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Research article

Comparative assessment of the heavy metal phytoextraction potential of vegetables from agricultural soils: A field experiment

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ABSTRACT

A field study was established to determine the phytoextraction potential of six vegetable species, namely *Amaranthus viridis* L., *Basella alba* L., *Brassica chinensis* var. *Parachinensis*, *Brassica rapa* L., *Capsicum frutescens* L., and *Ocimum tenuiflorum* L.. These edible plants were selected for their short growth cycles and high biomass production, which are some traits for efficient phytoremediation. Following acid digestion of the soil and vegetable samples using the USEPA 3050B acid digestion method, the extracts were analyzed for Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn using ICP-OES. Results in soil samples showed that the concentrations of both beneficial and essential heavy metals, and non-essential heavy metals are below the WHO, USEPA, and CCME soil quality guidelines. Al is one of the highest concentrations found in the soil samples but it tends to accumulate in the root part of all vegetable species compared to the aboveground parts. In general, *B. rapa* L. accumulated the highest level of Cd (0.4 mg/kg) and Pb (5.71 mg/kg), while *B. alba* L. accumulated the highest Cr (2.62 mg/kg) in all plant parts. The findings in this study indicated that Co, Cu, Fe, Mn and Zn were mostly accumulated in leaves of *A. viridis* L. (Co, Cu, Fe, Mn and Zn), *B. alba* L. (Co, Fe and Mn), *B. chinensis* (Mn and Zn) and *O. tenuiflorum* L. (Mn), and roots of *C. frutescens* L. (Co, Cu, Fe and Mn), *B. alba* L. (Co, Cu and Zn), *A. viridis* L. and *B. chinensis* (Cu and Fe) and *B. rapa* L. (Fe). Cr, Pb and Ni were significantly greater in *B. alba* L. (Cr) And *B. rapa* L. (Ni and Pb) roots. MTF >1 was observed in the roots of all species for Co, Cd, Zn, and Ni. BTC values varied between the different vegetable species with *A. viridis* L. having the greatest heavy metal mobility between its plant parts and the best heavy metal phytoextraction potential among other species. The PCA biplots showed that heavy metals were partitioned differently between various plant parts of the vegetable species and can be explained by the first two components (PC1 and PC2) which were associated with the root and/or leaf parts for most vegetable species.

1. Introduction

The bioavailability of heavy metals in the environment has increased dramatically in recent decades as a result of expanding industrialization and urbanization, raising serious concerns throughout the world [1]. The growth and development of intensive farming industries contribute to the proliferation of heavy metal concentrations in agricultural soils due to the heavy application of

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fertilizers that may contain trace amounts of heavy metals [2,3]. Physical and chemical remediation strategies have been widely and continuously developed to remove toxic heavy metal pollutants from soils or to render them harmless in soils [4–6]. However, these expensive approaches are only efficient when the pollutants or contaminants are present at large concentrations [4,7]. Although chemical remediation can quickly clean the environment, it needs the use of a large amount of costly chemical agents that can lead to soil degradation and secondary pollution [4,7,8]. Hence, developing a cost-effective and environmentally friendly remediation technique is necessary to mitigate heavy metal contamination in soils.

Phytoremediation, or the adoption of plants for restoring a polluted environment, has drawn much attention in recent years [9,10]. Among the phytoremediation strategies, phytoextraction, which refers to the extraction of heavy metals by plants from soil matrix and their accumulation in the harvestable plant parts, has been put forward as a potential green alternative to traditional, physical, and chemical methods [11]. One advantage of using plants to extract heavy metals, particularly fast-growing and high biomass plants, is that plants may absorb ionic compounds from the soil through their root system even if the concentrations of soil pollutants are low [12]. They can also extend their roots into the rhizospheric environment that accumulates heavy metals and then adjust their bioavailabilities, stabilizing soil fertility by reducing excess pollutants [4,7,13].

There is a multitude of merits to using a plant-based approach, which includes: (i) a cost-effective technique – plants are autotrophs and have low maintenance, making them simple to manage and economically cheap to install, (ii) an environmentally-friendly approach – plants can reduce the exposure of pollutants from the soil environment, (iii) applicability – phytoremediation can be applied extensively in fields and readily be disposed of, (iv) stability – it reduces the risk of pollutants spreading by stabilizing heavy metal in soils, thus preventing erosion and metal leaching, and, (v) soil amendment – improves soil fertility and properties by releasing organic matters to the soil [6,13,14].

Exploring plants with phytoextraction or phytoremediation potential is crucial in searching for an effective phytoremediation technology [10,15]. A plant can be defined to have phytoremediation potential if the hyperaccumulating plants can remove pollutants such as toxic heavy metals from the contaminated soil [15]. The most decisive element in developing an efficacious phytoremediation technique is the selection of promising plants [10]. Plants accumulating heavy metals from contaminated soils in their tissues are accumulators or hyperaccumulators [15]. However, hyperaccumulators are generally used for plants that can accumulate large amounts of at least one heavy metal from the contaminated soils in their living tissues [16,17]. Furthermore, hyperaccumulating plants have a 100- to 1000-fold greater potential to absorb heavy metals from polluted soils than non-hyperaccumulating plants [18]. Most studies on accumulating or hyperaccumulating plants are centered around native plants growing in metalliferous habitats [16,17] and not vegetables. For example, Rigola et al. [19] reported a hyperaccumulator, *Thlaspi caerulescens*, that attracted much attention as a potential plant for phytoremediation due to its capability of accumulating and translocating considerable amounts of Cd from soils to shoots and its hyper-tolerance to Cd toxicity.

However, Rascio and Navari-Izzo [20] suggested that for a large-scale phytoremediation effort, high shoot biomass and fast-growing plants, such as leafy vegetables, would be more suitable for phytoextraction of metals in soils. Several plant traits are ideal for phytoextraction, such as the higher uptake of heavy metals in plant tissues, the rapid transfer factor from roots to shoots, greater tolerance to metal accumulation in leaves [20], faster growth rate, higher shoot biomass production [10], and the plants are readily harvestable [21].

It is hypothesized that vegetable species differ greatly in their ability to uptake and accumulate heavy metals from the soils, even among cultivars and varieties within the same species [22–24]. Therefore, this study aims to investigate the uptake of ten heavy metals in different plant parts of several vegetable species with high biomass production for its potential phytoremediation application. This study involves analyzing the heavy metal contents in soils and vegetables grown in an agricultural farmland in Brunei Darussalam using an Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES). The specific objectives are as follows: (i) to compare the heavy metal phytoextraction of different vegetables grown, (ii) to study the phytoextraction indices such as the metal transfer factor and the biotranslocation coefficient between the different parts of each vegetable species.

2. Materials and methods

2.1. Study area

The phytoremediation study was conducted in an agricultural farmland (0.06 ha) situated at Jalan Melati, Bukit Agok, Brunei Darussalam (4°54’58.9"N, 114°47’44.4"E; Zunaidi et al., 2021b). Brunei covers an area of 5765 km^2 on the northwest coast of Borneo Island in South-East Asia [26,27]. Brunei’s climate is typically hot and humid throughout the year, with an average temperature of 28.0 °C and average precipitation of 3300 mm in 2021 [28]. It had a daily temperature of 27.6 °C and a total rainfall of 546.4 mm from September to October 2021, which were the growing periods of vegetable species in the farmland.

2.2. Study species, sampling, and experimental design

The six vegetables used in this study were: *Amaranthus viridis* L. (amaranth; Amaranthaceae; *A. viridis* L. hereafter), *Basella alba* L. (Chan Choy or Ceylon/Malabar spinach; Basellaceae; *B. alba* L. hereafter), *Brassica chinensis* var. *Parachinensis* (white stalk Choy-sum; Brassicaceae; *B. chinensis* hereafter), *Brassica rapa* L. (Pak-choi; Brassicaceae; *B. rapa* L. hereafter), *Capsicum frutescens* L. (chili; Solanaceae; *C. frutescens* L. hereafter) and *Ocimum tenuiflorum* L. (basil; Lamiaceae; *O. tenuiflorum* L. hereafter). The seeds were purchased from a local market. These vegetables were chosen for the study not only because they are locally and commonly produced in Brunei [29], but also due to their high germination rates, short growing periods, and high biomass production, all of which may be advantageous traits for the phytoextraction potential of heavy metals in soils.

