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Heavy metals accumulation and distribution pattern in different vegetable crops

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Different vegetable crops grown on heavy metal contaminated soil showed marked difference in metal accumulation, their uptake and distribution pattern. Crop species also showed remarkable difference in metal concentration of various plant parts. Based on metal accumulation in edible parts and whole plants, root vegetables namely, radish and carrot registered lower accumulation of almost all heavy metals except Zn in radish root. However, leafy vegetables namely, spinach, amaranthus, mustard and fenugreek recorded higher accumulation of both essential and non-essential heavy metals, except Cd and Ni which showed less accumulation in fenugreek. Potato and onion showed lower accumulation of Zn and Cu and higher accumulation of Cd and Ni. Cauliflower and cabbage, however, showed greater accumulation of Pb and Ni, but less accumulation of Cu and Cd. Among fruit type vegetables, pea, soybean and cluster bean showed greater accumulation of Pb and Ni and very less accumulation of Cd. Among different vegetables cauliflower and cabbage recorded highest uptake of Zn, Pb and Ni, while mustard showed higher uptake of Zn and Cd. In general the uptake of Cd was lowest in almost all the crops except mustard. Generally the root and leafy vegetables namely. radish, carrot, spinach, amaranthus, mustard, cauliflower and cabbage showed higher distribution of metals to the edible parts, whereas fruit types vegetables specially tomato and brinjal exhibited least transport of metals to fruits except leguminous fruit vegetables pea and soybean. Leafy vegetables namely, spinach, amaranthus and mustard seemed to be unsafe and not suitable for cultivation on heavy metal contaminated soil. Most of the fruit type vegetables could be suggested for cultivation on Cd contained soil but not for Ni and Pb contained soil.

Key words: Heavy metals, accumulation, distribution, uptake.

INTRODUCTION

Due to rapid urbanization the demand for food crops is rising day by day, and as the vegetables can be grown in small fields with intensive use of inputs within shorter period, its cultivation is gaining popularity and fetching profitability in peri-urban areas of mega cities. This is a matter of serious concern as vegetables particularly leafy once, being prolific accumulators of heavy metals provide an easy entry into food chain to these dreaded metals. The excessive intake of these elements from the soil creates dual problems; first the harvested crops get contaminated, which serve as a source of heavy metal in our diet, and secondly the crop yield decline due to the inhibition of metabolic processes (Sanders et al., 1987; Singh and Aggarwal, 2006). Increasingly higher quantities of heavy metals are being released into the environment through various anthropogenic activities such as smelting industries, sewage sludge, municipal solid wastes, burning of fossil fuel, pesticides etc. (Sheila, 1994, Rattan et al., 2002). Zinc, copper, iron, manganese, lead and cadmium contents in soils receiving sewage sludge accumulated mostly in the top 0 to 15 cm layers. Heavy metals occur in the soil both in soluble and combined forms. However, only soluble exchangeable and chelated metal species in the soils are mobile and hence available to the plants (Mc Bride, 1981; Miller et al., 1986; Singh and Kumar, 2006). Vegetable crop plants have high ability to accumulate metals from the

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environment, which may pose risks to human health when they are grown on or near contaminates lands and consumed. Metal accumulation in plant depends on plant species, growth stages, types of soil and metals, soil conditions, weather and environment (Asami, 1981; Chang et al., 1984; Khairiah et al., 2004). Thus accumulation of heavy metals in the edible parts of vegetables represents a direct pathway for their incorporation into the human food chain (Florijin, 1993). The health risk will depend upon the chemical composition of the waste material, its physical characteristics, types of vegetables cultivated and the consumption rate (Cobb et al., 2000).

Keeping in view the significance of metal contaminated fertile land in the peri-urban areas, and their judicious utilization for agricultural purposes, the present study was undertaken to examine the crop species differences in heavy metal accumulation and distribution in various edible and non-edible plant parts and to suggest the cultivation of different vegetable crops in soil contaminated with different heavy metals based on their accumulation in edible plant part.

