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ORIGINAL ARTICLE

Comparative Accumulation of Heavy Metals in Selected Vegetables, Their Availability and Correlation in Lithogenic and Nonlithogenic Fractions of Soils from Some Agricultural Areas in Malaysia

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ABSTRACT

Heavy metal content was determined in selected vegetables cultivated in some highland and lowland areas in Peninsular Malaysia. Leafy vegetables were represented by convolvulus (*Ipomoea aquatica*) and green mustard or sawi (*Brassica rapa* var. *parachinensis*), tubers and bulbs by sweet potato (*Ipomoea batatas*) and onion (*Allium cepa*), and fruity vegetables by chilly (*Capsicum annuum*), brinjal (*Solanum melongena)* and long bean (*Vigna sinensis*), respectively. Heavy metals from lithogenic and nonlithogenic soil fractions were studied at Cameron Highlands situated in the Pahang state and at lowland areas in Klang, Bangi, Gombak and Sepang districts in the Selangor state. The aim of the study was to investigate the availability of heavy metals and their potential uptake by vegetables in selected agricultural areas. The metals analysed were ferrum (Fe), zinc (Zn) cadmium (Cd), manganese (Mn), plumbum (Pb), copper (Cu) and chromium (Cr). Three soil samples were collected from each area and sampling was done at 1-30 cm depth. Extraction of heavy metals was carried out using sequential extraction and four fractions were produced comprising the easily leachable and ion exchange fraction, the acid reducible fraction, the oxidation organic fraction and the resistant fraction respectively. Heavy metal content in plant and soil samples were determined by atomic absorption spectrophotometry following standard methods (AOAC). Most metals were found at concentrations normally observed in vegetables grown in uncontaminated agricultural areas, with zinc (Zn) and manganese (Mn) content being highest, followed by copper (Cu), plumbum (Pb) and cadmium (Cd). However, the levels of potentially toxic metals such as Pb, Cd and Cr in the vegetables studied were found to be below the stipulated levels. Analysis of soil samples showed that the highest concentrations of heavy metals were obtained from the resistant fraction as compared to the other soil fractions. Concentration of Fe and Pb was found to be high in Sepang, whereas that of Cu was highest in Gombak and Cd levels were generally high in Sepang and Gombak. In contrast, the concentration of metals in the easily leachable and ion exchange fractions were low. Since differential uptake and accumulation of metals in the various plant parts are influenced by the availability of metals from the latter two fractions of the soils, the results indicate that availability of heavy metals to the cultivated plants (and thus, its consequent health risk to consumers) is also low. Based on the results obtained, the availability of heavy metals can be arranged as follows: Zn > Mn > Cd > Cu > Pb > Fe. The agricultural soils were found to contain high levels of Fe, Mn and Zn, whilst Cd and Cr were found in very low levels, well below the critical soil levels listed for arable land.

Key words: Heavy metals, vegetables, soil, Malaysia

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Introduction

Human activities such as industrial production, mining, agriculture and transportation release high loads of heavy metals to the biosphere. Accumulation of heavy metals in crop plants is often of great concern due to its potential for food contamination through the soil-root interface [13]. As plants acquire the necessary nutrients, such as nitrogen, phosphorus and potassium, they also take in and accumulate metals such as lead and cadmium [14]. Although Cd and Pb are not essential for plant growth they are readily taken up and accumulated by plants in appreciable amounts [13].

Ingestion of vegetables grown in soils contaminated with heavy metals have been suggested as a possible risk to human health and wildlife. These health risks will depend on the chemical composition of the contaminated soil, its physical characteristics, the type of vegetables cultivated and the consumption rate [14]. The uptake of heavy metals by plants are often influenced by plant species, growth stage, soil type, metal species and environmental factors. Heavy metal concentration in the soil solution play a critical role in controlling metal availability to plants. Most findings have proved that increasing the levels of heavy metals in the soil may cause increased uptake by plants. However, the availability of heavy metal ions are influenced by various factors including soil pH, physical and chemical soil properties, clay content and Mn oxide concentration [30].

