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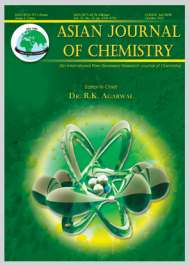

Risk Assessment of Heavy Metal Contamination in Fresh Vegetables from Markets in Luoyang City, China

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Consumption of vegetables contaminated with heavy metals has been identified a major food chain route for human exposure. Heavy metal concentrations in 15 species of fresh vegetables from markets in Luoyang City were investigated. The results showed that mean concentrations of Pb in wax gourd, pumpkin, potato, carrot and lettuce and mean Cd concentrations in pumpkin, marrow, tomato, green pepper, potato, carrot and lettuce exceeded the permissible limits in China. The maximum concentrations of Pb and Cd were both found in potato, exceeding the permissible limits in China by 17.0 times and 2.9 times, respectively. Generally, Cd and Pb were the commonest metal pollutants, particularly in root-stem vegetables. Cu, Zn, Ni and Cr concentrations were all below the permissible limits. The results of health risk assessment showed that Cd and Pb had potential health risk for both adult and children consumers, while Cu, Zn, Ni and Cr were generally safe.

Key Words: Vegetables, Heavy metals, Risk assessment, Cadmium, Contamination.

INTRODUCTION

The increasing use of heavy metals over the past few decades has inevitably led to an increased release of metallic substances in various environments, including agricultural lands. Hence, crops growing in heavy metal-polluted sites may accumulate trace elements at high concentrations and pose a serious health risk when they are consumed. Long-term or high-dose exposure to heavy metals, even those essential for human health, can cause deleterious effects in humans. Six metals and/or their compounds have been recognized as human carcinogens, *i.e.* As, Be, Cd, Co, Ni and Cr(VI) by international agencies (International Agency for Research on Cancer, European Union). Consumption of food crops contaminated with heavy metals is a major food chain route for human exposure. Hence, heavy metal contamination in crops deserves much attention.

Numerous investigations have found that heavy metals are the most important types of contaminants that can be found in fresh vegetables in many countries and regions[1-6]. According to the first national census of pollution sources, heavy metals (Cd, Cr, As, Hg and Pb) have become China's main pollutant, with nearly 900 tons emitted every year[7]. It was estimated that nearly 20 million hectares of China's arable land -about one-fifth of China's total - are estimated to be contaminated with heavy metals, which was assumed to result in a reduction of more than 10 millions tons of food supplies in China annually[8]. Recently, heavy metal residues in vegetables have been extensively reported in China, particularly in areas around mining and smelting sites[9-17]. Irrigation with wastewater, waste disposal, smelter stacks, atmospheric deposition, fertilizer and pesticide use and the application of sewage sludge in arable land are considered the main factors leading to elevated levels of heavy metals in vegetables.

Luoyang is an important heavy industrial city situated in Henan Province, China, with more than 3000 years of history. Since the 1990s, Luoyang has been one of the fastest developing districts in industrialization and urbanization. Mechanics and electronics, petrochemical industry, metallurgy, building materials, food and light and textile industry are the pillar industries of Luoyang. Heavy metals contamination is serious in urban soil and the main pollution source is industrial discharge, atmospheric emissions from the various factories and traffic emission[18,19]. Vegetables retailed in agricultural product markets are mainly supplied from suburban vegetable fields. Heavy metals in these vegetables may be affected by industrial wastewater, waste disposal and atmospheric deposition, *etc.*[20]. The purposes of present study are to determine

the residues of heavy metals in vegetables marketed in Luoyang and to assess the risk of health from these vegetables by estimating the daily dietary intake exposure.