MATERIALS AND METHODS

Experimental set up and crop management

A field trial was conducted at the Research Farm, Indian Agricultural Research Institute during *Rabi* season of 2005 to 2006. To examine the magnitude of heavy metal accumulation and their distribution in various edible and non-edible plant parts, sixteen different vegetable crops comprising of root vegetables (radish and carrot), tuber and bulb vegetables (Potato and Onion), leafy vegetables (Spinach, Amaranthus, Fenugreek, Mustard and Cabbage), fruit vegetables (Okra, Brinjal, Tomato, Soyabean, Pea and Cluster bean) and others (Cauliflower) were grown in the field pre-contaminated with heavy metals namely Cu, Zn, Pb, Cd and Ni @20kg/ha metal equivalent by incorporating their salts into the soils. The seeds and seedlings of different vegetable crops were procured from reliable sources and were sown/planted in the field at recommended spacing of different crops with three replications each around twenty days after the amendment of soil with heavy metals. The experiment was conducted in simple Randomized Block Design.

Plant sampling and heavy metal analysis

The various plant parts of fresh samples of vegetable crops (including edible and non-edible) were separated and weighed for metal analysis. Half of the samples were oven dried as such and rest half were oven dried after thorough washing with tap water in order to determine the contribution of heavy metal contamination through aerial deposition. The chemical analysis of heavy metal in the vegetable samples involved two main processes that is, (1) acid or wet digestion of samples during which the organic chemical integrity of the plant tissues are disintegrated into inorganic and molecular forms, which is essential for the estimation of metal elements in plant samples and (2) estimation of metals in the acid digested samples. The heavy metal content was determined with the help of Atomic Absorption Spectrophotometer (Singh et al., 1999). The statistical analysis was taken up to see the critical difference between the treatments using SPSS (Statistical Package for Social Sciences).

RESULTS AND DISCUSSION

The accumulation of metals has been described as their content or concentration in different parts on the basis of their amount per unit dry weight of tissues (µg/g dry weight).

Metal accumulation in different plant parts of vegetable crops

When considered the zinc concentration in various plant parts of vegetable crops, the leaves contained maximum zinc followed by roots, stem and fruits. Average accumulation recorded in leaf, root, stem and fruit were 68, 62, 60 and 53 µg/g, respectively. Among the crops and various plant parts, tomato stem showed the highest Zn accumulation (115 µg/g dry weight) followed by leaf and root of Brinjal (112 and 108 µg/g dry weight respectively) and potato leaves (106 µg/g dry weight). Roots of soybean, okra and carrot showed the lowest amount of zinc accumulation (21, 23 and 28 µg/g dry weight respectively) (Table 1).

Among the various plant parts, roots showed highest accumulation of copper followed by stem, leaf and fruits. When considered all parts of different crops, root of fenugreek and stem of soybean showed its highest concentration that is 115 and 101 µg/g dry weight respectively. The lowest accumulations were recorded in cauliflower stem (10 µg/g dry weight), cabbage head (11 µg/g dry weight) and leaf (12 µg/g dry weight). Among the crops, potato, fenugreek, cauliflower and soybean recorded greater accumulation as compared to other crops (Table 1).

Regarding lead accumulation in different vegetables and their different plant parts, average content of lead was recorded highest in crop leaves followed by stem, roots and fruits. Leaves of Brinjal and potato showed highest content of lead accumulation (87 and 74 µg/g dry weight respectively), whereas fruit of Brinjal and root of radish recorded its lowest concentration (2 and 3 µg/g dry weight respectively) (Table 1).

Cadmium was found to be accumulated more in the roots of potato and onion (44 and 35 µg/g dry weight) followed by stem and leaves of potato, spinach roots and leaves, amaranthus leaves, fenugreek roots, and mustard leaves, while cluster bean, peas, carrot and soybean crops registered its lower accumulation. On an average Cd content was found highest in roots, followed by leaves, stem and fruits of vegetable crops (Table 2).

In general, Ni content was registered highest in roots followed by stem, leaves and fruits with 27, 23, 22 and 20 µg/g dry weight respectively. Among the crops and their various parts, roots of cauliflower and Brinjal and stem of fenugreek were found to accumulate highest amount of

Table 1. Heavy metal accumulation in various plant parts of different vegetable crops grown on metal contaminated soil.