Sequential extraction is widely used to obtain qualitative information on the form and association of metals and also indirectly their availability for plant uptake and migration in the soil [11]. The aim of the present study was to look into the accumulation and distribution of heavy metals in vegetables.

Materials and methods

Seven types of vegetables comprising storage roots, leafy vegetables and fruity vegetables were selected from the Sepang and Bangi agricultural areas of Selangor and the Cameron Highlands in Pahang. The latter area comprises upland soils while Bangi and Sepang areas have sandy and peat soils respectively. The plants studied were green mustard (*Brassica rapa*) and convolvulus (*Ipomoea aquatica*) for leafy vegetables, chilly (*Capsicum annuum*), long bean (*Vigna sinensis*) and brinjal (*Solanum melongena)* for fruity types, and sweet potato (*Ipomoea batatas)* for storage roots. Three types of vegetables sampled in the Cameron Highlands were sweet potato, brinjal and onion (*Allium cepa* L). Sampling was done randomly at three different times.

Determination of Heavy Metals in Plants

Freshly harvested vegetables were brought to the laboratory and washed in running water to remove the soil, followed by three washings with distilled water. Samples were cut into small pieces with a plastic knife before being oven dried at 70°C to a constant weight, then pulverized with a mortar and pestle. Weighed samples were subjected to wet digestion with $HNO_{3:}$ $HClO_4$ (2:1) for 2-3 hr. [6]. Some 10 mL of HCl was added to dissolve inorganic and oxide salts. Digested samples were filtered through 0.45 mm pore size Millipore filter paper and made up to 100 mL with distilled water.

Determination of Heavy Metals in Soil

Three soil samples were taken randomly at 1-30 cm depth per sampling site from the study areas and then air dried at room temperature in the laboratory. This extraction method yields four fractions: easily leachable and ion exchange fraction (EFLE), acid reducible fraction (RA), oxidation organic fraction (OO) and resistant fraction (RR). Soil samples were air-dried in the laboratory before being ground and sieved using a 250 mm mesh. A 10 g soil sample was weighed into a Kartell bottle, and 50 mL 1.0 M NH_4CH_3OO (pH 7) was added to extract metals from the EFLE fraction [8]. The samples were shaken for 1½ hr, then centrifuged at 3000 rpm for 30 min before being filtered through 0.45 mm millipore filter paper and then made up to 50 mL with distilled water. Samples were washed with 50 mL distilled water, followed by further shaking and centrifugation as described previously. Then 50 mL $NH_2OH.HCl$ (pH 2) was added to extract metals from the acid reducible (RA) fraction using the procedure described above. Metals in the organic oxidation (OO) fraction were extracted by adding 15 mL of H_2O_2 to the sample placed in a water bath for 1-1½ hr, followed by 50 mL NH_4CH_3OO (pH 3.5). Samples were then digested using HNO_3:$HClO_4$ at 25:10 ratio in a sand bath at 100ºC as the RR extraction method. The digestion process was repeated until the samples turned whitish.

To determine heavy metal concentrations, the atomic absorption spectrometry (Perkin Elmer 1100B) was used with the following wavelengths (nm): Fe 248.9, Zn 213.9, Cd 228, Mn 213.9, Pb 283.3, Cu 324.8 and Cr 357.9 (AOAC, 1984). The recovery study was carried out using the BCR sequential extraction procedure as described by Kartel *et al.* (2006). 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.

Result and discussion

Metals in Cultivated Plants

The metal content determined in the vegetables is summarized in Tables 1 to 3. Results from the study areas showed higher metal concentrations in the fruit and root vegetables as compared to the leafy vegetables. By comparing the distribution of metals in different tissues of the cultivated plants (Table 1), it was observed that the highest levels of Fe, Cd, Pb and Cr occurred in sweet potato tubers from Cameron Highlands. Mn levels were highest in sweet potato tubers from Klang, while Zn and Cu were highest in the onion stems from Klang.

