PWHPTC 10th Anniversary Scientific Conference

Health Effects of Heavy Metal Exposures and Prevention Strategies

Accumulation and Health Risk of Heavy Metals in Vegetables Grown on Contaminated Soil

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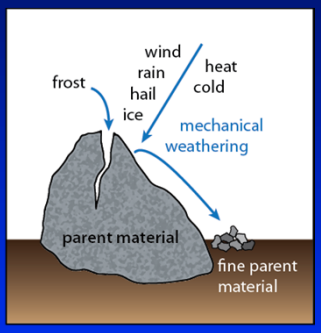
Health risk of heavy metals in vegetables

Lecture outline and take home messages

- Heavy metals – persistence, toxicity
- Sources of heavy metals in agricultural soils
  Natural – weathering of rocks
  Anthropogenic – atmospheric deposits, waste water, fertilisers, waste sludge, manure, compost
- Uptake of heavy metals in vegetables
  Contaminated agricultural soils
  Atmospheric deposits
- Risk management and prevention (monitoring)

Natural sources of heavy metals in soils
Occur at trace levels and rarely toxic

- Weathering of rock outcrops
  Rock types and environmental conditions ⇒ composition and concentrations of heavy metals
  Soils mostly from sedimentary rock (not easily weathered)
- Volcanic emissions
- Windblown dusts
- Forrest fire, sea salts, vegetations



Heavy metal composition of typical uncontaminated soils and agricultural crops (mg/kg, ranges)

Heavy metals	Soils	Agricultural crops
Cd	0.01–0.7	0.2–0.8
Co	1–40	0.05–0.5
Cr	5–3,000	0.2–1.0
Cu	2–100	4–15
Fe	7,000–55,000	–
Mn	100–4,000	15–100
Mo	0.2–5	1–100
Ni	10–00	1.0
Pb	2–200	0.1–10
Zn	10–300	15–200

Nagajyoti PC et al. Environ Chem Lett 2010; 8: 199-216

Anthropogenic sources of heavy metal pollution

Changes in agricultural land use

Paddy rice to high-value cash crops (e.g. vegetables)

- Farmyard manure as fertilisers
- Food additives (heavy metals, antibiotics) in animal feed
- Cadmium, copper, zinc accumulate in soils years later

(Wu LH et al. Environ Sci Pollut Res 2013)

Paddy rice → Vegetables

Heavy metal concentrations (mg/kg) in soil amendments

Metals	Sewage sludge	Compost refuse	Farmyard manure	Phosphate fertilisers	Nitrate fertilisers	Lime	Pesticides
Cr	8.40-600	1.8-410	1.1-55	66-245	3.2-19	10-15	-
Ni	6-5,300	0.9-279	2.1-30	7-38	7-34	10-20	-
Cu	50-8,000	13-3,580	2-172	1-300	-	2.-125	-
Zn	91-49,000	82-5,894	15-556	50-1,450	1-42	10-450	-
Cd	<1-3,410	0.01-100	0.1-0.8	0.1-190	0.05-8.5	0.04-0.1	-
Pb	2-7,000	1.3-2,240	0.4-27	4-1,000	2-120	20-1,250	11-26

Nagajyoti PC et al. Environ Chem Lett 2010; 8: 199-216

Assessing heavy metal sources in soils

Multivariate / geostatistical analyses of spatial distribution

- Multivariate analysis
  Principal component analysis, cluster analysis
- Geostatistical analysis
  Spatial distribution correlated with their sources
- Time trend analysis (natural vs arthropogenic)
- Hangzhou (Co, Mn, Ni vs Hg, Cd) (Chen T et al, 2000)
- Fujian (As, Ni, Cu vs Cd, Zn, Pb) (Yu J et al, 2012)
- Shandong (Cr, As, Ni vs Cd, Cu, Zn, Hg, Pb) (Liu P)
- Beijing (As, Pb vs Cd, Cu, Zn, Hg) (Lu AX et al, 2012)

Soil and air pollution enhances accumulation

Atmospheric deposition = a major source of heavy metal contamination for vegetables grown in urban and industrial districts

Greenhouse

Atmospheric deposition

Irrigation

Fertilisers

Farm

Market

From production, transport to sales of vegetables

Vegetables absorb heavy metals from soils

Factors affecting uptake by vegetables

- Leafy > flowering > root > fruit vegetables
- Pakchoi with the lowest uptake in leafy ones
- Higher concentrations of heavy metals in soils
- Cadmium > other heavy metals
- -ve correlation with soil pH
- -ve correlation with soil clay content
- -ve correlation with soil organic matter content
- Greenhouse farming

Effects of greenhouse vegetable farming
Heavy metal accumulation in soils and vegetables

- Greater accumulation of heavy metals in soils (especially over time, and solar greenhouse > round-arched plastic greenhouse) compared to open-field soils, because of:

  Accelerated decomposition/humification of organic fertilisers, ↓ soil pH, more fertilisers/pesticides used

Calculation of the transfer factor (TF)
Transfer of heavy metals from soil to vegetables

TF, bioconcentration factor (BCF) or accumulation factor (AF)

$$TF = \frac{\text{Metal concentration in edible part vegetables (dry weight)}}{\text{Metal concentration in root soil (dry weight)}}$$

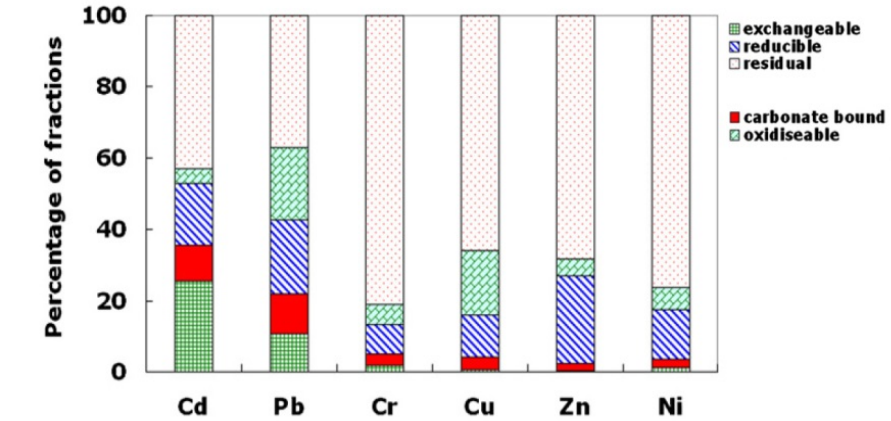
TF (mean, SD) of crops grown in reclaimed farmland of Pearl River Estuary

Crops	Cd	Pb	Cr	Cu	Zn	Ni
Leaf crop	0.909 ± 0.579	0.025 ± 0.009	0.013 ± 0.021	0.113 ± 0.046	0.246 ± 0.173	0.069 ± 0.033
Flowering crop	0.423 ± 0.437	0.014 ± 0.001	0.010 ± 0.002	0.113 ± 0.015	0.079 ± 0.017	0.064 ± 0.022
Root crop	0.224 ± 0.228	0.016 ± 0.001	0.023 ± 0.019	0.096 ± 0.035	0.112 ± 0.005	0.083 ± 0.069
Fruit crop	0.084 ± 0.184	0.011 ± 0.027	0.012 ± 0.004	0.092 ± 0.046	0.119 ± 0.041	0.055 ± 0.029
Rice	0.206 ± 0.047	0.006 ± 0.001	0.021 ± 0.003	0.113 ± 0.054	0.099 ± 0.008	0.059 ± 0.002

Li Q et al. J Hazard Mater 2012 ; 148-154

Chemical speciation of heavy metals in surface soils

Reclaimed farmland of Pearl River Estuary



Exchangeable = mobile, phytoavailable

Li Q et al. J Hazard Mater 2012 ; 148-154

Daily intake of heavy metals in vegetables

Daily intake of heavy metals (DIM) in vegetables is calculated using the following equation:

$$\text{DIM} = \frac{M \times K \times I}{W}$$

M = the concentration of heavy metals in plants (mg/kg)
K = conversion factor
I = daily intake of vegetables
W = average body weight of adults or children

Fresh weight of vegetables converted to dry weight by using the conversion factor 0.085

Average daily vegetable intakes for adults and children from the community survey

Health risk index (HRI)

Human health risk from intake of contaminated vegetables

Human health risk from intake of heavy metal-contaminated vegetables is characterised using the health risk index (HRI).

This index is calculated as the ratio of daily intake of heavy metals (DIM) in vegetables and an oral reference dose (RfD) expressed in the following equation:

$$HRI = \frac{DIM}{RfD}$$

The RfD values for Cd, Pb, Cr, Ni, Zn, and Cu are 0.001, 0.004, 1.5, 0.02, 0.3, and 0.04 mg/kg/day, respectively

If the HRI is <0.1, the exposed population is said to be safe

Multiple organ involvement after chronic oral exposures

Metals	Kidney	Neuro	Liver	Gut	Lung	Blood	Bone	Repro	Skin	Heart	Cancer
Arsenic		+	+	+	+	+		+	+	+	+
Cadmium	+			+	+		+	+			Smoker
Chromium									+		
Copper			+								
Lead	+	+		+		+		+	+		
Mercury	+	+		+	+			+			
Manganese		Parkinsonian						+			
Zinc						Cu def					

Eastern Turkey (Van region), upper GI cancers endemic; Cd, Pb, Cu, Co 2- to 50-fold higher concentrations in soil; fruits/vegetables 3.5- to 340-fold higher amounts of Co, Cd, Pb, Mn, Ni and Cu (Türkdoğ MK et al. Environ Toxicol Pharmacol 2002)

CAP 132V FOOD ADULTERATION (METALLIC CONTAMINATION) REGULATIONS

Schedule 2 Maximum permitted concentration of certain metals present in specified foods

A Metal	B Description of food	C Maximum permitted concentration in parts per million
Antimony (Sb)	Cereals and vegetables	1
	Fish, crab-meat, oysters, prawns and shrimps	1
	Meat of animal and poultry	1
Arsenic (AS_2O_3)	Solids other than – (i) fish and fish products; and (ii) shellfish and shellfish products	1.4
	All food in liquid form	0.14
Cadmium (Cd)	Cereals and vegetables	0.1
	Fish, crab-meat, oysters, prawns and shrimps	2
	Meat of animal and poultry	0.2

http://www.legislation.gov.hk/blis_pdf.nsf/CurAllEngDoc/05FECBCB00468409482575EE0042BB5B/$FILE/CAP_132V_e_b5.pdf

CAP 132V FOOD ADULTERATION (METALLIC CONTAMINATION) REGULATIONS

Schedule 2 Maximum permitted concentration of certain metals present in specified foods

A Metal	B Description of food	C Maximum permitted concentration in parts per million
Chromium (Cr)	Cereals and vegetables	1
	Fish, crab-meat, oysters, prawns and shrimps	1
	Meat of animal and poultry	1
Lead (Pb)	All food in solid form	6
	All food in liquid form	1
Mercury (Hg)	All food in solid form	0.5
	All food in liquid form	0.5
Tin (Sn)	All food in solid form	230
	All food in liquid form	230

http://www.legislation.gov.hk/blis_pdf.nsf/CurAllEngDoc/05FECBCB00468409482575EE0042BB5B/$FILE/CAP_132V_e_b5.pdf

Vegetable-borne nitrate and nitrite
Risk of methaemoglobinaemia

- In fresh, undamaged vegetables, the nitrite conc are usually very low. Under adverse post-harvest storage conditions, nitrite conc. in vegetables increase as a result of bacterial contamination and endogenous nitrate reductase action. Nitrite accumulation in vegetables is inhibited under frozen storage because endogenous nitrate reductase is inactivated. Pureeing releases endogenous nitrate reductase, increasing nitrite conc. in vegetables.
- Excessive use of nitrogen fertilisers should be avoided so as to reduce nitrate build up in soil or vegetables.
- Nitrate levels in some vegetables can decrease after cooking in water or blanching. Home prepared infant food with vegetables should be avoided until the infant is ≥3 months.

Chan TYK. Toxicol Lett 2011; 200: 107-108

Vegetables are the vital part of human diet
How to minimise toxic exposures to heavy metals

- Good farming practice
  - Agricultural soils
  - