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Biotransfer of heavy metals along a soil-plant-insect-chicken food chain: Field study

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Abstract

The accumulation and transfer of Pb, Zn, Cu, and Cd along a soil-plant-insect-chicken food chain at contaminated sites were investigated. The study site nearing the Pb/Zn mine had been contaminated by heavy metals severely. Cadmium and Pb concentrations steadily declined with increasing trophic level ($p < 0.01$), but concentrations of Zn and Cu slightly increased from plant to insect larva ($p > 0.05$). The concentrations of heavy metals were the highest in chicken muscle, with lower values in liver and blood. The bioaccumulation of Pb was observed in chicken livers. The eliminations of Pb, Zn, Cu, and Cd via insect and chicken feces avoid metal bioaccumulation in insect and chicken body. These results suggest that the accumulation of heavy metals in specific animal organ of tissues could not be neglected, although transfer of metals to chicken from plant and insect was limited.

Key words: heavy metal; food chain; insect; chicken; field study

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Introduction

The current rapid pace of industrial development in southern China has resulted in serious environmental problems, and soils around industrial areas are often contaminated with heavy metals (Wang and Arne, 2003; Bai *et al*., 2008). Enhanced uptake of heavy metals by plants at concentrations below phytotoxic levels may pose potential risks to food chains where farm animals are raised on contaminated soils (Winder *et al*., 1999). It has long been recognized that the heavy metal accumulation in soil may result in potential health risk to plants, carnivores and humans through indirect or direct pathway, or via food chain (Heikens *et al*., 2001; Prince *et al*., 2001; Blakbern, 2003).

Metal accumulation has been found in snails (Notten *et al*., 2005) and insects (Merrington *et al*., 1997) and invertebrates have been found to provide important links in transferring heavy metals from plant to carnivores (Milton *et al*., 2003; Gasparik *et al*., 2004; Vandecasteele *et al*., 2004). A particular concern with heavy metals transfer and biomagnification of metals has been demonstrated (Gorree *et al*., 1995). It is concluded from the previous studies that, metal biomagnification is not general to all environmental ecosystems (Goodyear and McNeill, 1999), which may be due to the differences in the ecophysiology of metals, or the experimental methodology, or species difference, or food chains (Lindquist, 1992).

The aim of the present work was to evaluate heavy metal transfer along a plant-insect-chicken food chain on metal-contaminated soil.

1 Materials and methods

The study site is located near the Lechang lead/zinc (Pb/Zn) mine at North Guangdong Province, China. Farmland around this Pb/Zn mine has been severely contaminated with Pb, Zn, Cu, and Cd. *Rumex* K-1 (*Rumex patientia* × *Rumex tianschanicus*) is one of hybridized perennial species of the family Polygonaceae. Seeds of *Rumex* K-1 were sown in this contaminated field, and insect (*Spodoptera litura*) larva began to infest the leaves of *Rumex* K-1 naturally.

The chicken feeding trial lasted for 50 d. Forty-eight chicks (100–150 g) were divided into two groups. One group (the experimental group) was fed with feedstuff and insect larvae collected from the leaves of *Rumex* K-1, and another group was only fed with feedstuff served as control. The total amount of insect consumed by the experimental group of chickens was 2237 g (mean 93 g per chicken fresh weight (fw)), and the ingestion of feedstuff for experimental chicken and control chicken was 21650 g (902 g per chicken fw) and 22863 g (953 g per chicken, fw), respectively. Concentrations of Pb, Zn, Cu, and Cd in feedstuff were 8.7, 168, 31, and 0.31 mg/kg, respectively.

Forty insect larvae (1 cm length) collected from *Rumex* K-1 leaves were divided into four groups equally. Insect

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larvae were kept in a cultivation chest, with a 12 h/12 h light/dark illumination regime at a constant temperature of 27°C. The insect larva feeding experiment was conducted for 6 d until mature insect (3–4 cm length) emerged. The total amount of *Rumex* K-1 fresh leaves feeding insect larva was 630 g per group. The fresh leaves of *Rumex* K-1, feces of insect and insect larvae were collected and oven-dried. The liver, muscle, and blood of chicken were sampled, stored with liquid azote, and freeze-dried.