Selected vegetable species were grown on one rectangular raised agricultural bed (60 m × 0.6 m) to determine their phytoextraction efficacies. Before sowing the seeds, the bed was covered with a sheet of black plastic mulch, and circular holes (*ca.* 20 cm in diameter) were punctured into the plastic sheet at a distance of *ca.* 20 cm apart, resulting in a 3 row × 5 column grid for each species ($n = 15$ planting holes) (Fig. 1). In total, there were 90 planting holes for the six vegetables species.

For each vegetable grown on the bed, five pre-harvest topsoil samples at a depth of 0–20 cm were randomly collected, resulting in a total of 30 topsoil samples for the analysis of selected physicochemical properties of soils, such as textural class [30], moisture content [31], pH [32], electrical conductivity [33], total organic carbon (OC) and organic matter (OM) content [34], total nitrogen (N) and total phosphorus (P) contents [31], soil nutrient content (Ca, Mg, Na, and K) and cation exchange capacity (CEC) [35] (Table 1). The agricultural soils are sandy loam in texture with slightly acidic, nutrient-rich soil (Table 1).

The seeds were sown directly into each hole on the planting bed at a depth of 1 cm ($n = 15$ holes per vegetable species) in September 2021. It took approximately a week for the seeds to germinate and 5 weeks for the plants to mature before harvesting for the heavy metal analysis. Thinning of the plants was performed after the emergence of young shoots, leaving only three plants growing in each hole. This resulted in a total of 45 plants per species and 270 plants for the study. The plants were covered with green netting which was positioned at a height of approximately 70 cm above the plant bed to avoid the plants from being exposed to direct sunlight. No fertilizers were applied during the growing period to reduce any possible contributing factors to the number of heavy metals present in the soils and hence metal uptake by the plants. The vegetables were harvested on week 5, where all of the vegetables apart from chili, reached the typical leaf mass (BBCH 49) (Fig. 2A–D, 2F), following the BBCH scale by Feller et al. [37]. Chili was at BBCH 39, where the leaf rosette has reached 70% of the expected diameter (Fig. 2E). A total of 45 plants were harvested for each species and the samples were bulked for chemical analysis.

2.3. Analytical procedures

The same pre-harvest soil samples with the physicochemical properties as reported in Table 1 were analyzed for heavy metal contents (Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn). Plant samples were thoroughly washed with distilled water and separated into three different parts, namely leaf, stem, and root. Each plant part per species was bulked to study the accumulation of heavy metals in plants. Both soil and plant samples were oven-dried at 70 °C to a constant weight. The dried matter was ground and homogenized using a pestle and mortar and sieved using a sieve of mesh size <1 mm. The metal extraction procedure was based on the standard guidelines, USEPA 3050B acid digestion method, as reported by the United States Environmental Protection Agency [38], which involved digesting 1 g of oven-dried and homogenized samples using 15 mL of HNO_3 (Sigma Aldrich, ACS reagent, 67%), 10 mL H_2O_2 (Sigma Aldrich, 30%) and 10 mL HCl (Sigma Aldrich, ACS reagent, 35.4%) at 95 ± 5 °C for 2 h using a hot plate. The samples were filtered and made to volume (100 mL) using distilled water after cooling to room temperature (*ca.* 24 °C).

The soil and plant samples were analyzed using an ICP-OES (ICP-OES Thermo Scientific iCAP 6000 Series, USA). The accuracy of instrumental analyses and method of sample extraction were validated using a certified reference material (CRM) IAEA-359 (Table 2) and metal analyses were performed in triplicates. The operating conditions of the ICP-OES used in this study were described in Zunaidi et al. [25].

2.4. Data analysis

Two indices (metal transfer factor and biotranslocation coefficient) were determined for each vegetable so that they can be used to deduce which vegetables have the greatest phytoextraction potential. According to Buscaroli [39], plants with both indices more than

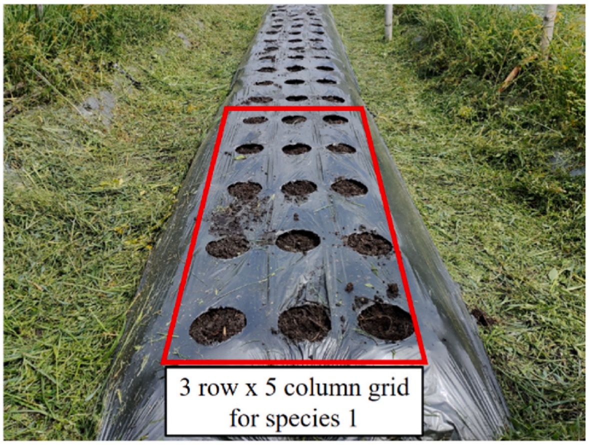


Fig. 1. Experimental design of the planting bed for one species. This accommodated a total of 15 planting holes and 45 plants (3 plants per hole). Altogether, there were 90 planting holes and 270 plants for six vegetable species.

Table 1
Selected physicochemical properties of agricultural soils (mean ± standard deviation) from the Bukit Agok agricultural farmland.

Soil parameters	Soil
Taxonomy[a]	Spodosols
Textural class	Sandy loam
Sand (%) (0.05–2.00 mm)	49.5 ± 1.70
Silt (%) (0.002–0.050 mm)	45.9 ± 3.50
Clay (%) (<0.002 mm)	4.50 ± 2.40
% moisture	15.6 ± 2.30
pH	5.00 ± 0.04
Electrical conductivity (dS/m)	0.77 ± 0.02
Total organic C (%)	3.46 ± 0.65
Organic matter (%)	5.96 ± 1.12
Total N (mg/kg), dry weight	5960 ± 190
Total P (mg/kg), dry weight	2916 ± 600
Ca (mg/kg), dry weight	3850 ± 358
Mg (mg/kg), dry weight	2610 ± 54
Na (mg/kg), dry weight	2092 ± 66
K (mg/kg), dry weight	3669 ± 103
CEC (cmol/kg)	215 ± 36.5

[a] Soil taxonomy based on the United States Department of Agriculture (USDA) obtained from Grealish et al. [36].

1 are suitable for phytoextraction.

2.4.1. *Metal transfer factor*

Metal transfer factor (MTF) is considered as one of the essential parameters in determining the uptake efficiency of metals from the soils to the different portions of plants and it can be calculated using Eq. (1) [40]:

$$\textit{Metal transfer factor}\ (MTF) = \frac{C_{\text{plant part}}}{C_{\text{soil}}} \tag{1}$$

where $C_{\text{plant part}}$ and C_{soil} are the heavy metal concentrations in the different parts of the plant (leaf, stem, or root) (mg/kg) and the concentration of the respective heavy metals in the soils (mg/kg) on dry weight basis, respectively.

2.4.2. *Biotranslocation coefficient*

Ratios between the root part of each plant species to the aerial parts (leaf or stem) were determined based on the biotranslocation coefficient (BTC) using Eq. (2) following the modified formula by Cui et al. [41] and Li et al. [42]:

$$\textit{Biotranslocation coefficient}\ (BTC) = \frac{\text{Cleaf}/\text{Cstem}}{\text{Croot}} \tag{2}$$

where C_{leaf} and C_{stem} are the heavy metal concentrations in the leaf and stem, respectively and C_{root} is the heavy metal concentrations in the root part of the plant.