EXPERIMENTAL

Fifteen species of common vegetables (27 samples of each species) were purchased from three biggest local retailers in Luoyang City, once a month between Sep. and Nov., 2007. These vegetables can be divided into three types: leafy vegetables, fruit vegetables and root-stem vegetables (Table-1). Parts of the samples that were obviously dust contaminated, damaged by insects or mechanically injured were removed. Then, the selected samples were washed in tap water and then de-ionized water. The edible portions of the samples were chopped into small pieces. The fresh samples were weighed and dry weights were recorded after oven-drying at 70 ºC till the constant weight was achieved. Then the dried samples were ground using a stainless steel blender and passed through a 2 mm sieve for analysis.

HNO_3 and $HClO_4$ for wet-digestion of vegetable samples were guaranteed reagents. All other chemicals used were of analytical reagent grade. All solutions were prepared in de-ionized water (zero metal concentration). Calibration standards for each metal were purchased from the National Research Center for Geoanalysis, China.

Cu, Zn, Pb, Ni, Cr and Cd concentrations in dried and ground plant material were determined by inductively coupled plasma atomic emission spectrometry (Varian AA240) after wet-digestion with a mixture of concentrated HNO_3 and $HClO_4$ (3:2, v/v) mixed acid.

The blank reagent and standard reference plant materials (from the National Research Center for Standards in China) were included in each sample batch to verify the accuracy and precision of the digestion procedure and subsequent analyses. Recovery values in the range of ± 2 % were accepted, otherwise analyses were repeated.

The daily intake of metals (DIM) was determined by the following equation.

$$DIM = \frac{C_{metal} \times W_{vegetable}}{B_{average\ weight}} \quad (1)$$

where C_{metal}, $W_{vegetable}$ and $B_{average\ weight}$ represent the heavy metal concentrations in plants (mg kg^{-1}), the daily average consumption of vegetables (fresh weight) and average body weight, respectively. The average daily vegetable intakes for adults and children were considered to be 0.345 and 0.232 kg/person/day fresh weight, respectively, while the average adult and child body weights were considered to be 55.9 and 32.7 kg, respectively, as used in previous studies[21,22].

The health risk index (HRI) for the locals through the consumption of contaminated vegetables was assessed based on the food chain and the reference oral dose (RfD) for each metal. This risk estimation method has recently been used in many researches[21-24]. If the HRI is equal to or greater than 1, there will be health risk.

$$HRI = \frac{DIM}{RfD}\left(US-EPA, 2002\right)^{25} \quad (2)$$

Oral reference doses (RfD) for Cd, Cr, Cu, Ni, Pb and Zn are 0.001, 1.5, 0.04, 0.02, 0.0035 and 0.3 mg kg^{-1} day^{-1}, respectively[26].

The data were statistically analyzed using a statistical package SPSS 11.5. The measures were expressed in terms of means and the ranges were also given.

RESULTS AND DISCUSSION

Heavy metal concentrations (mg kg^{-1}, on fresh weight basis) in edible portions of vegetables were compared with the permissible limits (Table-1). The concentrations of Cu (0.02-1.98 mg kg^{-1}) and Zn (0.14-18.20 mg kg^{-1}) in all samples were within the maximum permissible limits. Potato had the highest Cu and Zn contents. Chromium concentrations were safe in the 14 vegetables (excluding potato), ranging from 0.01 to 0.29 mg kg^{-1}. Only in potato, 22 % of samples exceeded the permissible limit of Cr concentrations. Nickel concentrations were within the permissible limit in all the examined vegetable except for green onion, 67 % of samples of which exceeded the permissible limit. The concentrations of Pb exceeded the permissible limit in partial samples of spinach, cucumber and wax gourd and all samples of pumpkin, potato, carrot and lettuce. The concentrations of Cd exceeded the permissible limit in partial samples of cucumber and wax gourd and all samples of pumpkin, marrow, tomato, green pepper, potato, carrot and lettuce. The maximum concentrations of Pb and Cd were both found in potato (1.80 and 0.39 mg kg^{-1}, respectively), which exceeded the permissible limits in China by 17.0 times and 2.9 times, respectively. On the whole, Cd and Pb contaminations occurred more seriously than other heavy metals, particularly in root-stem vegetables.