Vegetable crop	Zn content (ug/g dry wt.)				Cu content (ug/g dry wt.)				Pb content (ug/g dry wt.)			
	Root	Stem	Leaf	Fruit	Root	Stem	Leaf	Fruit	Root	Stem	Leaf	Fruit
Radish	67	-	59	-	29	-	60	-	3	-	10	-
Carrot	28	-	52	-	13	-	16	-	15	-	22	-
Potato	90	96	106	-	92	26	48	-	46	43	74	-
Onion	33	49	33	-	23	17	18	-	13	13	17	-
Spinach	81	-	86	-	43	-	29	-	11	-	23	-
Amaranthus	58	54	87		52	24	26	-	17	24	35	-
Fenugreek	58	51	70	-	115	55	88	-	21	33	36	-
Mustard	37	48	64	-	25	42	32	-	14	15	27	-
Cauliflower	104	33	60	53	90	10	14	13	40	26	38	29
Cabbage	92	37	32	-	28	11	12	-	35	30	34	-
Soybean	21	31	30	71	29	101	64	51	10	13	34	18
Cluster bean	29	29	67	53	41	87	56	48	24	21	48	11
Tomato	90	115	73	29	19	26	32	24	10	14	25	6
Brinjal	108	87	112	29	45	39	58	43	30	46	87	2
Peas	79	87	80	71	33	13	24	17	22	23	36	19
Okra	23	66	72	65	21	18	34	71	26	19	48	33
Mean	63	60	68	53	44	29	38	38	21	25	37	17
CD at 5%	28	24	19	15	44	66	13	33	18	21	6	5

nickel in the order of 84, 60 and 50 µg/g dry weight respectively (Table 2).

Metal accumulation in edible parts

Heavy metals showed differential level of their accumulation in different vegetable crops tested. In case of zinc, it varied from 29 to 87 µg/g dry weight of edible parts of different vegetables. Edible parts such as roots of carrot and fruits of tomato and Brinjal showed the minimum level of its accumulation in the order of 28, 29 and 29 µg/g dry weight respectively, whereas leaves of amaranthus, palak and fruits of pea recorded with its highest level of accumulation as 87, 86 and 71 µg/g dry weight respectively. However, copper was found to be highest in leaves of fenugreek (88 µg/g dry weight), followed by okra fruit (71 µg/g dry weight) and soybean fruit (51 µg/g dry weight). The lowest copper concentration was found in cauliflower curd (13 µg/g dry weight) followed by roots of carrot and cabbage head (13 and 17 µg/g dry weight respectively). In case of lead the range of accumulation varied from 3 to 43 µg/g dry weight, being lowest in radish and highest in potato tubers. Amaranthus leaves and potato tuber were found with higher concentration of cadmium (28 and 30 µg/g dry weight respectively), while soybean fruit, carrot root, cluster bean and pea fruits registered its lowest concentration (2, 2, 2 and 1 µg/g dry weight respectively). For Nickel the highest accumulation was recorded in onion bulb (30 µg/g dry weight) followed by cabbage head and Brinjal fruit (29 µg/g dry weight) (Table 2).

Heavy metal uptake and their distribution in different plants parts

Heavy metals are mobile and easily taken up by the plants grown in metal contaminated environments. Since the plants have high ability to accumulate the metals in their different parts from

Table 2. Heavy metal accumulation in various plant parts of different vegetable crops grown on metal contaminated soil.