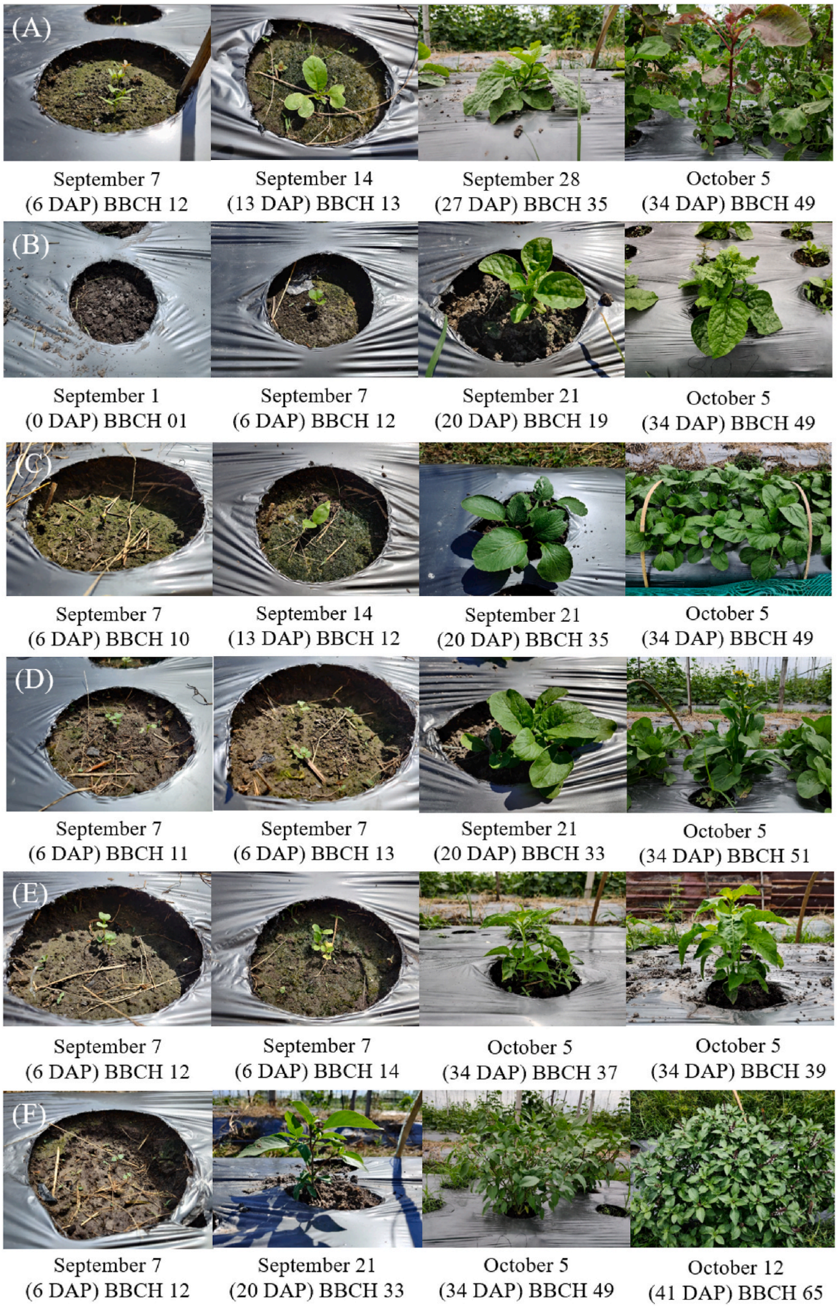
2.5. *Statistical analysis*

All statistical analyses were performed using SPSS software [43]. The significant differences in mean heavy metal contents in different plant parts (leaf, stem, and root) of each of the six vegetables were analyzed using one-way analysis of variance (ANOVA) and TukeyHSD tests at 5% significance level. Prior to ANOVA, the datasets were checked for normality and homogeneity of variance using Shapiro-Wilk normality tests and Levene's tests, respectively. The heavy metal concentrations in all vegetables were used to derive the principal component analysis (PCA) of metal elements across the three different plant parts using the SPSS software.

3. Results and discussions

3.1. *Heavy metals in soils and vegetables*

The heavy metal concentrations in the pre-harvest agricultural soils are presented in Table 3. The soils were found to contain the highest amount of Fe (360 mg/kg), followed by Al (221 mg/kg). Similar to the findings reported by Zunaidi et al. [25], Fe and Al concentrations in the agricultural soils of Brunei were also the highest amongst other metals at 251 mg/kg and 215 mg/kg, respectively. Cd is a non-essential heavy metal and has the lowest concentration (0.05 mg/kg) among other non-essential heavy metals, such as Cr (0.58 mg/kg) and Pb (2.60 mg/kg). Based on the soil quality guidelines published by the World Health Organization (WHO) [44], the USEPA [45], and the Canadian Council of Ministers of the Environment (CCME) [46], the concentrations of Cd, Cr, and Pb were



September 7 (6 DAP) BBCH 12
September 14 (13 DAP) BBCH 13
September 28 (27 DAP) BBCH 35
October 5 (34 DAP) BBCH 49

September 1 (0 DAP) BBCH 01
September 7 (6 DAP) BBCH 12
September 21 (20 DAP) BBCH 19
October 5 (34 DAP) BBCH 49

September 7 (6 DAP) BBCH 10
September 14 (13 DAP) BBCH 12
September 21 (20 DAP) BBCH 35
October 5 (34 DAP) BBCH 49

September 7 (6 DAP) BBCH 11
September 7 (6 DAP) BBCH 13
September 21 (20 DAP) BBCH 33
October 5 (34 DAP) BBCH 51

September 7 (6 DAP) BBCH 12
September 7 (6 DAP) BBCH 14
October 5 (34 DAP) BBCH 37
October 5 (34 DAP) BBCH 39

September 7 (6 DAP) BBCH 12
September 21 (20 DAP) BBCH 33
October 5 (34 DAP) BBCH 49
October 12 (41 DAP) BBCH 65

Fig. 2. Phenological stages of: (A) Amaranthus viridis L., (B) Basella alba L., (C) Brassica chinensis var. Parachinensis, (D) Brassica rapa L., (E) Capsicum frutescens L., and (F) Ocimum tenuiflorum L. according to the BBCH scale [37]. Note: 01 (beginning of seed imbibition), 10 (cotyledons completely unfolded), 11 (first true leaf unfolded), 12 (second true leaf unfolded), 13 (third true leaf unfolded), 14 (fourth true leaf unfolded), 19 (9 or more true leaves unfolded), 33 (leaf rosette has reached 30% of the expected diameter), 35 (leaf rosette has reached 50% of the expected diameter), 39 (leaf rosette has reached 70% of the expected diameter), 49 (typical leaf mass reached), 51 (main inflorescence visible between uppermost leaves), 65 (full flowering: 50% of flowers open). DAP (days after planting) and BBCH (Biologische Bundesanstalt, Bundessortenamt and Chemical Industry).

below their safety limits. The beneficial and essential heavy metals such as Co and Cu, Mn, Ni, and Zn were found to be in the range of 0.10–77.8 mg/kg, but none of these metal elements exceed the standard soil quality guidelines.

The concentrations of heavy metals in different plant parts (leaf, stem, and root) of *A. viridis* L., *B. alba* L., *B. chinensis*, *B. rapa* L., *C. frutescens* L., and *O. tenuiflorum* L. are shown in Table 4. Although Al concentration was one of the highest in the soils (Table 3), each vegetable species showed similar trend in Al accumulation in which Al tends to significantly accumulate in the root part (36.2–357.0

Table 2

Operational ICP-OES parameters, limit of detection (LOD), limit of quantification (LOQ), and validation of the USEPA acid extraction method using CRM IAEA-359.

ICP-OES parameters	Elements						
	Cr	Fe	K	Mg	Mn	Na	Zn
Wavelength (nm)	284	372	404	280	403	590	481
LOD (μg/L)	2.00	12.0	1.00	2.00	0.50	1.00	9.00
LOQ (μg/L)	6.00	38.0	2.00	7.00	1.00	3.00	31.0
R^2 value	1.00	1.00	0.99	1.00	1.00	1.00	1.00
Certified value (mg/kg)	1.30	148	32500	2160	31.9	580	38.6
Experimental value (mg/kg)	1.60 ± 0.50	145 ± 2.90	27881 ± 1173	1620 ± 85.0	36.8 ± 1.30	658 ± 47.1	37.2 ± 4.50
% Recovery	119 ± 37.3	97.8 ± 2.00	85.8 ± 0.04	75.0 ± 4.00	115 ± 4.10	113.4 ± 9.80	96.3 ± 11.7

Table 3

Heavy metal concentrations (mean ± standard deviation, SD) in pre-harvest agricultural soils. The agricultural soil quality guidelines from the World Health Organization [44], United States Environmental Protection Agency [45], and Canadian Council of Ministers of the Environment [46] are presented.

Heavy metals (mg/kg)	Agricultural soil	Soil quality guidelines		
	(n = 30)	WHO [44]	USEPA [45]	CCME [46]
Al	221.2 ± 83.1	NA	NA	NA
Cd	0.05 ± 0.04	NA	3.00	1.40
Co	0.10 ± 0.02	NA	NA	40.0
Cr	0.58 ± 0.30	100	150	64.0
Cu	4.95 ± 0.55	30.0	140	63.0
Fe	360 ± 110	NA	NA	NA
Mn	77.8 ± 7.60	NA	NA	NA
Ni	0.33 ± 0.11	NA	75.0	45.0
Pb	2.60 ± 1.60	NA	300	70.0
Zn	10.6 ± 2.40	200	NA	250

NA – Not available.