The estimated daily intake of metals (DIM) of heavy metals through the food chain for adults and children was presented in Table-2. Generally, consumption of root-stem led to vegetables higher intake of metals. The highest DIMs of Cd, Cr, Cu, Ni, Pb and Zn were from the consumption of potato for both adults and children. The average health risk indexes (HRI) of Cu, Zn, Pb, Cd, Cr and Ni was 4.42E-02, 3.99E-02, 5.03E-01, 8.11E-01, 5.07E-04 and 3.13E-02, respectively for adults and 5.08E-02, 4.59E-02, 5.78E-01, 9.32E-01, 5.83E-04 and 3.59E-02, respectively for children. Health risk indexes of Cd in garlic bolt, leek, potato, carrot and lettuce for both adults and children were higher than 1. Health risk index of Pb greater than 1 was only found in potato for adults and children, which reached 3.17 and 3.65, respectively.

Copper and zinc concentrations in all examined vegetables were safe for consumers. Although slightly higher Ni and Cr concentrations than permissible limits were found in partial samples of one vegetable respectively, health risk indexes were all much lower than 1, indicating there was no health risk for these metals. For easy comparison with other reports, the conversion factor 0.085 was generally used to convert fresh green vegetable weight to dry weight[29]. It can be found that the mean of Cu concentrations in the present study was much lower than the concentrations (61.20 mg kg^{-1}, dry weight basis) in edible vegetables cultivated in agricultural soil in the suburb of Zhengzhou, a city about 120 km away from Luoyang City, but the mean of Cr concentrations in ours approximated the concentrations (2.06 mg kg^{-1}) in their study[30]. Similar to most