Vegetable crop	Cd content (ug/g dry wt.)				Ni content (ug/g dry wt.)				Metal content in edible parts (ug/g dry wt.)				
	Root	Stem	Leaf	Fruit	Root	Stem	Leaf	Fruit	Zn	Cu	Pb	Cd	Ni
Radish	6	-	11	-	10	-	5	-	67	29	3	6	10
Carrot	2	-	3	-	12	-	41	-	28	13	15	2	12
Potato	44	30	32	-	45	27	31	-	96	26	43	30	27
Onion	35	4	4	-	26	28	28	-	49	17	13	4	28
Spinach	28	-	20	-	16	-	11		86	29	23	20	11
Amaranthus	17	13	28	-	22	10	16	-	87	26	35	28	16
Fenugreek	25	8	4	-	12	50	5	-	64	88	36	4	5
Mustard	13	16	20	-	20	16	26	-	70	32	27	20	26
Cauliflower	10	4	7	3	84	32	38	40	53	13	29	3	40
Cabbage	18	4	8	-	35	24	29	-	32	12	34	8	29
Soybean	4	4	4	2	7	10	15	16	71	51	18	2	16
Cluster bean	3	1	6	2	14	12	23	17	53	48	11	2	17
Tomato	9	5	6	3	18	34	21	17	29	24	6	3	17
Brinjal	7	6	8	2	60	18	35	1	29	43	2	2	1
Peas	6	3	2	1	21	15	20	15	71	17	19	1	15
Okra	5	7	12	7	24	22	27	7	65	71	33	7	7
Mean	15	8	11	3	27	23	23	20	59	34	22	9	19
CD at 5%	10	7	5	2	19	8	10	11	22	11	9	7	8

the environment, metals taken up by the crop plants may pose risks to human health when they are grown on or near contaminated areas through various food chains. The amount of heavy metals absorbed and the proportion of their translocation/ distribution to different edible and non-edible parts of tested vegetable crops plants are briefly discussed as below.

Total metal uptake by different crops

Irrespective of different crops and plant parts, the total uptake of metals was recorded in the order of Zn>Cu>Pb>Ni>Cd. Among the crops, zinc uptake ranged between 5 to 80 mg/m^2 crop dry weights, being the highest in cauliflower and lowest in fenugreek. Copper uptake ranged from 3 to 45 mg/m^2 crop dry weight, which was found to be lowest in onion, spinach and fenugreek (3 to 5) and highest in mustard. Lead uptake was recorded to be lowest in onion, spinach, fenugreek and soybean (2 to 6 mg/m^2 dry weight) and highest in cauliflower and cabbage (45 mg/m^2 dry weight). Cadmium uptake was recorded lowest with a range of 1 to 5 mg/m^2 in spinach, onion, fenugreek, soybean carrot, radish, brinjal, okra, whereas mustard and amaranthus manifested maximum uptake of Cd (22 mg/m^2 dry weight). Similarly nickel uptake varied from 1 mg/m^2 dry weight in fenugreek to 57 mg/m^2 dry weight in cauliflower. In general, fenugreek recorded lowest uptake of all the metals, while cauliflower recorded the highest uptake for almost all the metals except cadmium where mustard recorded the highest value of its uptake (Table 3).

Metal distribution in different plant parts

Among the different plant parts, spinach leaves recorded the highest proportion of zinc distribution (83%) followed by radish roots (78%), while lowest proportion was transported in roots of pea (1%). In stem, the zinc distribution ranged

Table 3. Heavy metal and their distribution in various plant parts of different vegetables.

Vegetable crop	Metal uptake (mg/m^2 crop area)					Zn distribution in different plant parts (%)				Cu distribution in different plant parts (%)			
	Zn	Cu	Pb	Cd	Ni	Root	Stem	Leaf	Fruit	Root	Stem	Leaf	Fruit
Radish	28	16	2	3	4	78		22	-	60	-	40	-
Carrot	39	15	18	2	25	40		60	-	51	-	49	-
Potato	20	11	8	3	4	5	75	20	-	9	77	14	-
Onion	7	3	3	1	6	4	66	30	-	5	73	22	-
Spinach	13	5	3	3	2	17	-	83	-	25	-	75	-
Amaranthus	35	14	14	10	7	10	36	54	-	22	39	39	-
Fenugreek	5	4	2	1	1	10	45	45	-	16	38	46	-
Mustard	67	45	25	22	25	7	42	51	-	7	55	38	-
Cauliflower	80	28	45	8	57	18	4	40	38	45	4	26	25
Cabbage	56	18	45	9	38	17	30	53	53	17	33	50	-
Soybean	15	19	6	1	4	2	16	12	70	3	39	20	38
Cluster bean	24	36	15	2	9	9	28	41	22	9	55	23	13
Tomato	48	14	9	3	14	23	48	25	4	16	36	37	11
Brinjal	58	28	29	4	20	32	40	25	3	27	37	27	9
Peas	47	11	14	1	10	1	15	15	69	3	9	19	69
Okra	36	19	18	5	14	6	45	29	20	10	24	25	41
Mean	36	18	16	5	15	17	31	38	32	20	40	34	29
CD at 5%	21	12	10	3	5	12	9	8	9	8	12	6	8

between 4 to 75% in potato and cauliflower. Leaves of spinach manifested maximum proportion of Zn distribution (83%) and minimum in soybean 12(%). Among the fruits of various crops under study, the highest proportion of zinc was transported in soybean fruits (70%) and the lowest in brinjal (3%) (Table 3). Among different types of vegetables, root types such raddish showed greatest distribution of copper in their leaves (60%) and lowest was recorded in soybean and peas (3%). The lowest percentage of copper was recorded in cauliflower stem (4%) and highest in potato (77%), whereas in leaves the distribution pattern of Cu was maximum in spinach (75%) and lowest in potato (14%). Peas and brinjal fruits manifested 69 and 9% respectively the distribution of copper (Table 3). Radish showed highest proportion of lead distribution in its roots (50%) and lowest in peas (2%). Stem of onion recorded the maximum distribution of lead (75%) and minimum in cauliflower with 6%. Almost all the plants showed highest proportion of lead distribution in their leaves. The leafy vegetables such as spinach, amaranthus and fenugreek recorded Pb distribution to the extent of 90, 53 and 41% respectively. Edible portion of peas (pods) recorded the highest distribution of lead (62%) followed by cabbage heads (54%) and the least was recorded in tomato fruits (5%) (Table 4). Compared to the percent distribution of Cd in various crops, many of them showed higher distribution in their roots like radish (64%), carrot (44%) and 35% in tomato. However, cauliflower showed lowest proportion of Cd distribution in their stem (5%). Among the leaves of various crops, the highest proportion of Cd was recorded in spinach (76%) and the lowest was in fenugreek and peas (17%). In fruits the distribution was in the range of 3 to 58% being lowest in brinjal and highest in peas (Table 4). The highest percent of Ni distribution was recorded in radish roots (86%) and lowest was in peas roots (2%). The magnitude of Ni distribution in stem was 90% in fenugreek and 6% in cauliflower. Spinach leaves recorded the highest percent of Ni distribution

Table 4. Heavy metal and their distribution in various plant parts of different vegetables.

Vegetable crop	Pb distribution in different plant parts (%)				Cd distribution in different plant parts (%)				Ni distribution in different plant parts (%)			
	Root	Stem	Leaf	Fruit	Root	Stem	Leaf	Fruit	Root	Stem	Leaf	Fruit
Radish	50	-	50	-	64	-	36	-	86	-	14	-
Carrot	46	-	54	-	44	-	56	-	27	-	73	-
Potato	6	68	26	-	18	34	48	-	12	55	29	-
Onion	3	75	22	-	24	52	24	-	3	70	27	-
Spinach	10	-	90	-	24	-	76	-	24	-	76	-
Amaranthus	7	40	53	-	10	30	60	-	18	33	49	-
Fenugreek	7	52	41	-	31	52	17	-	4	90	6	-
Mustard	7	34	59	-	8	44	48	-	10	36	54	-
Cauliflower	12	6	44	38	20	5	52	23	21	6	35	38
Cabbage	8	38	54	-	21	44	35	-	10	39	51	-
Soybean	4	17	32	47	10	32	26	32	4	18	22	56
Cluster bean	13	32	48	7	13	20	55	12	12	31	38	19
Tomato	14	33	48	5	35	28	32	5	17	50	25	8
Brinjal	17	43	40	-	29	41	27	3	15	25	23	37
Peas	2	13	23	62	5	20	17	58	2	12	18	68
Okra	13	28	39	20	10	38	37	15	18	45	31	6
Mean	14	37	45	30	23	27	40	21	17	39	36	33
CD at 5%	12	15	9	11	12	10	8	6	13	12	11	9

(76%), while lowest was found in fenugreek leaves (6%). Pea showed the highest degree of Ni distribution in pods (68%), while the lowest proportion of the same was recorded in okra fruits (6%) (Table 4).

Crops suggested for heavy metal contaminated soils

Based on the pattern of metal accumulation and their distribution in edible plant part of different crop plants, it is concluded that carrot, tomato, brinjal, clusterbean, cabbage, cauliflower, potato and onion could be safely grown on Zn and Cu contaminated soils. Contrary to this, several vegetables like spinach, fenugreek, mustard and soybean are not suitable for their cultivation on Cu and Zn contaminated soils. The study showed that mustard, amaranthus, spinach, cabbage, cauliflower, clusterbean, potato and onion should not be grown on lead, cadmium and nickel contaminated soils. However, some fruit type vegetables like tomato and brinjal could be safely grown on almost all metal contaminated soils except tomato on Cd contaminated soil. Root type vegetable such as radish could be suggested for cultivation on Cu, Pb and Ni contaminated soil but not on Cd contaminated soil, while carrot could be grown safely on Cd and Ni contaminated soil (Table 5).

Increased concentrations of heavy metals in different parts of vegetable crops, as recorded in the present investigation confirm the findings of other researchers (Allinson and Dzialo, 1981; Barman and Lal, 1994; Barman et al., 2000; Kim et al., 2002; Wang and Stuanes, 2003). Heterogeneous accumulation of heavy metals in different crop species, and different plant parts of same crop species under present investigation have also been reported by Barman et al. (2000) and Singh and Aggarwal (2006), which could be attributed to their diverse morphological characteristics and position of edible parts on the plants in respect of their distance from roots and

Table 5. Suggested vs not suggested vegetable crops in heavy metal contaminated soils.

Crop	Soil contaminated with heavy metal				
	Zinc	Copper	Lead	Cadmium	Nickel
Radish	X	√	√	X	√
Carrot	√	√	X	√	√
Spinach	X	X	X	X	√
Amaranthus	X	√	X	X	X
Fenugreek	X	X	X	√	√
Mustard	X	X	X	X	X
Soybean	X	X	X	√	√
Tomato	√	√	√	X	√
Pea	X	√	X	√	√
Okra	√	X	X	X	√
Brinjal	√	√	√	√	√
Clusterbean	√	√	X	X	X
Cabbage	√	√	X	X	X
Cauliflower	√	√	X	X	X
Potato	√	√	X	X	√
Onion	√	√	X	X	X

Where sign √ refers to crops suggested and X for crops not suggested for cultivation in different metal contaminated soils.

selective uptake of metal by each crop (Mohamed and Rashed, 2003). Low metal accumulation in fruit type vegetables as compared to leafy vegetable crops, and in reproductive organs than in vegetative parts have also been observed by Allinson and Dzialo (1981), Iretskaya and Chien (1998), Kim et al. (2002) and Singh and Aggarwal (2006). This may possibly be due to poor metal mobility within the plants. In contrast, however, Barman and Lal (1994) reported higher accumulation of heavy metals (Cu, Zn, Pb, Cd) in edible parts than in non-edible plant parts. In general, lower levels of heavy metals particularly Pb and Cd in reproductive organs than in vegetative parts, may be due to their poor mobility in plants as compared to essential metal nutrients that is, Cu and Zn. Very low concentration of Cd in fruits of fruit type vegetable and their poor uptake indicates the possibility of safe cultivation of such type of vegetables on cadmium contaminated fields. Such variation in metals uptake and their distribution/compartmentalisation between different parts of different crop plants may be useful for selecting crop species suitable for cultivation on metal contaminated soils to reduce the movement of metals into food chains.

It is clearly evident from the present findings that most of the leafy vegetables are hyper accumulators of most of the non-essential heavy metals such as lead and cadmium. The diverse vegetable crop species also showed marked differences in respect of metal uptake and their distribution to various plant parts especially to the edible part, which could be emphasized for selection of vegetable crops for cultivation on metals contaminated soils depending on their metal uptake potential and their transportation/distribution to edible part. In conclusion our results may be useful for selecting suitable crop species for different metal contaminated soils.

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