Table 4

(A) Heavy metal concentrations (mean ± standard deviation, SD) in different plant parts (leaf, stem, and root) of *Amaranthus viridis* L., *Basella alba* L., and *Brassica chinensis* var. *Parachinensis*. Different letters per heavy metal (row) represent significantly different means for the different parts (leaf, stem, and root) for each species after analyzing using one-way ANOVA and TukeyHSD tests at 5% significance level.

Heavy metals (mg/kg)	*A. viridis* L. (Amaranth)			*B. alba* L. (Chan choy)			*B. chinensis* (Choy sum)		
	Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root
Al	16.8 ± 1.63^{b}	4.60 ± 0.04^{a}	36.2 ± 1.81^{c}	33.5 ± 2.70^{a}	36.9 ± 8.97^{a}	282 ± 28.9^{b}	18.2 ± 1.17^{a}	4.81 ± 0.38^{a}	220 ± 22.2^{b}
Cd	0.16 ± 0.06^{a}	0.08 ± 0.01^{a}	0.10 ± 0.01^{a}	0.14 ± 0.06^{a}	0.08 ± 0.06^{a}	0.11 ± 0.01^{a}	0.15 ± 0.01^{a}	0.12 ± 0.02^{a}	0.12 ± 0.03^{a}
Co	0.44 ± 0.04^{b}	0.36 ± 0.03^{ab}	0.23 ± 0.02^{a}	0.47 ± 0.01^{b}	0.27 ± 0.06^{a}	0.50 ± 0.01^{b}	0.46 ± 0.01^{a}	0.34 ± 0.01^{a}	0.41 ± 0.06^{a}
Cr	0.52 ± 0.02^{a}	0.50 ± 0.06^{a}	0.41 ± 0.05^{a}	0.43 ± 0.01^{a}	0.51 ± 0.01^{a}	1.68 ± 0.44^{b}	0.47 ± 0.06^{a}	0.41 ± 0.03^{a}	0.66 ± 0.15^{a}
Cu	2.07 ± 0.03^{b}	0.35 ± 0.11^{a}	2.46 ± 0.12^{b}	1.90 ± 0.07^{a}	2.21 ± 0.31^{a}	4.96 ± 0.21^{b}	2.99 ± 0.01^{ab}	1.54 ± 0.28^{a}	7.50 ± 2.02^{b}
Fe	34.7 ± 2.67^{b}	17.3 ± 1.42^{a}	28.6 ± 1.16^{b}	43.0 ± 5.63^{a}	36.7 ± 13.32^{a}	22.1 ± 0.10^{b}	42.8 ± 7.94^{a}	18.9 ± 2.45^{a}	152 ± 29.7^{b}
Mn	47.8 ± 6.09^{b}	12.6 ± 0.34^{a}	12.7 ± 0.06^{a}	36.0 ± 0.72^{b}	18.1 ± 3.47^{a}	18.3 ± 2.12^{a}	29.1 ± 3.60^{b}	11.3 ± 0.34^{a}	18.6 ± 1.18^{a}
Ni	0.40 ± 0.19^{a}	0.30 ± 0.01^{a}	0.49 ± 0.16^{a}	0.49 ± 0.01^{a}	0.38 ± 0.28^{a}	1.03 ± 0.14^{a}	0.49 ± 0.04^{a}	0.36 ± 0.08^{a}	0.93 ± 0.39^{a}
Pb	1.28 ± 0.36^{a}	1.27 ± 0.01^{a}	0.73 ± 0.15^{a}	1.63 ± 0.01^{a}	0.86 ± 0.55^{a}	2.21 ± 0.25^{a}	1.57 ± 0.09^{a}	1.29 ± 0.13^{a}	1.28 ± 0.37^{a}
Zn	26.8 ± 5.29^{a}	19.6 ± 0.48^{a}	11.5 ± 3.95^{a}	19.0 ± 1.05^{a}	24.1 ± 0.71^{a}	58.4 ± 1.74^{b}	38.1 ± 3.72^{b}	19.8 ± 5.43^{ab}	12.7 ± 4.57^{a}

The agricultural crops quality guideline (dry weight) based on the Food and Agriculture Organization and the World Health Organization [52] are: Cd (0.01 mg/kg), Co (50.0 mg/kg), Cr (0.10 mg/kg), Cu (73.0 mg/kg), Fe (425 mg/kg), Mn (500 mg/kg), Ni (67.0 mg/kg), Pb (0.30 mg/kg), Zn (100 mg/kg).

mg/kg) of all vegetables compared to their stem and leaf parts (0.22–46.2 mg/kg). *B. rapa* L. contained the highest total Al concentration in all plant parts among the other vegetables. Among the six species analyzed, *O. tenuiflorum* L. accumulated the least amount of Al. A study by Panda et al. [47] suggested that Al phytotoxicity mainly occur in the root tips, which usually affects cell division and elongation of plant root, resulting in root growth retardation associated with reduced water and nutrient uptake to the aboveground parts. Even if the plants take up Al, it has no specific biological functions in plants, except promotion of growth and nutrient uptake, and increasing tolerance and resistance to biotic stress in Al accumulators that are well adapted in acid soils [48]. Al can form a complex with organic acids and phosphate ions upon early entry into the cell cytoplasm, and then sequester in the vacuoles, causing minimal damage to other cytoplasmic organelles [49].

Despite Fe being the most abundant element in soils, only the roots of *B. chinensis, B. rapa* L. and *C. frutescens* L. had significantly higher Fe content (153 mg/kg, 63.0 mg/kg and 129 mg/kg, respectively) than the shoot (leaf and stem) component (18.9–42.8 mg/kg). In addition, Fe levels were found to be significantly higher in the leaf and stem parts for *B. alba* L., and leaf and root parts for *A. viridis* L. than root and stem, respectively. However, there was no significant differences in Fe content in plant parts for *B. chinensis* and *O. tenuiflorum* L.. In addition to being an essential element for photosynthesis and chlorophyll biosynthesis, Fe also serves as a cofactor for numerous enzymes that are essential for respiration, DNA biosynthesis and nitrogen metabolism [50]. However, if Fe level is in excess in plants, Zahra et al. [51] reported that it can affect plant growth and development, enzyme metabolic activities, respiratory and photosynthetic efficiencies, and cause oxidative stress through the production of free-catalyzed reactive oxygen species (ROS).

The non-essential heavy metals such as Cd, Cr, and Pb exhibited concentration levels above the safety limits set up by the [52] at 0.01 mg/kg, 0.10 mg/kg, and 0.30 mg/kg, respectively, with *B. rapa* L. accumulating the most Cd (0.40 mg/kg) and Pb (5.71 mg/kg), and *B. alba* L. accumulating the most Cr concentration (2.62 mg/kg) in all plant parts in total (Table 4). Among the six vegetable species, the highest Cd (0.30 mg/kg), Cr (1.00 mg/kg), and Pb (2.90 mg/kg) concentrations were observed in the edible parts (leaf and stem) of *B. rapa* L., *A. viridis* L. and *B. chinensis*, respectively, and these values were 3–10 times much greater than the safety limits [52]. Similar results were reported by Ngweme et al. [53] with *A. viridis* L. accumulating over 1.00 mg/kg of Cr in the aerial parts of the plant. Moreover, statistical analysis showed that Cd contents were not significantly different across the different plant parts (leaf, stem, and root) in all species. Cd, Cr, particularly Cr(VI), and Pb are highly mobile in soil-plant system but some plants can manage the toxic effects of these heavy metals by performing intracellular detoxification through cell wall binding and chelation, and vacuolar sequestration in plant cells [54–57]. All vegetables also did not show significant differences in Cr and Pb contents among plant parts, except for Cr in *B. alba* L. and Pb in *B. rapa* L., which were the highest in the root parts than in edible parts (leaf and stem) (Table 4).