TABLE-1
HEAVY METAL CONCENTRATIONS (mg kg^{-1}, FRESH WEIGHT BASIS) AND PERCENTAGE MEETING STANDARD OF VEGETABLES

Vegetables		Value	Cu	Zn	Pb	Cd	Cr	Ni
Leafy vegetables	Celery	Mean	0.07	0.24	0.15	0.07	0.09	0.03
		Range	0.06-0.87	0.23-0.24	0.12-0.18	0.07-0.08	0.07-0.13	0.02-0.03
		PMS (%)	100	100	100	100	100	100
	Pakchoi	Mean	0.07	0.22	0.18	0.07	0.03	0.02
		Range	0.06-0.08	0.22-0.22	0.14-0.19	0.07-0.07	0.02-0.04	0.02-0.02
		PMS (%)	100	100	100	100	100	100
	Spinach	Mean	0.11	0.31	0.19	0.10	0.13	0.03
		Range	0.08-0.14	0.30-0.32	0.12-0.33	0.10-0.11	0.11-0.16	0.02-0.04
		PMS (%)	100	100	100	100	100	100
	Garlic bolt	Mean	0.96	6.10	0.19	0.19	0.15	0.13
		Range	0.74-1.15	5.30-7.05	0.17-0.20	0.17-0.20	0.15-0.16	0.10-0.15
		PMS (%)	100	100	100	100	100	100
	Leek	Mean	0.14	0.57	0.18	0.18	0.12	0.08
		Range	0.12-0.16	0.55-0.59	0.17-0.19	0.17-0.19	0.04-0.19	0.07-0.09
		PMS (%)	100	100	100	100	100	100
	Green onion	Mean	0.41	4.14	0.12	0.12	0.09	0.67
		Range	0.35-0.50	3.85-4.31	0.11-0.14	0.11-0.14	0.04-0.16	0.17-1.10
		PMS (%)	100	100	100	100	100	33
Fruit vegetables	Cucumber	Mean	0.03	0.21	0.08	0.05	0.02	0.03
		Range	0.02-0.03	0.14-0.34	0.02-0.12	0.04-0.05	0.01-0.03	0.03-0.04
		PMS (%)	100	100	67	100	100	100
	Wax gourd	Mean	0.03	0.15	0.11	0.04	0.03	0.02
		Range	0.03-0.03	0.15-0.15	0.08-0.14	0.04-0.05	0.00-0.06	0.02-0.02
		PMS (%)	100	100	78	100	100	100
	Pumpkin	Mean	0.09	0.34	0.26	0.10	0.07	0.08
		Range	0.08-0.09	0.34-0.35	0.20-0.28	0.10-0.11	0.02-0.13	0.02-0.16
		PMS (%)	100	100	0	0	100	100
	Marrow	Mean	0.06	0.19	0.06	0.06	0.05	0.04
		Range	0.05-0.07	0.18-0.19	0.06-0.06	0.06-0.06	0.05-0.06	0.02-0.05
		PMS (%)	100	100	100	0	100	100
	Tomato	Mean	0.14	1.10	0.13	0.13	0.10	0.05
		Range	0.09-0.19	0.37-2.55	0.12-0.13	0.12-0.13	0.07-0.13	0.02-0.08
		PMS (%)	100	100	0	0	100	100
	Green pepper	Mean	0.07	0.23	0.08	0.08	0.05	0.03
		Range	0.06-0.08	0.22-0.23	0.07-0.08	0.07-0.09	0.04-0.06	0.01-0.04
		PMS (%)	100	100	100	0	100	100
Root-stem vegetables	Potato	Mean	1.74	14.21	1.80	0.39	0.44	0.21
		Range	1.47-1.98	9.08-18.20	1.65-1.95	0.35-0.42	0.38-0.52	0.18-0.24
		PMS (%)	100	100	0	0	78	100
	Carrot	Mean	0.16	0.52	0.33	0.18	0.22	0.05
		Range	0.15-0.19	0.51-0.53	0.28-0.42	0.17-0.19	0.20-0.24	0.04-0.06
		PMS (%)	100	100	0	0	100	100
	Lettuce	Mean	0.21	0.56	0.42	0.21	0.26	0.05
		Range	0.20-0.21	0.54-0.58	0.37-0.45	0.18-0.23	0.22-0.29	0.04-0.08
		PMS (%)	100	100	0	0	100	100
		Mean	0.29	1.94	0.29	0.13	0.12	0.10
		Range	0.02-1.98	0.14-18.20	0.02-1.95	0.04-0.39	0.00-0.52	0.01-1.10
Permissible limit [f]			10	20	0.1[a]; 0.3[b]	0.1[c]; 0.2[d]; 0.05[e]	0.5	0.3

*Percentage meeting standard (%); [a] vegetables excluding bulb vegetables, leaf vegetables; [b] bulb vegetables and leaf vegetables; [c] Stem vegetables and root vegetables; [d] Leaf vegetables and celery; [e] other vegetables; [f] SEPA, 1994[27], 2005[28];

studies, Cu, Zn, Ni and Cr were generally safe in vegetables[21,30], even in vegetables with sewage irrigation[22,31] or in metal smelter contaminated sites[10].

Cadmium and lead were the most common metal pollutants reported in vegetables in China[32], Australia[2], India[4,5], Spain[33], UK[34] and Turkey[35,36]. In the present study, we also found five of the surveyed vegetables were seriously polluted by Cd and had potential health risk (HRI >1). The present study showed that the Cd concentration (range 0.59-4.59, mean 1.53 mg kg^{-1}, dry weight basis) in 15 vegetables from Luoyang was similar to the vegetables from Varanasi, India (0.5-4.36 mg kg^{-1})[4] and from Nanjing, China (2.53-4.19 mg kg^{-1})[15], but much higher than the vegetables from Zhengzhou, China (range 0.036-0.18 mg kg^{-1}, mean 0.10 mg kg^{-1})[30], from Beijing, China (0.03-0.73 mg kg^{-1})[31], from Egypt (0.002-0.08 mg kg^{-1})[37] and lower than those form Titagarh, India (10.37-17.79 mg kg^{-1})[6] and from endemic upper gastrointestinal cancer region of Turkey (25 mg kg^{-1})[38].