Soil, plant, and feces samples were ground, digested with acid mixture of HNO_3 (16 mol/L) and $HClO_4$ (12 mol/L) at ratio of 5:1 (*V/V*). Chicken tissues and insect larvae were digested by HNO_3 (16 mol/L) and H_2O_2 (30%) as described by Jeffrey (2003). The heavy metals in soils were extracted with diethylene-tetramine-pentaacetate acid (DTPA). The concentrations of Pb, Zn, Cu were measured by flame atomic absorption spectrometry (AAS, Model 3030, Perkin-Elmer, USA) and Cd concentration was measured by graphite-furnace atomic absorption spectrometry (GAAS, Model 3030, Perkin-Elmer, USA). Certified reference materials GBW 07406 for soils, 07602 for plants, GBW 08552 (pig muscle) for insects and GBW 08551 (pig liver) for chicken samples were used for quality control. Four replicates of soil, plant, and feces samples were applied. Recovery of heavy metals from matrix and reagent blank spikes was found to be 95%–98%.

One-way analysis of variance (ANOVA) was carried out to compare the means of different treatments, differences between individual means were tested using Tukey-HSD test at 0.05 or 0.01 significant level.

2 Results and discussion

The concentrations of total and DTPA-extractable heavy metals in soil were in the order of Pb > Zn > Cu > Cd. Compared with the metal concentrations in soil, *Rumex* K-1 accumulated relatively low concentrations of heavy metals (Table 1).

Heavy metal transfer from soil to plant is dependent on many factors, such as soil properties, plant species, and metals bioavailability for uptake in the soil-plant system (Adriano, 1986). In the present study, the total heavy metal concentrations in the contaminated soil were higher than the background values in Guangdong (36, 47, 17, and 0.06 mg/kg for Pb, Zn, Cu, and Cd, respectively). The DTPA-extractable concentration indicated bioavailability was relatively low. *Rumex* K-1 grown on the contaminated soil accumulated low concentrations of heavy metals, and higher heavy metals concentrations were located in root than shoot. The concentration of Pb in *Rumex* K-1 was low compared to Zn concentration in *Rumex* K-1 (Table 1), which indicated that Pb mobility was much lower than Zn in the mining soil. The feces of insect always accumulated higher concentrations of heavy metals than insect larvae. The concentrations of Pb and Cd were reduced during transfer to insects; however, transfer of Cu and Zn was slightly higher to insect larvae than to plants, even though large amount was removed in feces (Table 1). Uptake of Pb and Cd from soil declined basically along the food chain to the muscle tissues of chickens, but Cu and Zn accumulations in insects were significantly higher than those in chicken muscle (Fig. 1).

Biomagnification of metals has been reported previously (Leita *et al*., 1991; Goodyear and McNeill, 1999). In the present study (Fig. 1), a declining trend of Pb and Cd transfer from one trophic level to the next in the food chain was observed in respect that Cd and Pb are non-essential elements and their assimilation in food chain, which in accordance with Van Gestel *et al*. (1993) and Heikens *et al*. (2001). Chicken has significantly high accumulation of Pb in liver (3.62 mg/kg) in comparison with brown hare and red deer (0.221–1.904 mg/kg) reported by Kramárová *et al*. (2005). Furthermore, Cd mobility in animal tissues has also been found to be very high, for example in grasshoppers (Devkota and Schmidt, 2000). Although the decreases of Cu and Zn in carnivores along the food chain were demonstrated here, the insect larvae always accumulated higher concentrations of Cu and Zn than plant leaves ($p < 0.05$), which may result from the fact that Cu and Zn are essential microelement involved in several key physiological processes (e.g., insect blood comprises Cu element) in insects (Roeder, 1953). It has also been suggested that some kinds of proteins play roles in the accumulation and storage of Cu and Zn by binding the protein metallothionein (Cherian and Nordberg, 1983). Metal trophic transfer may depend upon the dominant pathway of metal detoxication in prey. It had reported that metal associated with heat-stable, low molecular weight metal-binding proteins (e.g., metallothioneins–MT) is highly available to predators while the sequestration of metal as metal-rich granules reduces trophic transfer. Therefore, some complex mechanisms might exist in the higher tropic level of the food chain to tolerate the contaminated environment and should be further investigated.