The sequence of metal accumulation for the various types of vegetables studied in decreasing order was: Zn > Cu > Pb > Cd. Differences in heavy metal content of vegetables seemed to imply their different abilities in accumulating the metals. Zn was the most highly accumulated in the long bean followed by sweet potato. These plants appeared to tolerate higher levels of Zn in the soil compared to other vegetables. Metal content in the vegetables and soils were comparable to results from previous studies done in the same area [17] but lower than that reported from tin tailing areas of Bidor in Perak (Table 4) [5] and other contaminated sites in Malaysia [28,7].

In general, the uptake and distribution of metals in vegetables were influenced by the availability of the metals in the soil, plant parts and species concerned, whereby crops differed in their ability to take up and accumulate heavy metals [1]. Plants are known to respond to the amounts of readily mobile species of metals in the soils despite differences in mechanisms involved in the elemental uptake by roots. The availability of metals, and thus uptake by plants, were related both to their total concentration and their forms and association in the soil, especially metals in the easily leachable and ion exchange fractions [1]. On the other hand, nutrients, growth stage, soil pH and other factors controlling plant growth may indirectly affect the metal concentrations in plants [30] Vousta *et al.* [29] concluded from their studies that the metal content of vegetable roots and leaves were related solely to the soil or atmospheric inputs of each element except for Cu and Mn in roots, while Tjell *et al.* [25] deduced that foliar uptake accounted for 90-99 percent of total Pb in the foliage of rye-grass. Pb occurs mostly as a superficial deposit on leaves, whereas Cu, Zn and Cd are reported to have greater leaf penetration [15].

The results of the present study (Table 1) indicate that onion roots, long bean fruits and sweet potato tubers were good accumulators of Cd, whereas in the leafy vegetables (green mustard and convolvulus) Cd was not detected. Chlopecka and Adriano (1997) showed in their study that the highest amounts of Cd and Pb occurred in the root of maize (*Zea mays*) followed by the old leaves, the stem and grain in decreasing order. The roots mostly accumulate Pb but the Cd and Pb levels in plants may depend on their total and available concentrations in the soil, soil properties, plant species, age and cultivar. Among the vegetables studied, brinjal roots in the upland soils of Cameron Highlands and sweet potato tubers in the peat soils of Sepang appeared to accumulate the highest levels of Pb (Tables 1 & 2). In most soils Pb is mainly bound in silicates (residue fraction); however in contaminated soils, large amounts of Pb may be associated with Fe-Mn oxides and the organic fraction [12,15].

The interaction between elements occurring at the root surface and within the plant can affect the uptake, as well as translocation and toxicity[18]. In the soil Cd is fairly mobile and exists primarily organically bound, exchangeable and water-soluble [11]. Cd is found to be readily tranlocated throughout the plant following the uptake by roots [15].

Cobb *et al.* [14] studying metal accumulation by vegetables grown in mine wastes near Salt Lake City in Utah, USA, found that tomatoes and Roma bush beans confined Pb, Cd, As and Zn mainly in their roots and little were translocated to the fruits. However, radish roots accumulated less metals compared to the leaves and lettuce roots and leaves accumulated similar concentrations of metals. Thus, they concluded that lettuce leaves and radish roots accumulated significantly more metals than bean and tomato fruits and that if radish and lettuce were to be grown in mine waste and tailing areas, these two vegetables would pose a greater risk to humans and wildlife in terms of contaminant intake. High concentration of Zn in the vegetables that were studied may be associated with its role as an essential element and an activator of many enzymes involved in photosynthesis and thus Zn is important in the early growth stages of seedlings [9,8]. Zn content in wheat grain have been reported to increase by increasing the supply of Zn to the soil [9].