Lead concentrations also exceeded the permissible limit in 7 vegetables, but potential health risk was only found in

TABLE-2
DAILY INTAKE OF METALS (DIM) AND HEALTH RISK INDEX (HRI) FOR INDIVIDUAL HEAVY METALS CAUSED BY THE CONSUMPTION OF VEGETABLES

Vegetables		Individuals		Cu	Zn	Pb	Cd	Cr	Ni
	Celery	Adults	DIM	4.57×10^{-4}	1.48×10^{-3}	9.26×10^{-4}	4.32×10^{-4}	5.55×10^{-4}	1.85×10^{-4}
			HRI	1.14×10^{-2}	4.94×10^{-3}	0.26	0.43	3.70×10^{-4}	9.26×10^{-3}
		Children	DIM	5.25×10^{-4}	1.70×10^{-3}	1.06×10^{-3}	4.97×10^{-4}	6.39×10^{-4}	2.13×10^{-4}
			HRI	1.31×10^{-2}	5.68×10^{-3}	0.30	0.50	4.26×10^{-4}	1.06×10^{-2}
	Pakchoi	Adults	DIM	4.32×10^{-4}	1.36×10^{-3}	1.11×10^{-3}	4.32×10^{-4}	1.85×10^{-4}	1.23×10^{-4}
			HRI	1.08×10^{-2}	4.53×10^{-3}	0.32	0.43	1.23×10^{-4}	6.17×10^{-3}
		Children	DIM	4.97×10^{-4}	1.56×10^{-3}	1.28×10^{-3}	4.97×10^{-4}	2.13×10^{-4}	1.42×10^{-4}
			HRI	1.24×10^{-2}	5.20×10^{-3}	0.36	0.50	1.42×10^{-4}	7.09×10^{-3}
	Spinach	Adults	DIM	6.79×10^{-4}	1.91×10^{-3}	1.17×10^{-3}	6.17×10^{-4}	8.02×10^{-4}	1.85×10^{-4}
			HRI	1.70×10^{-2}	6.38×10^{-3}	0.34	0.62	5.35×10^{-4}	9.26×10^{-3}
		Children	DIM	7.80×10^{-4}	2.20×10^{-3}	1.35×10^{-3}	7.09×10^{-4}	9.22×10^{-4}	2.13×10^{-4}
			HRI	1.95×10^{-2}	7.33×10^{-3}	0.39	0.71	6.15×10^{-4}	1.06×10^{-2}
	Garlic bolt	Adults	DIM	5.92×10^{-3}	3.76×10^{-2}	1.17×10^{-3}	1.17×10^{-3}	9.26×10^{-4}	8.02×10^{-4}
			HRI	1.48×10^{-1}	1.25×10^{-1}	0.34	1.17	6.17×10^{-4}	4.01×10^{-2}
		Children	DIM	6.81×10^{-3}	4.33×10^{-2}	1.35×10^{-3}	1.35×10^{-3}	1.06×10^{-3}	9.22×10^{-4}
			HRI	1.70×10^{-1}	1.44×10^{-1}	0.39	1.35	7.09×10^{-4}	4.61×10^{-2}
	Leek	Adults	DIM	8.64×10^{-4}	3.52×10^{-3}	1.11×10^{-3}	1.11×10^{-3}	7.41×10^{-4}	4.94×10^{-4}
			HRI	2.16×10^{-2}	1.17×10^{-2}	0.32	1.11	4.94×10^{-4}	2.47×10^{-2}
		Children	DIM	9.93×10^{-4}	4.04×10^{-3}	1.28×10^{-3}	1.28×10^{-3}	8.51×10^{-4}	5.68×10^{-4}
			HRI	2.48×10^{-2}	1.35×10^{-2}	0.36	1.28	5.68×10^{-4}	2.84×10^{-2}
	Green onion	Adults	DIM	2.53×10^{-3}	2.56×10^{-2}	7.41×10^{-4}	7.41×10^{-4}	5.55×10^{-4}	4.14×10^{-3}
			HRI	6.33×10^{-2}	8.52×10^{-2}	0.21	0.74	3.70×10^{-4}	2.07×10^{-1}
		Children	DIM	2.91×10^{-3}	2.94×10^{-2}	8.51×10^{-4}	8.51×10^{-4}	6.39×10^{-4}	4.75×10^{-3}
			HRI	7.27×10^{-2}	9.79×10^{-2}	0.24	0.85	4.26×10^{-4}	2.38×10^{-1}
Fruit vegetables	Cucumber	Adults	DIM	1.85×10^{-4}	1.30×10^{-3}	4.94×10^{-4}	3.09×10^{-4}	1.23×10^{-4}	1.85×10^{-4}
			HRI	4.63×10^{-3}	4.32×10^{-3}	0.14	0.31	8.23×10^{-5}	9.26×10^{-3}
		Children	DIM	2.13×10^{-4}	1.49×10^{-3}	5.68×10^{-4}	3.55×10^{-4}	1.42×10^{-4}	2.13×10^{-4}
			HRI	5.32×10^{-3}	4.97×10^{-3}	0.16	0.35	9.46×10^{-5}	1.06×10^{-2}
	Wax gourd	Adults	DIM	1.85×10^{-4}	9.26×10^{-4}	6.79×10^{-4}	2.47×10^{-4}	1.85×10^{-4}	1.23×10^{-4}
			HRI	4.63×10^{-3}	3.09×10^{-3}	0.19	0.25	1.23×10^{-4}	6.17×10^{-3}
		Children	DIM	2.13×10^{-4}	1.06×10^{-3}	7.80×10^{-4}	2.84×10^{-4}	2.13×10^{-4}	1.42×10^{-4}
			HRI	5.32×10^{-3}	3.55×10^{-3}	0.22	0.28	1.42×10^{-4}	7.09×10^{-3}
	Pumpkin	Adults	DIM	5.55×10^{-4}	2.10×10^{-3}	1.60×10^{-3}	6.17×10^{-4}	4.32×10^{-4}	4.94×10^{-4}
			HRI	1.39×10^{-2}	6.99×10^{-3}	0.46	0.62	2.88×10^{-4}	2.47×10^{-2}
		Children	DIM	6.39×10^{-4}	2.41×10^{-3}	1.84×10^{-3}	7.09×10^{-4}	4.97×10^{-4}	5.68×10^{-4}
			HRI	1.60×10^{-2}	8.04×10^{-3}	0.53	0.71	3.31×10^{-4}	2.84×10^{-2}
	Marrow	Adults	DIM	3.70×10^{-4}	1.17×10^{-3}	3.70×10^{-4}	3.70×10^{-4}	3.09×10^{-4}	2.47×10^{-4}
			HRI	9.26×10^{-3}	3.91×10^{-3}	0.11	0.37	2.06×10^{-4}	1.23×10^{-2}
		Children	DIM	4.26×10^{-4}	1.35×10^{-3}	4.26×10^{-4}	4.26×10^{-4}	3.55×10^{-4}	2.84×10^{-4}
