0.035e	0.031e	0.160c
- Sepang	0.475a	0.223b	0.007e	0.268b	0.017d	0.017d	0.093c
Brinjal							
- Cameron	0.176a	0.101b	0.002d	0.069c	0.003d	0.029cd	0.059c
- Sepang	0.157a	0.117b	0.002g	0.046c	0.009f	0.011e	0.027d

Heavy metal: Fe, Zn, Pb, Mn, Cr, Cd, Cu.

Means within a row followed of each fraction by the same letter are not significantly different at $p>0.05$.

Table 2. Concentration of heavy metals ($\mu g\ g^{-1}$) in soil grown with sweet potato from Cameron Highlands and Sepang.

Fraction - Location	Fe	Zn	Cd	Mn	Pb	Cu	Cr
EFLE							
- Cameron	0.38d	0.39d	0.04g	2.09b	0.35d	0.20e	0.11f
- Sepang	0.07fg	1.35c	0.06g	9.71a	0.46d	0.36d	0.11f
AR							
- Cameron	9.75b	1.66e	0.04j	24.73a	0.22h	0.11j	0.19h
- Sepang	2.14d	1.52f	0.04j	4.73c	0.19h	0.25h	0.33g
OO							
- Cameron	50.48b	13.24d	0.10i	38.18c	1.53h	3.16fg	3.81f
- Sepang	144.36a	27.30c	0.20i	48.19b	2.50g	10.21d	5.18e
RR							
- Cameron	144.95a	20.84d	0.34i	17.38d	8.39ef	3.87h	7.05f
- Sepang	144.30a	26.02c	0.24i	19.35d	9.92e	31.87b	4.71g

Heavy metal: Fe, Zn, Cd, Mn, Pb, Cu, Cr.

Means within a row followed of each fraction by the same letter are not significantly different at $p>0.05$.

Table 3. Concentration of heavy metals (μg g^{-1}) in soil grown with onion from Cameron Highlands and Sepang.

Fraction - Location	Heavy metal Fe	Zn	Cd	Mn	Pb	Cu	Cr
EFLE							
- Cameron	0.19 f	1.16 c	0.04 g	3.47 b	0.19 f	0.71 d	0.12 f
- Sepang	0.23 f	1.21 c	0.04 g	5.74 a	0.33 e	0.64 d	0.12 f
AR							
- Cameron	1.49 f	3.54 d	0.03 k	53.27 a	0.45 g	0.15 i	0.40 g
- Sepang	1.96 e	3.03 d	0.06 j	34.81 b	5.61 c	0.18 h	0.34 g
OO							
- Cameron	29.75 c	24.65 c	0.09 i	49.30 b	0.69 h	13.27 d	3.45 f
- Sepang	75.30 a	29.52 c	0.18 i	50.76 b	1.05 g	10.56 e	3.61 f
RR							
- Cameron	149.38a	33.30 c	0.64 g	48.54 b	11.88 e	10.86ef	10.19ef
- Sepang	154.28a	33.50 c	0.31 g	36.66 c	9.10 f	19.03 d	6.15g

Means within a row of each fraction followed by the same letter are not significantly different at $p>0.05$.

Table 4. Concentration of heavy metals (μg g^{-1}) in soil grown with brinjal from Cameron Highlands and Sepang.

Fraction - Location	Heavy metal Fe	Zn	Cd	Mn	Pb	Cu	Cr
EFLE							
- Cameron	0.28e	0.90c	0.05f	6.14a	0.35e	0.81c	0.18e
- Sepang	0.49d	1.74b	0.06f	7.13a	0.48d	0.27e	0.17e
AR							
- Cameron	2.06d	3.07c	0.06h	33.3a	0.40e	0.11g	0.06h
- Sepang	1.40d	1.65d	0.08gh	9.06b	0.38e	0.20f	0.28e
OO							
- Cameron	4.48g	20.63d	0.13j	45.03bc	1.89I	7.97f	2.66h
- Sepang	135.31a	33.56c	0.16j	52.88b	2.06I	13.51e	7.33f
RR							
- Cameron	145.14a	32.82c	0.45f	53.60b	19.82d	13.28e	11.37e
- Sepang	142.33a	30.56c	0.22f	33.52c	22.58d	23.04d	9.10e

Means within a row of each fraction followed by the same letter are not significantly different at $p>0.05$.

fractions in the soils from both locations. In the OO fraction, Mn and Fe were found to be higher in the soil from Cameron Highlands and Sepang, respectively. In the RR fraction, it was found that the Fe content was extremely high in the soil from Cameron Highlands and Sepang. In general it seems that the Cd content in the soils was the lowest. The low concentration of heavy metals detected in the vegetables was also probably due to the relatively low availability of these metals in the soils.

Generally, metal content in the EFLE fractions and non-lithogenic phase of the agricultural soils studied were low. Metals from the resistant fraction were strongly bonded to various components of the soil and thus were not easily leached out to the environment or taken up by plants (Li et al. 1994). The ratios of heavy metals in crops *vs.* soils to determine the possibility of heavy metal accumulation in crops (Li et al. 1994). Based on their findings, it is not surprising that Fe, Zn and Mn were found to be higher in the vegetables studied.

However it should be noted that the pH and the organic matter content determines the solubility of metals in the soil and their availability for uptake by plants. Mulchi et al. (1991) indicated that the main factor affecting the uptake of metals by plants is soil pH and the level and chemical content of contaminants. Low soil pH may induce metals to be easily soluble and have ion exchange comparable to high soil pH. Errikson (1989) and Tuin (1989) found that low soil pH will increase solubility of Cu, Cd and Zn bonded to organic matter, secondary minerals and clay surface. Soil pH values ranged from 4.54-5.58 in the Sepang soils and from 6.3-6.9 in soils from the Cameron Highlands. Within this pH range, metals were easily soluble in the soil solution.

In conclusion, the metal concentrations found in the vegetables studied are lower than the maximum limit as permitted in the Malaysian Food Act (1983). Therefore, the vegetables grown in these areas are safe as they less contaminated than the allowed limit. Heavy metals such as Pb, Cd and Cr were present in small quantities. Agricultural soils from these areas were also less polluted as most of the metals were present at concentrations lower than the critical limits (Kabata-Pendias and Pendias 1992).

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