At the end of feeding experiment (50 d), there was no significant difference in weight between the two groups of chickens. The concentrations of heavy metals in feces and chicken from the experimental and control groups were at the similar level (Fig. 2). However, the concentration of Pb

Table 1 Concentrations of Pb, Zn, Cu, and Cd in soil, *Rumex* K-1 (*Rumex patientia* × *R. tianschanicus*), insect (*Spodoptera litura*) larvae and feces (mean ± SE, *n* = 4, mg/kg fw)

Metal	Soil		Plant		Insect	
	Total	Extractable	Shoot	Root	Larvae	Feces
Pb	991 ± 152	91 ± 14	1.6 ± 0.3	4.0 ± 1.1	3.3 ± 0.8	14 ± 4.3
Zn	793 ± 127	46 ± 8.6	8.4 ± 1.9	24 ± 2.6	70 ± 5.1	90 ± 7.2
Cu	60 ± 4.0	2.2 ± 1.1	1.4 ± 0.09	2.0 ± 0.37	6.9 ± 0.7	7.3 ± 2.7
Cd	8.4 ± 0.56	0.32 ± 0.04	0.31 ± 0.01	0.73 ± 0.03	0.05 ± 0.0	1.1 ± 0.0

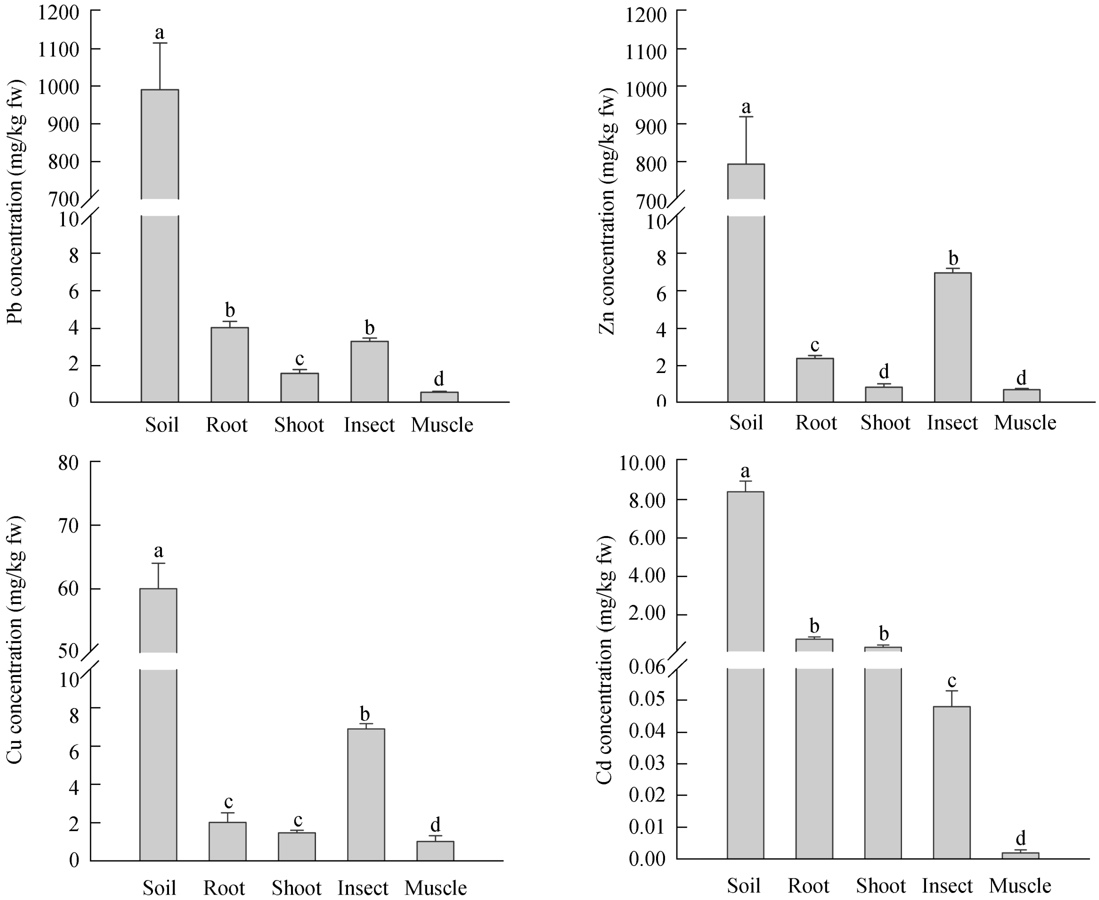

Fig. 1 Concentrations of Pb, Zn, Cu, and Cd in the food chain (soil-plant-insect-chicken). Different letters in the same figure indicate a significant difference at $p < 0.05$ according to Tukey-HSD test.

in the liver of experimental chicken was significantly ($p < 0.01$) higher than that in its counterpart. The concentrations of Zn and Cu in the muscle, and Cd in the muscle of the experimental chicken were less than their counterparts. In general, the concentrations of heavy metals in the chicken tissues and feces were in the sequence: feces > liver > muscle > blood.

Concentrations of Pb and Cd in edible tissues of poultry are of the greatest concern. From the present results (Figs. 1 and 2), the extraordinary high Pb contents in muscle (0.58 mg/kg fw) and liver (3.62 mg/kg fw) were higher than the maximum level for Pb in meat (0.1 mg/kg fw) and liver (0.5 mg/kg fw) of poultry proposed by EC Commission Regulation (Kabata-Pendias and Mukherjee, 2007). Moreover, Pb concentration in liver of chicken (3.62 mg/kg fw) fed with insect was significantly higher than that of the control (2.08 mg/kg fw). Therefore, the potential health risk associated with Pb through consumption of muscle and liver of chicken could not be neglected. In China, the maximum permissible concentration for Cd in meat and liver of poultry is 0.1 and 0.5 mg/kg fw, respectively (MHPRC, 2005). The concentrations of Cd in muscle and liver under experimental conditions were below the limits. The results showed that the concentrations of heavy metals in the vicinity of Lechang Pb/Zn mine are ecologically important, mainly of Pb. The hygienic control of poultry from the polluted area should be intensified with regard to human consumption.

It has been known that metals accumulated in higher level in the liver and the kidney than other body tissues (Kim *et al*., 1996). The significantly higher concentrations of Pb, Zn, Cu, and Cd in chicken and insect feces, compared to the chicken body tissues and insect larvae indicated that feces might be an important elimination or avoidance route, which in accordance with the previous studies (Crawford *et al*., 1995). It has indicated that the excretion mechanisms are sequestration through the digestive tract to the feces or feathers. Bio-concentration of metals will dependent on the differences in metal uptake, storage and regulatory mechanisms within species (Roeder, 1953; Hopkin, 1989).

3 Conclusions

In conclusion, the decreases of heavy metals along the soil-plant-insect-chicken food chain were demonstrated. Cd steadily declined with increasing trophic level, but concentrations of Zn and Cu slightly increased from plant to insect larva. An important route to avoid bioaccumulation was the elimination of the four elements in feces of insect and chicken. Metal concentrations in liver, muscle, and blood of chickens was highly variable, but were the highest in the liver and the lowest in blood. The chicken fed with insect-larva accumulated significantly high Pb in their