			HRI	1.06×10^{-2}	4.49×10^{-3}	0.12	0.43	2.36×10^{-4}	1.42×10^{-2}
	Tomato	Adults	DIM	8.64×10^{-4}	6.79×10^{-3}	8.02×10^{-4}	8.02×10^{-4}	6.17×10^{-4}	3.09×10^{-4}
			HRI	2.16×10^{-2}	2.26×10^{-2}	0.23	0.80	4.11×10^{-4}	1.54×10^{-2}
		Children	DIM	9.93×10^{-4}	7.80×10^{-3}	9.22×10^{-4}	9.22×10^{-4}	7.09×10^{-4}	3.55×10^{-4}
			HRI	2.48×10^{-2}	2.60×10^{-2}	0.26	0.92	4.73×10^{-4}	1.77×10^{-2}
	Green pepper	Adults	DIM	4.32×10^{-4}	1.42×10^{-3}	4.94×10^{-4}	4.94×10^{-4}	3.09×10^{-4}	1.85×10^{-4}
			HRI	1.08×10^{-2}	4.73×10^{-3}	0.14	0.49	2.06×10^{-4}	9.26×10^{-3}
		Children	DIM	4.97×10^{-4}	1.63×10^{-3}	5.68×10^{-4}	5.68×10^{-4}	3.55×10^{-4}	2.13×10^{-4}
			HRI	1.24×10^{-2}	5.44×10^{-3}	0.16	0.57	2.36×10^{-4}	1.06×10^{-2}
Root-stem vegetables	Potato	Adults	DIM	1.07×10^{-2}	8.77×10^{-2}	1.11×10^{-2}	2.41×10^{-3}	2.72×10^{-3}	1.30×10^{-3}
			HRI	2.68×10^{-1}	2.92×10^{-1}	3.17	2.41	1.81×10^{-3}	6.48×10^{-2}
		Children	DIM	1.23×10^{-2}	1.01×10^{-1}	1.28×10^{-2}	2.77×10^{-3}	3.12×10^{-3}	1.49×10^{-3}
			HRI	3.09×10^{-1}	3.36×10^{-1}	3.65	2.77	2.08×10^{-3}	7.45×10^{-2}
	Carrot	Adults	DIM	9.87×10^{-4}	3.21×10^{-3}	2.04×10^{-3}	1.11×10^{-3}	1.36×10^{-3}	3.09×10^{-4}
			HRI	2.47×10^{-2}	1.07×10^{-2}	0.58	1.11	9.05×10^{-4}	1.54×10^{-2}
		Children	DIM	1.14×10^{-3}	3.69×10^{-3}	2.34×10^{-3}	1.28×10^{-3}	1.56×10^{-3}	3.55×10^{-4}
			HRI	2.84×10^{-2}	1.23×10^{-2}	0.67	1.28	1.04×10^{-3}	1.77×10^{-2}
	Lettuce	Adults	DIM	1.30×10^{-3}	3.46×10^{-3}	2.59×10^{-3}	1.30×10^{-3}	1.60×10^{-3}	3.09×10^{-4}
			HRI	3.24×10^{-2}	1.15×10^{-2}	0.74	1.30	1.07×10^{-3}	1.54×10^{-2}
		Children	DIM	1.49×10^{-3}	3.97×10^{-3}	2.98×10^{-3}	1.49×10^{-3}	1.84×10^{-3}	3.55×10^{-4}
			HRI	3.72×10^{-2}	1.32×10^{-2}	0.85	1.49	1.23×10^{-3}	1.77×10^{-2}