Beneficial heavy metal contents (Co, Cu, Mn, and Ni) vary in their concentrations in the plant parts (Table 4). For example, Co contents in *A. viridis* L. and *B. alba* L. were significantly higher in the leaves than in other parts (stem and/or root), while for *C. frutescens* L., the Co level was significantly greater in the root compared to the leaf and stem parts. Moreover, there were no significant differences in Co contents in different plant parts in the other vegetables (*B. chinensis*, *B. rapa* L. and *O. tenuiflorum* L.). Studies by Lotfy et al. [58] and Akeel et al. [59] reported that the translocation, distribution and storage of Co in different plant parts is possibly species-specific, which was similarly shown in this study. Co is considered beneficial for some species in promoting nutrient uptake, increasing nodulation and enhancing nitrogen fixation in legumes [60].

Cu, Mn, and Ni contents were also noted to be significantly greater in the roots compared to both leaf and stem parts of *B. alba* L. and *B. chinensis* (Cu), *B. rapa* L. (Ni), and *C. frutescens* L. (Cu, Mn, and Ni) (Table 4). Cu concentrations in the roots of *B. alba* L. reported in this study (4.96 mg/kg) were consistent with that of Chandra and Kumar [61] where Cu accumulated up to 4.28 mg/kg in *B. alba* L., despite the Cu contents in the roots were 2–3 times much lower than *B. chinensis*, *B. rapa* L. and *C. frutescens* L. roots. The leaves and roots of *A. viridis* L. and *C. frutescens* L. had significantly higher Cu than in stem. Moreover, there were no significant differences in Cu contents in various plant parts in *B. rapa* L. and *O. tenuiflorum* L.. Cu is an essential metal in a number of physiological processes in plants, particularly in the leaves due to its capability to exist in multiple oxidation states in plants [62]. Additionally, for Ni, none of the vegetables had significantly greater Ni in the leaves or stems than the roots. A study by Gupta et al. [63] showed that Ni tends to be accumulated and translocated evenly between the root and shoot parts of plants. Ni is able to exist in several oxidation states but Ni^{2+} was found to be the most stable form which is highly mobile and thus can be easily transported to different plant parts [1].

(B) Heavy metal concentrations (mean ± standard deviation, SD) in different plant parts (leaf, stem, and root) of *Brassica rapa* L., *Capsicum frutescens* L., and *Ocimum tenuiflorum* L. Different letters per heavy metal (row) represent significantly different means for the different parts (leaf, stem, and root) for each species after analyzing using one-way ANOVA and TukeyHSD tests at 5% significance level.

Heavy metals (mg/kg)	*B. rapa* L. (Pak-choi)			*C. frutescens* L. (Chilli)			*O. tenuiflorum* L. (Basil)		
	Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root
Al	46.2 ± 8.23^a	24.2 ± 6.07^a	357 ± 33.2^b	40.5 ± 2.68^b	12.9 ± 1.68^a	246 ± 35.6^c	6.09 ± 0.97^a	0.22 ± 0.27^a	51.9 ± 11.0^b
Cd	0.12 ± 0.03^a	0.19 ± 0.16^a	0.09 ± 0.04^a	0.10 ± 0.01^a	0.09 ± 0.01^a	0.16 ± 0.07^a	0.12 ± 0.04^a	0.06 ± 0.01^a	0.06 ± 0.02^a
Co	0.42 ± 0.04^a	0.29 ± 0.03^a	0.62 ± 0.23^a	0.38 ± 0.01^{ab}	0.28 ± 0.01^a	0.58 ± 0.01^b	0.47 ± 0.01^a	0.20 ± 0.04^a	0.29 ± 0.06^a
Cr	0.38 ± 0.02^a	0.43 ± 0.05^a	0.50 ± 0.30^a	0.38 ± 0.05^a	0.34 ± 0.04^a	0.93 ± 0.29^a	0.24 ± 0.09^a	0.29 ± 0.05^a	0.57 ± 0.23^a
Cu									

(*continued on next page*)

(*continued*)

Heavy metals (mg/kg)	*B. rapa* L. (Pak-choi)			*C. frutescens* L. (Chilli)			*O. tenuiflorum* L. (Basil)		
	Leaf	Stem	Root	Leaf	Stem	Root	Leaf	Stem	Root
	2.56 ± 0.25^{a}	1.45 ± 0.17^{a}	6.85 ± 0.79^{b}	2.57 ± 0.01^{a}	1.16 ± 0.06^{a}	14.0 ± 1.46^{b}	2.40 ± 0.02^{a}	1.08 ± 0.08^{a}	2.13 ± 1.27^{a}
Fe	38.3 ± 1.30^{b}	24.0 ± 3.79^{a}	63.0 ± 11.8^{c}	41.8 ± 0.97^{a}	20.5 ± 1.41^{a}	129 ± 10.4^{b}	47.0 ± 11.0^{b}	16.0 ± 1.92^{a}	8.08 ± 0.26^{a}
Mn	36.4 ± 0.48^{a}	16.5 ± 1.81^{a}	33.7 ± 21.7^{a}	31.3 ± 4.04^{b}	15.0 ± 0.26^{a}	46.9 ± 0.76^{c}	22.9 ± 1.14^{b}	7.45 ± 0.63^{a}	5.41 ± 1.95^{a}
Ni	0.41 ± 0.06^{a}	0.38 ± 0.08^{a}	1.67 ± 0.13^{b}	0.34 ± 0.06^{a}	0.30 ± 0.02^{a}	1.28 ± 0.17^{b}	0.41 ± 0.15^{a}	0.14 ± 0.03^{a}	1.30 ± 1.00^{a}
Pb	1.38 ± 0.02^{ab}	1.00 ± 0.14^{a}	3.33 ± 0.86^{b}	1.01 ± 0.13^{a}	1.08 ± 0.09^{a}	1.99 ± 0.61^{a}	1.42 ± 0.34^{a}	0.50 ± 0.01^{a}	1.84 ± 0.76^{a}
Zn	43.0 ± 1.33^{a}	26.9 ± 1.05^{a}	27.4 ± 13.7^{a}	28.4 ± 4.43^{a}	16.1 ± 4.32^{a}	19.0 ± 0.81^{a}	35.6 ± 11.4^{a}	9.45 ± 3.86^{a}	16.4 ± 5.81^{a}

The agricultural crops quality guideline (dry weight) based on the Food and Agriculture Organization and the World Health Organization [52] are: Cd (0.01 mg/kg), Co (50.0 mg/kg), Cr (0.10 mg/kg), Cu (73.0 mg/kg), Fe (425 mg/kg), Mn (500 mg/kg), Ni (67.0 mg/kg), Pb (0.30 mg/kg), Zn (100 mg/kg).

Mn content in *B. rapa* L. was not significantly different among plant parts (Table 4). However, Mn content was significantly higher in *A. viridis* L., *B. alba* L., *B. chinensis*, and *O. tenuiflorum* L. leaves than in both stems and roots. For *C. frutescens* L., Mn was highly concentrated in the roots, followed by leaf and stem parts. Concentrations of Mn are greater in the shoots of plants due to Mn being easily mobilized from the root parts to the shoots of plants [64]. Mn^{2+} is the most stable state and is the most soluble in soil systems thus can easily be accumulated in plant parts [65]. Mn tends to be accumulated more in the leaf part of plants as it is a cofactor in

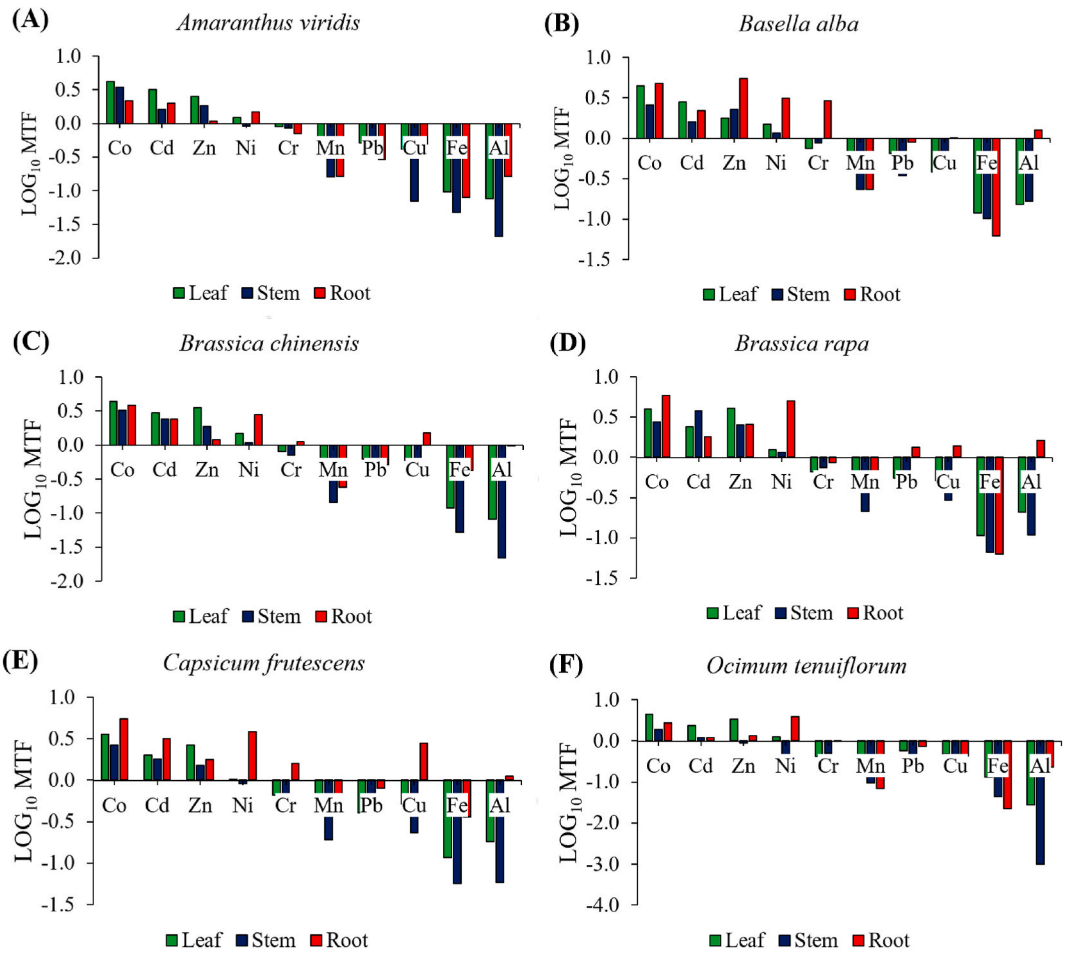


Fig. 3. Metal transfer factor or MTF ($\log_{10}$) of heavy metal elements from agricultural soils to different parts (leaf, stem, and root) of the following vegetables: (A) Amaranthus viridis L., (B) Basella alba L., (C) Brassica chinensis var. Parachinensis, (D) Brassica rapa L., (E) Capsicum frutescens L., and (F) Ocimum tenuiflorum L.

photosynthesis and chlorophyll production [65,66]. Simultaneously, *A. viridis* L., *B. rapa* L., *C. frutescens* L. and *O. tenuiflorum* L. revealed no significant differences in Zn content among the plant parts (Table 4). Zn was only significantly higher in *B. alba* L. roots and *B. chinensis* leaves compared to their respective plant parts. Similarly, a study by Chandra and Kumar [61] reported that *B. alba* L. was among the highest accumulator of Zn among fifteen other plant species in their studies. Generally, Zn tends to be accumulated in the root part than other plant parts as an indirect way to protect the aerial parts from photosynthetic defects due to toxicity [67]. However, accumulation of Zn in other plant parts have been observed in different plant species which could demonstrate Zn tolerance in those plants.

3.2. Metal transfer factors, biotranslocation coefficient, and principal component analysis

The migration pathway of heavy metals from the agricultural soils to the respective plant parts (leaf, stem, and root) was determined using the metal transfer factor (MTF – Eq. (1)). The results reported that all vegetables followed a similar pattern of MTF sequence with Co, Cd, Zn, and Ni shown to hyperaccumulate in all plant parts (MTF >1), with the exceptions of Zn in the roots of *A. viridis* L. and stems of *O. tenuiflorum* L., and Ni in the stems of *A. viridis* L., *C. frutescens* L. and *O. tenuiflorum* L. (Fig. 3).

Al, Cr, and Cu were observed to hyperaccumulate in the roots of *B. alba* L. (Al, Cr, Cu), *B. chinensis* (Cr, Cu), *B. rapa* L. (Al, Cu), and *C. frutescens* L. (Al, Cu). However, for Pb, the MTF >1 was revealed only in the roots of *B. rapa* L.. Non-essential heavy metals such as Al and Cr have no biological or physiological functions in plants and thus tend to only accumulate in the root part of plants [68]. On the other hand, other non-essential heavy metals such as Cd and Pb showed signs of hyperaccumulation for Cd where the amounts accumulated in the plant parts of each species were higher than the amounts in the soils (Tables 3 and 4), while Pb only hyperaccumulated in the root part of *B. rapa* L. (Fig. 3). Cd and Pb are generally present in divalent forms in soils and are usually present in water-soluble complexes where their mobility can be influenced by pH [69]. Thus, these heavy metals are easily mobilized into the roots of plants at low pH and with the soil of pH 5 (Table 1), Cd and Pb become more mobilized in the forms of $CdSO_4$ compounds, $CdCl^+$ and $CdHCO_3^+$ cations, and Pb^{2+}, respectively, which are water-soluble or mobile [70].

The biotranslocation coefficients (BTC) of individual heavy metals by each vegetable species are shown in Table 5 which shows the mobility of heavy metals between the different plant parts (root, stem, and leaf) after being accumulated from the soils through the root of the plants. A BTC >1 indicates high mobility of heavy metal from roots towards the stem and leaves, which suggests that heavy metal is readily translocated between the plant tissues and this is essential for effective phytoremediation of heavy metals [71]. Al and Ni had BTC ≤ 1 among all vegetable species, suggesting that Al and Ni are not easily mobilized throughout the plant parts (Table 5). Both *A. viridis* L. and *O. tenuiflorum* L. gave BTC^b values > 1 for almost all heavy metals analyzed, except for Al and Ni (both), Cr and Pb (*O. tenuiflorum* L.), and Cu (*A. viridis* L.). Together with the MTF values > 1 for Co, Cd, Zn, and Ni (Fig. 3), it can be implied that these two vegetables have high capacities to uptake high quantities of Co, Cd, and Zn, as well as Cr, Cu, Fe, Mn and Pb to a certain extent but not Al and Ni. BTC ≥ 1.0 was only observed in BTC^b for Cu in *O. tenuiflorum* L. which showed the high mobilization of Cu from the root part to the leaf part of the species compared to the other species. In addition, beneficial and essential heavy metals were discovered to present at the highest BTC values in *O. tenuiflorum* L. with Fe having the highest BTC^b value (5.82) from its root part to the leaf part, followed by Mn (4.23), Zn (2.44), Cd (2.00), Co (1.62) and Cu (1.13). BTC^a for *O. tenuiflorum* L. were observed for Cd, Fe and Mn. Meanwhile, for Cr, high BTC values (BTC^a and BTC$^{b)}$ were only observed in *A. viridis* L. for Cr, but not the other vegetables, which suggests that *A. viridis* L. readily mobilized Cr from its root part to the other plant parts. *B. chinensis* was also noted to have BTC values > 1 for Cd, Co, Mn, Pb, and Zn which showed that the aerial parts contained higher concentrations of these metals compared to its root part (Table 4). It was reported that *B. rapa* L. had the highest BTC^a value of 2.11 for Cd which suggested the mobility of Cd from the root part to the aerial parts (stem) was more efficient compared to the other vegetables in this study (Table 5). However, it is interesting to observe that *C. frutescens* L. only showed BTC >1 for Zn. This result suggests that *C. frutescens* L. has a low capacity to uptake heavy metals, thus this species can be a potential excluder of the heavy metals analyzed in this study. It could be that *C. frutescens* L. is a fruity vegetable, while the rests of the vegetables are leafy. A similar finding was also reported by Zhou et al. [22], in which the ability for

Table 5

Biotranslocation coefficient (BTC) of the heavy metals analyzed in Amaranthus viridis L., Basella alba L., Brassica chinensis var. Parachinensis, Brassica rapa L., Capsicum frutescens L., and Ocimum tenuiflorum L.

Metal elements	*A. viridis* L.		*B. alba* L.		*B. chinensis*		*B. rapa* L.		*C. frutescens* L.		*O. tenuiflorum* L.	
	BTC^a	BTC^b	BTC^a	BTC^b	BTC^a	BTC^b	BTC^a	BTC^b	BTC^a	BTC^b	BTC^a	BTC^b
Al	0.13	0.46	0.13	0.12	0.02	0.08	0.07	0.13	0.05	0.16	0.004	0.12
Cd	0.80	**1.60**	0.73	**1.27**	**1.00**	**1.25**	**2.11**	**1.33**	0.56	0.63	**1.00**	**2.00**
Co	**1.57**	**1.91**	0.54	0.94	0.83	**1.12**	0.47	0.68	0.48	0.66	0.69	**1.62**
Cr	**1.22**	**1.27**	0.30	0.26	0.62	0.71	0.86	0.76	0.37	0.41	0.51	0.42
Cu	0.14	0.84	0.45	0.38	0.21	0.40	0.21	0.37	0.08	0.18	0.51	**1.13**
Fe	0.61	**1.22**	**1.66**	**1.95**	0.12	0.28	**1.07**	**1.71**	0.16	0.32	**1.98**	**5.82**
Mn	0.99	**3.75**	0.99	**1.97**	0.61	**1.57**	0.49	**1.08**	0.32	0.67	**1.38**	**4.23**
Ni	0.61	0.82	0.37	0.48	0.39	0.53	0.23	0.25	0.23	0.27	0.11	0.32
Pb	**1.74**	**1.75**	0.39	0.74	**1.01**	**1.23**	0.30	0.41	0.54	0.51	0.27	0.77
Zn	**1.71**	**2.33**	0.41	0.33	**1.57**	**3.01**	0.98	**1.57**	0.85	**1.50**	0.65	**2.44**

BTC^a – Biotranslocation coefficient from the root part of the vegetables to the stem part of the vegetables; BTC^b – Biotranslocation coefficient from the root part of the vegetables to the leaf part of the vegetables. BTC values more than or equal to 1 are in bold.

heavy metal uptake and accumulation of leafy vegetables, such as edible amaranth (*Amaranthus tricolor* L.) were the highest compared to that of solanaceous vegetables, such as eggplant, red pepper, and tomato.

Principal component analysis (PCA) was performed for each of the six vegetables following Dimitrijević et al. [72], where PC components with eigenvalues >1.00 and loading coefficients ≥0.70 were taken into account. The first two components (PC1 and PC2) extracted for *A. viridis* L., *B. alba* L., *B. chinensis, B. rapa* L., *C. frutescens* L., and *O. tenuiflorum* L., explained 100%, 82.7%, 89.8%, 93.4%, 81.1% and 90.6% of the total variance, respectively (Table 6). The PCA loadings showed that a majority of heavy metals which are distributed in the different plant parts for all six species were correlated to each other and PC1, except for Cr and Cu (leaf and root), Fe (leaf and stem), Mn (all plant parts) and Ni (root) in *A. viridis* L., Co (leaf and root), Cr (stem), Ni and Pb (leaf) and Zn (stem and root) in *B. alba* L., Cd and Cu (leaf), Co (stem) and Zn (root) in *B. chinensis*, Cr (leaf) and Zn (stem) in *B. rapa* L., Co, Cr and Cu (leaf) in *C. frutescens* L. and Pb (stem) in *O. tenuiflorum* L., which were correlated to PC2 (Table 6). It was also reported that Al in leaf, stem and root, Cd in stem and root, Cu in stem, and Fe and Pb in root for all species were correlated to PC1.

In terms of PCA biplots, heavy metals in leaf, stem and root parts were partitioned differently for each vegetable species (Fig. 4). It seems that most heavy metals of the leaf and root parts were clustered together and positively correlated with PC2 for *A. viridis* L. (Fig. 4A). However, for *B. alba* L., majority of heavy metals of the leaf and root parts were partitioned from stem parts on PC1, thus were negatively correlated to PC1 (Fig. 4B). In addition, it was observed that most heavy metals in roots were clustered together and positively associated to PC1 in *B. chinensis*, *B. rapa* L. and *C. frutescens* L. (Fig. 4C–E), and negatively associated to PC1 in *O. tenuiflorum* L. (Fig. 4F). There seems to be a separate cluster for heavy metals in the leaf parts for *B. rapa* L. (negatively associated to PC1, Fig. 4D) and *O. tenuiflorum* L. (positively associated to PC1, Fig. 4E). Although bioavailable heavy metals are primarily stored in the root cells, they can still be transported to the aboveground part, such as leaves, due to the presence of metal chelating agents and metal transporters in plants, whereby they can be compartmentalized in inactive organelles and organs in plants, such as vacuoles, old and mature leaves, leaf sheaths, and leaf petioles [54].

Table 6

(A) Eigenvalues from principal component analysis (PCA) of 10 heavy metal elements across the different parts (leaf, stem, and root) of Amaranthus viridis L., Basella alba L., and Brassica chinensis var. Parachinensis, and percentage of the total variance and cumulative variance explained by each principal component (PC) axis. Loadings and signs of the correlation coefficient of each metal element for the first two PC axes for each species were presented. Variables with the highest loadings (≥0.70) were identified as significant variables and are in bold.

Variables	*A. viridis* L.		*B. alba* L.		*B. chinensis*	
	PCA1	PCA2	PCA1	PCA2	PCA1	PCA2
Al-leaf	**−.735**	.678	**−.995**		**.960**	
Cd-leaf	**.800**	.600	**.994**		.648	**−.736**
Co-leaf	**.928**		−.578	**.770**		−.555
Cr-leaf	−.449	**.894**		−.384	**−.821**	
Cu-leaf	.546	**.838**	**−.863**			**−.920**
Fe-leaf	−.631	**.776**	**−.991**		**−.994**	
Mn-leaf	−.435	**.900**	**.973**		**.997**	
Ni-leaf	**−.886**	.463		**.738**	**.846**	
Pb-leaf	**.999**			**.853**	**.781**	
Zn-leaf	**.951**		**−.402**		**−.951**	
Al-stem	**.870**	−.494	**.993**		**.985**	
Cd-stem	**−.964**		**.987**		**−.989**	
Co-stem	**−.999**		**.958**			**.852**
Cr-stem	**.960**			.496	.664	
Cu-stem	**−.892**	−.453	**.985**		**−.996**	
Fe-stem	−.671	**−.741**	**.995**		**−.971**	
Mn-stem	.536	**−.844**	**.982**		**−.956**	
Ni-stem	**.991**		**.995**		**−.989**	
Pb-stem	**.991**		**.981**		**−.866**	.410
Zn-stem	**.720**	−.694		.609	**.711**	.551
Al-root	**−.847**	−.532	**.998**		**.961**	
Cd-root	**.771**	.637	**−.893**		**−.961**	
Co-root	**.985**		−.472		**.937**	
Cr-root		**−.935**	**−.997**		**.939**	
Cu-root	.682	**−.731**	**−.947**		**.990**	
Fe-root	**.941**		**−.893**		**.992**	
Mn-root	.657	**.754**	**.991**		**.908**	.405
Ni-root		**.919**	**−.997**		**−.993**	
Pb-root	**−.956**		**−.974**		**−.958**	
Zn-root	**−.907**	.420		**−.943**		**.942**
Eigenvalue	19.5	10.5	20.8	4.05	22.3	4.67
Total variance explained (%)	65.1	34.9	69.2	13.5	74.3	15.6
Cumulative variance explained (%)	65.1	100	69.2	82.7	74.3	89.8