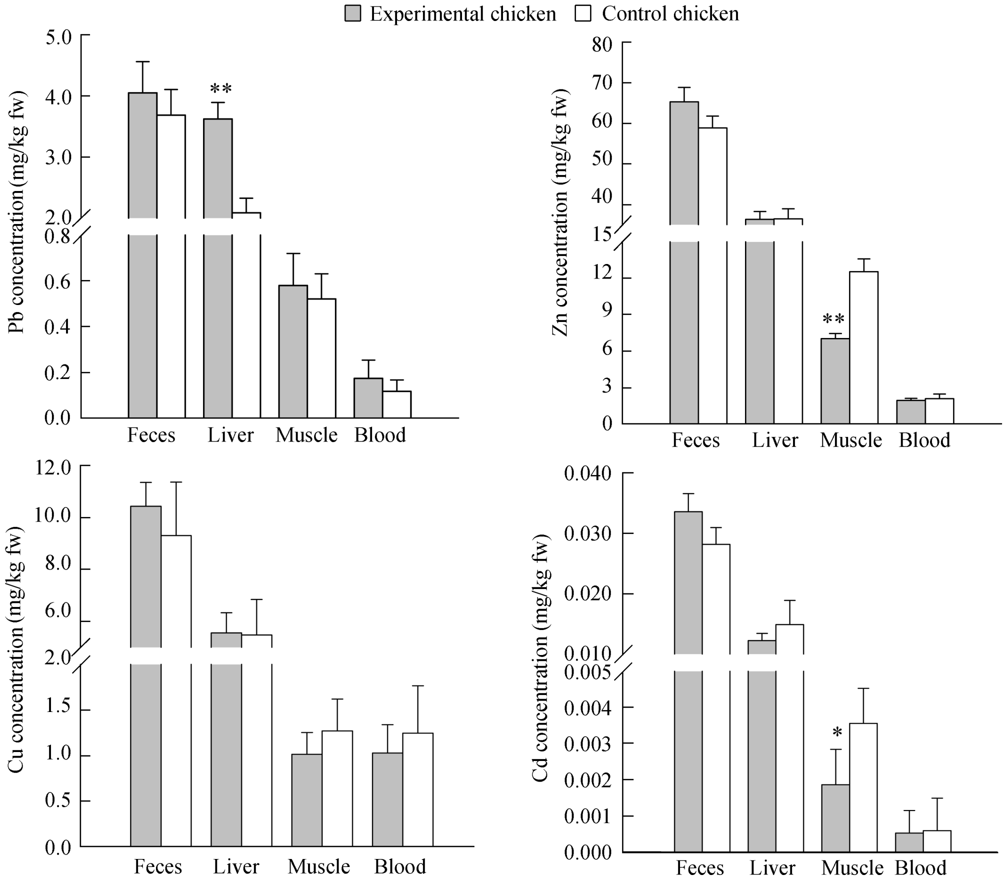

Fig. 2 Concentrations of Pb, Zn, Cu, and Cd (mean ± SE, $n = 24$) in the tissues and feces of chicken. * $p < 0.05$; ** $p < 0.01$.

livers, suggested that the accumulation of heavy metals in specific animal organ could not be neglected.

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References

Adriano D C, 1986. Trace Elements in the Terrestrial Environment. New York: Springer-verlag.

Bai J H, Cui B S, Wang Q G, Wang Q G, Gao H F, Ding Q Y, 2008. Assessment of heavy metal contamination of roadside soils in Southwest China. *Stochastic Environmental Research and Risk Assessment*, (in press)

Blakbern A A, 2003. Accumulation and migration of trace elements along trophic chains in ecosystems of the Chaktal Biophere Reserve (the Western Tien Shan, Uzbekistan). *Russian Journal of Ecology*, 34(1): 68–71.

Cherian M G, Nordberg M, 1983. Cellular adaptation in metal toxicology and metallothionein. *Toxicology*, 28(1-2): 1–15.

Crawford L A, Hodkinson I D, Lepp N W, 1995. The effects of elevated host-plant Cd and Cu on the performance of the aphid *Aphis fabae* (Homoptera: Aphididae). *Journal of Applied Ecology*, 32(3): 528–535.

Devkota B, Schmidt G H, 2000. Accumulation of heavy metals in food plants and grasshoppers from the Taigetos Mountains, Greece. *Agriculture, Ecosystems & Environment*, 78(1): 85–91.

Gasparik J, Massányi P, Slamecka J, Fabis M, Jurcik R, 2004. Concentration of selected metals in liver, kidney, and muscle of the red deer (*Cervus elaphus*). *Journal of Environmental Science and Health. Part A*, 39(8): 2105–2111.

Goodyear K L, McNeill S, 1999. Bioaccumulation of heavy metals by aquatic macro-invertebrates of different feeding guilds: A review. *Science of the Total Environment*, 229(1-2): 1–19.