potato. The Pb concentrations (range 0.71-21.18 mg kg^{-1}, mean 3.41 mg kg^{-1}) in present study was similar to the values reported in China (range 0.18-7.75 mg kg^{-1}, mean 2.09 mg kg^{-1})[30] and in Varanasi, India (3.09-15.74 mg kg^{-1})[4], but significantly lower than the mean concentration of Pb (409 mg kg^{-1}) reported in Turkey[38], in Nanjing, China (22.1-45.7 mg kg^{-1})[15] and in Titagarh (21.59-57.63 mg kg^{-1})[6].

Heavy metal contents in vegetables depend mainly on their genetic features and their growing environments. Different species and varieties of vegetables differ significantly in metal uptake capacity. Numerous studies have confirmed that root vegetables generally accumulated higher heavy metals than leafy and fruit vegetables. Gupta *et al*.[6] found among the 9 vegetable species, radish showed highest accumulation of Pb and Cd. Compared with other vegetables, lettuce grown in traffic areas had the highest amount of Cd and Pb[36]. Bosque *et al*.[33] found fruity vegetables contained low concentrations of Cd and Pb. Yang *et al*.[39] found carrot and radish accumulated more Cd. Present study found similar results that the concentrations of heavy metals particularly Cd and Pb generally followed the order: root and stem vegetables > leafy vegetables > fruit vegetables. When growing in heavy metal contaminated environments, plants mostly sequester toxic metals in roots to protect reproductive and photosynthetic tissues. Additionally, edible parts of root vegetables have a direct contact with heavy metals in soil. Thus, heavy metals may enter the edible root directly through the root tissue[40]. Plants may accumulate more heavy metals in their root and stem than in their leaf and fruit because of the translocation distance. Hence, heavy metal concentrations are generally higher in roots than in shoots or leaves for most vegetables[41,42]. Dunbabin and Bowmer[43] reported that under contaminated conditions, the greater proportion of heavy metals taken up by plants was retained in the roots with metal concentrations decreasing in the following order: roots > rhizomes > non-green leaves > green leaves. On the other hand, different varieties or cultivars of vegetables also show differences in metal accumulation. McLaughlin *et al*.[44] compared the uptake of Cd by 14 commonly grown potato cultivars and found significant differences between the cultivars with an average range of concentrations of 30-50 μg kg^{-1} Cd (fresh weight).

Oppositely, there also have been reports that leafy vegetables tend to accumulate more heavy metals in their edible parts when compared with fruit or even root vegetables[45-47]. Heavy metals can be transported passively from roots to shoots through the xylem vessels[48,49]. Yang *et al*.[47] reported that for Cd accumulation, the order of vegetable species was: leafy vegetables > solanaceous vegetables > kale vegetables > root vegetables > allimus > melon vegetables > legumes. Besides potato, carrot and lettuce, leek and garlic bolt were also found to contain high Cd concentrations, indicating that leafy vegetables could therefore pose potential health risks to consumers.

Vegetables take up heavy metals from contaminated soils where they grow, as well as from deposits on the above-ground parts of vegetables exposed to the air from polluted environments[50]. Numerous studies have found that irrigation with wastewater or sewage make a significant contribution to heavy metal accumulation in plants[3,6,22]. Bai and Lu[20] have reported heavy metal pollution in suburban cropland of Luoyang originated from industrial and agricultural pollution sources, which may partly explain present results. Obviously, environmental quality of vegetable fields, including soil, irrigation water and atmosphere, together with environmental factors influencing metal uptake by vegetables, needs to be monitored and evaluated, which may help to identify the pollution source of vegetables grown in this area.

Conclusion

The present results showed that mean concentrations of Pb in wax gourd, pumpkin, potato, carrot and lettuce and mean Cd concentrations in pumpkin, marrow, tomato, green pepper, potato, carrot and lettuce exceeded the permissible limits in China. The maximum concentrations of Pb and Cd were both found in potato (1.80 and 0.39 mg kg^{-1}, respectively), which exceeded the permissible limits in China by 17.0 times and 2.9 times, respectively. On the whole, Cd and Pb contaminations occurred more seriously than other heavy metals, particularly in root-stem vegetables. The results of health risk assessment showed that Cd in garlic bolt, leek, potato, carrot and lettuce and Pb in potato may have potential health risks associated with the ingestion of contaminated vegetables.

Copper and zinc concentrations in all examined vegetables were safe for consumers. Although slightly higher Ni and Cr concentrations than permissible limits were found in partial samples of one vegetable respectively, health risk indexes were all much lower than 1, indicating there was no health risk for these metals.

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