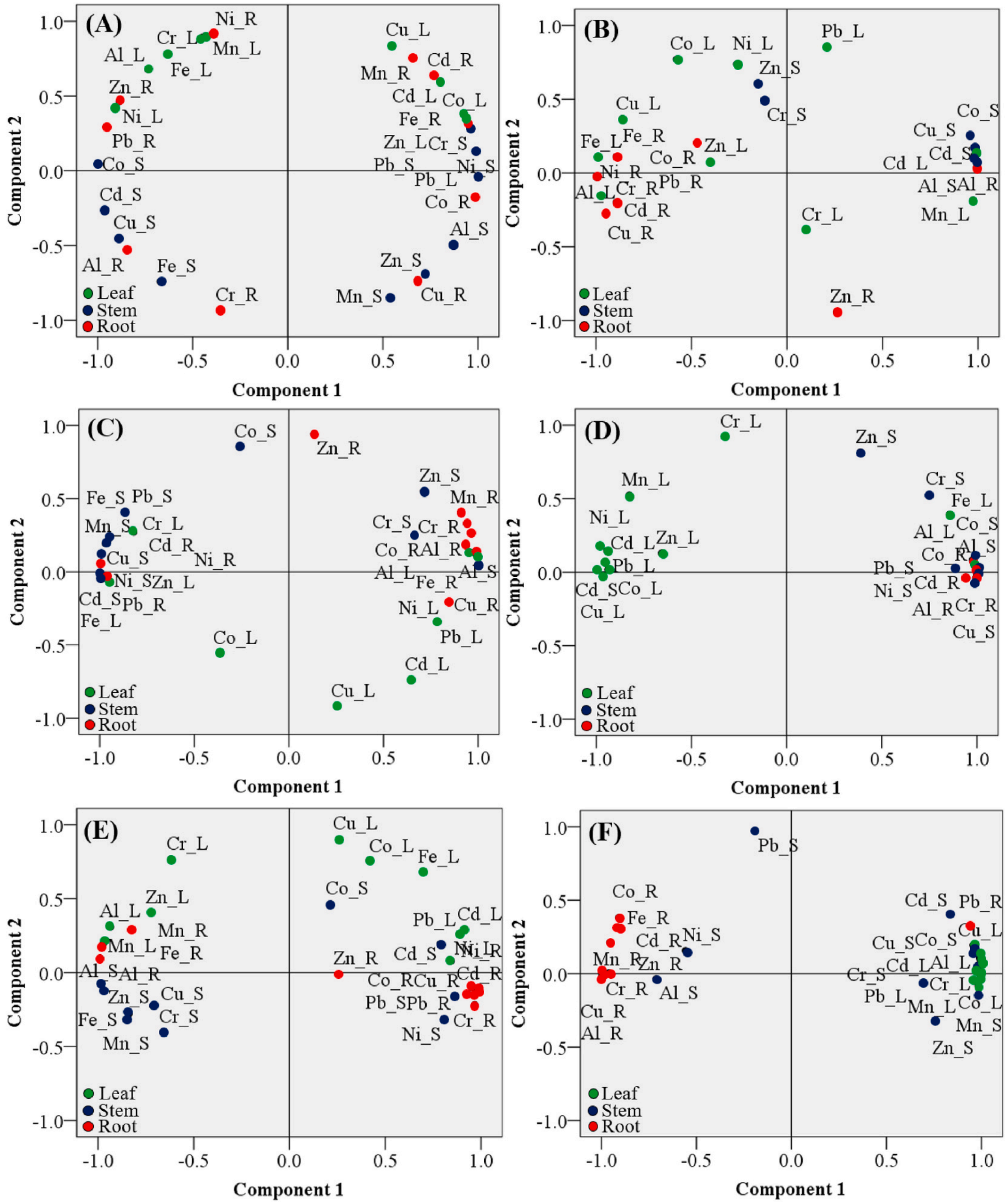


Fig. 4. Biplots of scores for principal component (PC) analysis axes 1 (component 1) and 2 (component 2) from principal component analysis (PCA) of 10 heavy metal elements across the different parts (leaf or L, stem or S, and root or R) of (A): Amaranthus viridis L., (B): Basella alba L., (C) Brassica chinensis var. Parachinensis, (D) Brassica rapa L., (E): Capsicum frutescens L., and (F) Ocimum tenuiflorum L.

(B) Eigenvalues from principal component analysis (PCA) of 10 heavy metal elements across the different parts (leaf, stem, and root) of *Brassica rapa* L., *Capsicum frutescens* L., and *Ocimum tenuiflorum* L., and percentage of the total variance and cumulative variance explained by each principal component (PC) axis. Loadings and signs of the correlation coefficient of each metal element for the first two PC axes for each species were presented. Variables with the highest loadings (≥0.70) were identified as significant variables and are in bold.

Variables	*B. rapa* L.		*C. frutescens* L.		*O. tenuiflorum* L.	
	PCA1	PCA2	PCA1	PCA2	PCA1	PCA2
Al-leaf	**.998**		**−.934**		**.968**	
Cd-leaf	**−.957**		**.912**		**.981**	
Co-leaf	**−.939**		.416	**.759**	**.982**	

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Variables	*B. rapa* L.		*C. frutescens* L.		*O. tenuiflorum* L.	
	PCA1	PCA2	PCA1	PCA2	PCA1	PCA2
Cr-leaf		**.922**	−.620	**.768**	**.990**	
Cu-leaf	**−.965**			**.898**	**.994**	
Fe-leaf	**.854**		.694	.681	**.998**	
Mn-leaf	**−.827**	.524	**−.972**		**.994**	
Ni-leaf	**−.980**		**.843**		**.991**	
Pb-leaf	**−.945**		**.888**		**.962**	
Zn-leaf	−.657		**−.722**	.407	**.984**	
Al-stem	**.997**		**−.985**		**−.712**	
Cd-stem	**−.999**		**.787**		**.836**	.404
Co-stem	**.976**			.465	**.956**	
Cr-stem	**.747**	.527	−.662	−.402	.693	
Cu-stem	**.985**		**−.712**		**.960**	
Fe-stem	**.984**		**−.969**		**.968**	
Mn-stem	**.986**		**−.853**		**.981**	
Ni-stem	**.938**		**.808**		−.558	
Pb-stem	**.884**		**.863**			**.971**
Zn-stem		**.817**	**−.839**		**.759**	
Al-root	**.998**		**−.988**		**−.999**	
Cd-root	**.995**		**.981**		**−.955**	
Co-root	**.999**		**.931**		**−.907**	
Cr-root	**.992**		**.967**		**−.995**	
Cu-root	**.999**		**.978**		**−.999**	
Fe-root	**.999**		**−.981**		**−.911**	
Mn-root	**.998**		**−.828**		**−.999**	
Ni-root	**.988**		**.950**		**.983**	
Pb-root	**.998**		**.969**		**.939**	
Zn-root	**.997**		.260		**−.961**	
Eigenvalue	25.7	2.35	20.4	3.94	25.4	1.82
Total variance explained (%)	85.6	7.82	67.9	13.1	84.5	6.06
Cumulative variance explained (%)	85.6	93.4	67.9	81.1	84.5	90.6

4. Conclusion

Based on the analyzed heavy metal contents in the agricultural soils used to grow the six species (*Amaranthus viridis* L., *Basella alba* L., *Brassica chinensis*, *Brassica rapa* L., *Capsicum frutescens* L., and *Ocimum tenuiflorum* L.) in this study, the soils did not contain heavy metals above the safety limit set by the CCME, USEPA and WHO guidelines. Overall, Co, Cu, Fe, Mn and Zn were mostly accumulated in *A. viridis* L. (Co, Cu, Fe and Mn), *B. alba* L. (Co, Fe and Mn), *B. chinensis* (Mn and Zn), *O. tenuiflorum* L. (Mn) Leaves and *C. frutescens* L. (Co, Cu, Fe and Mn), *B. alba* L. (Co, Cu and Zn), *A. viridis* L. and *B. chinensis* (Cu and Fe) and *B. rapa* L. (Fe) Roots. Cr, Pb and Ni were found to be significantly greater in roots of *B. alba* L. (Cr) And *B. rapa* L. (Ni and Pb). All the six vegetables showed hyperaccumulation of Co, Cd, Zn, and Ni in the same MTF pattern. MTF >1 for Cr was only observed in *B. alba* L., *B. chinensis*, and *C. frutescens* L., while *B. rapa* L. was a hyperaccumulator of Pb. On the other hand, only *B. rapa* L. and *C. frutescens* L. were observed to hyperaccumulate Cu amongst other species. High BTC values were observed for most heavy metals only in *A. viridis* L. and *O. tenuiflorum* L., which showed high uptake potential for the heavy metals, with *C. frutescens* L. having the lowest uptake capacity of heavy metals amongst the species. *A. viridis* L. seem to have the greatest phytoextraction potential of Co, Cd, and Zn among the other vegetables. PCA biplots revealed that heavy metals in leaf, stem and root parts were partitioned differently for each vegetable species, with most metals were positively or negatively associated to PC1. Therefore, monitoring heavy metals in plants for their phytoextraction potential from soils can be a cheaper and green alternative for removing heavy metal contaminants in soils as the accumulation of heavy metals has been shown to be species-specific.

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