Metals in Storage Roots of Vegetables

Comparing metal content in the roots of different vegetables (Table 2), it was found that the highest levels of Cr, Cd, Fe, Zn and Cu occurred in the onion roots from Sepang, while Pb levels were highest in the brinjal roots from Cameron Highlands. However, the values for PTEs in sweet potato roots from Klang and Cameron Highlands were relatively low.

In general, the levels of heavy metals in various parts of vegetables found in the present study were low compared to levels reported in previous studies from other areas. In previous studies of vegetables grown in the tin tailing areas of Bidor, (Ang *et al.,* 2000) it was found that Pb exceeded the allowable limit in all the plants studied, namely okra, long bean and sweet potatoes (with a range of 0.4811 - 3.365 mg/kg fresh weight). Leaves of both pink and white varieties of sweet potato from Bidor contained the highest levels of Pb compared to other plants (Table 4). Pb was most likely taken up from the soils by roots while Pb from air pollutants was absorbed by the leaves. Sweet potato showed good mobility and uptake of Pb and this was further enhanced by the basic soil conditions (pH 9-6.9).

The results of the current study also showed that Hg in the pink and white varieties of sweet potato in Bidor were in the range of 0.0006 - 0.0185 mg/kg-wet weight, and this exceeds the allowable limit, especially in the leaves. Hg was likely mobilized into the active growing tissues of the shoot, while Hg deposition upon the aerial plant parts from the air may be attributed to the use of organic chemicals, and to dust from contaminated soils.

Metals in Leafy Vegetables

Metal concentrations measured in the leaves of various plants in the current study were relatively low compared to those in other parts of the plants (Tables 1- 3). This would indicate that the metal content in the vegetables were mainly accumulated from the soil, with latter having low availability of those metals. Page *et al.* [21] reported that leafy vegetables such as silver beet (*Beta vulgaris* L.), lettuce and spinach (*Spniacia oleracea* L.) usually had higher concentrations of Cd than fruits and fruity vegetables.

High levels of Cu and Zn in the leaves are expected as both metals are required by plants as micronutrients and are involved in enzymatic activities especially in leaves. However, high levels of these metals could cause toxic effects in the plant. The enrichment of heavy metals in the soils may enhance the uptake of Zn, Cd and Pb by leafy vegetables (such as Chinese cabbage, lettuce and cabbage), as well as by root vegetables (like carrots, potatoes, radishes, etc) and fruity vegetables such as cucumbers, and tomatoes [26]. However, low levels of heavy metals were found in the fruity vegetables and in strawberries, although in some leafy and root vegetables Zn and Cd levels exceeded the statutory limits [26].

Metals in Fruity Vegetables

Among the fruity vegetables studied, brinjal fruits from both the Cameron Highlands and Klang areas showed relatively low levels of all metals (Tables 1 & 3), while the long bean fruits from Bangi and Sepang contained the highest levels of Fe, Zn, Cd and Mn (Table 3). Likewise, the chilly fruits from Bangi and Sepang areas showed high concentrations of Cd, Pb, Cu and Cr (Table 3). However levels of potentially toxic elements (PTEs) in the fruity vegetables are still considered quite low compared to the maximum allowable limits of 2.0 mg/kg, 1.0 mg/kg, 30.0 mg/kg and 40.0 mg/kg for Pb, Cd, Cu and Zn respectively, as stipulated under the Malaysian Food Act (1983) and Food Regulations (1985).

Metal content in chilly fruits from the Sepang and Bangi areas was observed to have the following range of values (mg/kg): Fe = 2.94-4.32, Cr = 0.08-0.14, Pb = 0.34-0.52, Cd = 0.06-0.11, Zn = 2.05-2.40, Cu = 0.82-1.01, Mn = 1.22-1.85 mg/kg respectively. Likewise, the values for long bean from both areas were in the following range (mg/kg): Fe = 6.50-6.57, Cr = 0.06-0.08, Pb = 0.26-0.33, Cd = 0.05-0.11, Zn = 4.68-4.96, Cu = 0.64-0.78 and Mn = 2.48-4.30 mg/kg respectively. Studies by Cobb *et al.* [14] on tomato fruits, roma bush bean, radish and lettuce showed different abilities for uptake of Pb, Cd, As and Zn by the vegetables studied. Cd was accumulated in all plant parts, namely shoots, leaves, roots and fruits while Pb and Zn mainly accumulated in the leaves and roots.

The mean metal content in the vegetables studied at the agricultural sites in the current exercise did not exceed the critical limits stipulated for food toxicity concerns [15]. The critical limits are as follows: Cr 5-30 mg/kg, Cu 20-100 mg/kg, Mn 300-500 mg/kg, Pb 20-300 mg/kg and Zn 100-400 mg/kg. The average content of heavy metals present in all plant tissues studied is still quite low and this was probably because the availability of heavy metals in the soils was very low.

Metals in the Soils

The results (Table 5) from the current study showed that the highest levels of metals in soils were found in the resistant fraction (RR) as compared to the other fractions. Fe, Cd and Pb were high in Sepang, Fe, Zn and Cu in Klang and Fe, Cd, Pb and Cu in Cameron Highland soils. Levels of Pb (0.19-0.48 mg/kg) and Cu (0.20-0.80 mg/kg) were highest in the sandy soils of Bangi as compared to the peat soils of Sepang and Klang, However, Bangi and Sepang soils contained low levels of Cr and Cd, and thus are considered quite safe for agriculture. Bangi soils have the upper pH range of 7.11-7.45 as compared to the Sepang peat soils (pH 4.54-5.58). Hence there would be less mobility (leachability) of PTEs from basic soils into the root system of plants because metals would be strongly bound to the resistant fractions of the soil. Under certain conditions Pb could be easily taken up by plants, while Zn often occurs in an easily soluble form in the soil and thus is readily available to plants [24].

Generally, metal content in the easily leachable and ion exchange fraction (EFLE) and non-lithogenic phase of the agricultural soils studied were low. In contrast, soils from contaminated sites and low pH soils showed high levels of metals in the EFLE fractions [5,7]. The main factors in determining solubility of metals in soils and availability for uptake by plants is pH and organic content of soils [4,20]. Organic matter will bind metals via chelating reactions. Under acidic soil conditions of pH 5-6, metals often form strong bonds with functional groups such as carboxyl and hydroxyl in the organic matter [15].

Soil pH values were in the range of 4.54-5.58 in the Sepang soils and from 7.11-7.45 in the Bangi soils, between 6.38-6.95 in Cameron Highlands, and 3.93-5.48 in Klang soils respectively. Under these pH conditions small amounts of Cd could be extracted in the non-lithogenic phase. Smith [23] postulated that Cd and Zn which were not taken up by plants were usually tightly bound to hydroxides and carbonates in the soil. Uptake of Cd and Pb depended on the availability of metals in the soils. Increasing the soil pH would reduce the concentration of Cd in the soil solution and consequently Cd uptake by vegetables [27].

Correlations between Metals in Soils, Plants and Other Biota

Most of Pb, Cd, Cu and Zn in the study sites occurred in the lithogenic phase, and hence difficult for plants to uptake, as they were highly bound to various soil components, especially silicates [17]. Positive correlations were also found between Cd ($r = 0.746$) sweet potato tubers, onion roots and long bean fruits and in their respective root zone soils (Table 6) and likewise for Pb, Zn, Fe and Cr in the various plant parts compared to their root zone soils. Metals in the EFLE are most easily available for uptake and accumulation into the food chain. Results of initial screening studies at Putrajaya Lake and wetlands indicated that the rooted grasses (macrophytes), fish, and snails formed the major groups of organisms for PTEs bioaccumulation through the food chain [2].

Luo and Rimmer [18] concluded from their studies on metal uptake from soils by plants that 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. Since different uptake of metals by plant parts are affected by mobility from the EFLE fraction, availability of PTEs to plants (with consequent health risk) is also low in the agricultural sites of the present study areas. In contrast, data from contaminated sites such as tin tailings (Bidor) and ore from mines (such as the large Mamut Copper Mine in Sabah) have indicated elevated uptake of PTEs in some cultivated plants [5,7].

Baba *et al.* [7] who studied metal distribution extensively in large parts of the Ranau District in Sabah, found that three metals (Ni, Cr and Cu) were above the threshold of toxicity levels in crops Ni and Cu could have direct effects on crops while Cr (although probably not toxic to crops) might affect animals that feed on the crops. In Sabah, areas around Pinousuk Plateau, Ranau Valley and Lohan Valley comprise very important agricultural land for the local population. PTEs in these soils are associated with serpentine or serpentinite parent material and tailings of the Mamut copper mine, the largest copper mine in Sabah [5].

Likewise, in West Malaysia, PTEs in tin tailings are mainly derived from geological formation and deposits, except for Cd [22]. PTEs are released as by-products of mining activities, for example Hg may be sourced from fugitive vapours of fresh Hg used in gold extraction, and/or Hg naturally found in soils. Agricultural practices may be a source of some PTE inputs, for example from empty fruit bunches and chicken manure [5]. Studies into PTE accumulation in tissues of wild fish species collected from the relatively unpolluted natural lake and river ecosystems of Pahang indicated strong correlations between metal concentrations and sediment particle size, pH and organic content [3]. Metal levels however were highest in the sediment compared to levels found in the fish tissues.

Conclusion

Accumulation and distribution of metals in vegetables varied depending on the types and parts of vegetables, metals and the soil types studied. Metal content in the vegetables studied were in decreasing order of: Zn > Cu > Pb > Cd, with storage roots and fruity vegetables showing a higher tendency of metal accumulation as compared to leafy vegetables. Concentrations of metals in vegetables were in the range of those found in uncontaminated areas. Uptake of metals by plants depended on the availability of the metals in the soil. According to the Malaysian Food Act 1983 and Food Regulations 1985 [5], the maximum limits allowable for metal contamination in vegetable produce are as follows: 2 mg/kg for Pb, 30 mg/kg for Cu, 40 mg/kg for Zn and 1 mg/kg for Cd. The metal concentrations found in the vegetable samples studied did not exceed the stipulated limits, thus they are safe for human consumption.

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Table 1: Comparative mean metal contents in onion stems, sweet potato tubers and brinjal fruits sampled from the study areas (n=18) (mg/kg)

Plants	Sites	Heavy metals						
		Fe	Zn	Cd	Mn	Pb	Cu	Cr
Onion stems	Cameron Highlands	0.353	0.277	0.003	0.064	0.014	0.014	0.051
Onion stems	Klang	0.279	0.774	0.009	0.188	0.020	0.075	0.127
Sweet potato tuber	Cameron Highlands	0.549	0.219	0.010	0.099	0.035	0.031	0.160
Sweet potato tuber	Klang	0.475	0.223	0.007	0.268	0.017	0.017	0.093
Brinjal	Cameron Highlands	0.176	0.101	0.002	0.069	0.003	0.029	0.059
Brinjal	Klang	0.157	0.117	0.002	0.046	0.009	0.011	0.027

Bold figures indicates highest values

Table 2: Comparative mean metal contents in the roots of brinjals, sweet potato and onions sampled from the study areas

Vegetable	Location	Metals in roots (mg/kg dry wt)						
		Fe	Zn	Cd	Mn	Pb	Cu	Cr
Brinjal	Cameron Highlands	4.340[a]	1.125[a]	0.005[a]	0.426[a]	0.040[a]	0.146[a]	0.040[a]
Brinjal	Klang	1.423[b]	0.544[b]	0.002[b]	0.158[b]	0.012[b]	0.030[b]	0.032[a]
S-Potato	Cameron Highlands	2.365[a]	0.252[b]	0.004[b]	0.124[b]	0.021[a]	0.031[a]	0.039[a]
S-Potato	Klang	0.634[b]	0.350[a]	0.006[a]	0.661[a]	0.020[b]	0.022[b]	0.035[a]
Onion	Cameron Highlands	1.187[b]	0.400[b]	0.003[b]	0.134[b]	0.014[b]	0.164[b]	0.062[b]
Onion	Sepang	5.350[a]	1.595[a]	0.014[a]	0.891[a]	0.024[a]	1.029[a]	0.249[a]

Bold figures indicates highest values

Note : Same letters in the same columns of each crop indicate no significant differences ($p>0.05$)

Table 3: Range of metals accumulated in vegetable fruits (A) and leafy vegetable (B) of the study areas A. vegetable fruits

Fruits mg/kg	Fe	Zn	Cd	Mn	Pb	Cu	Cr
Long beans	6.50 -	4.60 -	0.05 - 0.11	2.48-	0.26 -	0.64 -	0.06 -
Bangi/Sepang	6.57	4.96		4.30	0.33	0.78	0.08
Brinjal	0.157 -	0.101 -	0.002 -	0.046 -	0.003 -	0.011 -	0.027 -
Klang/Cameron Highlands	0.176	0.117	0.002	0.069	0.009	0.029	0.059
Chilly	2.94 -	2.05 -	0.06 -	1.22 -	0.34 -	0.82 -	0.08 -
Bangi /Sepang	4.32	2.40	0.11	1.85	0.52	1.01	0.14

B. Leafy vegetable

Leafy (mg/kg)	Fe	Zn	Cd	Mn	Pb	Cu	Cr
Sawi	0.018-	0.021-	0.001-	0.011-	0.002-	0.005-	0.001-
Bangi/Sepang	0.106	0.103	0.002	0.054	0.003	0.021	0.002
Kangkung	0.023-	0.014-	0.001-	0.012-	0.001-	0.005-	0.001-
Bangi /Sepang	0.177	0.034	0.001	0.086	0.003	0.011	0.001

Bold figures indicates the highest values

Table 4: Mean metal contents in the root zone soils of potato (A), brinjal (B) and onion (C) from the Cameron Highlands and Klang study areas A. Potato

	Fe	Zn	Cd	Mn	Pb	Cu	Cr
EFLE*	0.38	0.39	0.04	2.09	0.35	0.20	0.11
AR*	9.75	1.66	0.04	24.73	0.22	0.11	0.19
OO*	50.48	13.24	0.10	38.18	1.53	3.16	3.81
RR*	144.95	20.84	0.34	17.38	8.39	3.87	7.05
EFLE#	0.07	1.35	0.06	9.71	0.46	0.36	0.11
AR#	2.14	1.52	0.04	4.73	0.19	0.25	0.33
OO#	144.36	27.30	0.20	48.19	2.50	10.21	5.18
RR#	144.30	26.02	0.24	19.35	9.92	31.87	4.71

B. Brinjal

	Fe	Zn	Cd	Mn	Pb	Cu	Cr
EFLE*	0.28	0.9	0.05	6.14	0.35	0.81	0.18
AR*	2.06	3.07	0.06	33.3	0.4	0.11	0.06
OO*	4.48	20.63	0.13	45.03	1.89	7.97	2.66
RR*	145.14	32.82	0.45	53.6	19.82	13.28	11.37
EFLE#	0.49	1.74	0.06	7.13	0.48	0.27	0.17
AR#	1.4	1.65	0.08	9.06	0.38	0.2	0.28
OO#	135.31	33.56	0.16	52.88	2.06	13.51	7.33
RR#	142.33	30.56	0.22	33.52	22.58	23.04	9.1

C. Onion

	Fe	Zn	Cd	Mn	Pb	Cu	Cr
EFLE*	0.19	1.16	0.04	3.47	0.19	0.71	0.12
AR*	1.49	3.54	0.03	53.27	0.45	0.15	0.40
OO*	29.75	24.65	0.09	49.30	0.69	13.27	3.45
RR*	149.38	33.30	0.64	48.54	11.88	10.86	10.19
EFLE#	0.23	1.21	0.04	5.74	0.33	0.64	0.12
AR#	1.96	3.03	0.06	34.81	5.61	0.18	0.34
OO#	75.30	29.52	0.18	50.76	1.05	10.56	3.61
RR#	154.28	33.50	0.31	36.66	9.10	19.03	6.15

Note: Easily leachabale and ion exchange fraction (EFLE), acid reducible fraction (AR), oxidation organic fraction (OO), resistant fraction (RR), * = Cameron, # = Klang
Bold figures indicates the highest values

Table 5: Uptake of PTEs in sweet potato tubers from tin tailings of Bidor (Ang *et al.,* 2000)

Metals in plants	Soil, n=4	Tubers, n = 10	Leaves, n = 10
Cd White sw pot	0.325±0.005; pH 6.9	1.228±1.046; pH 4.5	0.663±0.274; pH 4.9
Cd Pink sw pot	0.325±0.005; pH 6.9	1.063±0.607; pH 4.9 **	0.910±0.485; pH 5.2
Ni White sw pot	1.640±0.472; pH 6.9	0.588±0.681; pH 4.5	1.983±0.373; pH 4.9
Ni Pink sw pot	1.640±0.472; pH 6.9	0.990±0.387; pH 4.9	1.738±0.737; pH 5.2
PbWhite sw pot	6.493±3.368; pH 6.9	3.563±0.498; pH 4.5	6.105±4.893; pH 4.9
Pb pink sw pot	6.492±3.367; pH 6.9	4.218±3.187; pH 4.5	9.808±0.708; pH 4.9
Zn White sw pot	26.013±9.77; pH 6.9	9.290±4.09; pH 4.5	25.198±3.80; pH 4.9
Zn Pink sw pot	26.013±9.78; pH 6.9	8.910±1.542; pH 4.9	21.298±3.63; pH 5.2
Hg White sw pot	0.055±0.010; pH 6.9	0.017±0.014; pH 4.5	0.038±0.031; pH 4.9
Hg Pink sw pot	0.055±0.010; pH 6.9	0.011±0.008; pH 4.9	0.027±0.025; pH 5.2
As White sw pot	0905±0.292; pH 6.9	0.305±0.192; pH 4.5	0.398±0.081; pH 4.9
As Pink sw pot	0905±0292; pH 6.9	0.528±0.309; pH 4.9	0.420±0.098; pH 5.2

(** figures in bold are above permissible limits)

Table 6: Significant positive correlations between metals in plant parts and in the soils

Plant Parts/Soil Tpes (Non-resistant fraction)	Correlation Coefficients (r) (Plant Parts - Soils)
Sawi (*B. rapa var parachinensis)* leaves (Sepang-Peat)	Cu-Cu (0.766)
Sawi (B.*rapa var parachinensis*) stems (Bangi-sandy)	Fe-Fe (0.571)
Sawi (B.*rapa var parachinensis*) leaves (Bangi-sandy)	Cr-Cr (0.682)
Convolvulus (*I.aquatica*) stems (Bangi-sandy)	Cr-Cr (0.708), Cu-Cu (0.949)
Convolvulus (*I.aquatica*) leaves (Bangi-sandy)	Cr-Cr (0.844)
Sweet potato (*I.batatas)* leaves (Bangi-sandy)	Cu-Cu (0.972), Zn-Zn (0.821)
Sweet potato (*Ipomea batatas)* tubers (Sepang-peat)	Pb-Pb (0.673), Cd-Cd (0.999), Fe-Fe (0.992),
Cd-Zn (0.782) Brinjals (*Solanum melongena)* fruits (Cameron-upland)	Zn-Cd (0.7720), Cd-Cd (0.850), Zn-Pb (0.749)
Long bean (*Vigna sinensis*) fruits (Sepang-peat soil)	Cd-Fe (0.956), Mn-Fe=0.857, Cu-Cu (0.739)

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