Gorree M, Tamis W L M, Traas T P, Elbers M A, 1995. BIOMAG: a model for biomagnificaion in terrestrial food chain. The case of cadmium in the Kempen, The Netherlands. *Science of the Total Environment*, 168(3): 215–223.

Heikens A, Peijinenburg W J G M, Hendriks A J, 2001. Bioaccumulation of heavy metals in terrestrial invertebrates. *Environmental Pollution*, 113(3): 385–393.

Hopkin S P, 1989. Ecophysiology of Metals in Terrestrial Invertebrates. New York: Elsevier Applied Science.

Jeffrey M L, 2003. Cadmium and lead in tissues of mallards (*Anas platyrhynchos*) and wood ducks (*Aix sponsa*) using the Illinois River (USA). *Environmental Pollution*, 122(2): 177–181.

Kabata-Pendias A, Mukherjee A B, 2007. Trace Elements from Soil to Human. NewYork: Springer-Verlag. 82.

Kim E Y, Ichihashi H, Saeki K, Atrashkevich G, Tanabe S, Tatsukawa R, 1996. Metal accumulation in tissues of seabirds from Chaun, Northeast Siberia, Russia. *Environmental Pollution*, 92(3): 247–252.

Kramárová M, Massányi P, Slamecka J, Tataruch F, 2005.

Distribution of cadmium and lead in liver and kidney of some wild animals in Slovakia. *Journal of Environmental Science and Health, Part A*, 40(3): 593–600.

Leita L, Enne G, Nobili D M, Baldini M, Sequi P, 1991. Heavy metal bioaccumulation in lamb and sheep bred in smelting and mining areas of S.W. Sardinia (Italy). *Bulletin of Environmental Contamination and Toxicology*, 46(6): 887–893.

Lindquist L, 1992. Accumulation of cadmium, copper, and zinc in five species of phytophagous insects. *Environmental Entomology*, 21(1): 160–163.

Merrington G, Winder L, Green I, 1997. The uptake of cadmium and zinc by the bird cherry oat aphid *Rhopalosiphum padi* (Homoptera: Aphididae) feeding on wheat grown on sewage sludge amended agricultural soil. *Environmental Pollution*, 96(1): 111–114.

MHPRC (Ministry of Health of the People's Republic of China), 2005. Maximum levels of contaminants in foods (GB2762-2005). Beijing, China: MHPRC.

Milton A, Cooke J, Johnson M, 2003. Accumulation of lead, zinc, and cadmium in a wild population of *Clethrionomis glareolus* from an abandoned lead mine. *Archives of Environmental Contamination and Toxicology*, 44: 405–411.

Notten M J M, Oosthoek A J P, Rozema J, Aerts R, 2005. Heavy metal concentrations in a soil-plant-snail food chain along a terrestrial soil pollution gradient. *Environmental Pollution*, 138(1): 178–190.

Prince W S P M, Senthil kumar P, Subburam V, 2001. Mulberry-silkworm food chain – a templet to assess heavy metal mobility in terrestrial ecosystems. *Environmental Monitoring and Assessment*, 69(3): 231–238.

Roeder K D, 1953. Insect Physiology. New York: Wiley.

Vandecasteele B, Samyn J, Quataert P, Muys B, Tack Filip M G, 2004. Earthworm biomass as additional information for risk assessment of heavy metal biomagnification: a case study for dredged sediment-derived soils and polluted floodplain soils. *Environmental Pollution*, 129(3): 363–375.

Van Gestel C A M, Dirven-Van Breemen E M, Baerselman R, 1993. Accumulation and elimination of cadmium, chromium, and zinc and effects of grown and reproduction in *Eisenia andrei* (Oligochaeta, Annelida). *Science of the Total Environment*, (Supplement 1): 585–597.

Wang H Y, Arne O S, 2003. Heavy metal pollution in air-water-soil-plant system of Zhuzhou City, Hunan Province, China. *Water, Air and Soil Pollution*, 147(1-4): 79–107.

Winder L, Merrington G, Green I, 1999. The tri-trophic transfer of Zn from the agricultural use of sewage sludge. *Science of the Total Environment*, 229(1-2): 73–81.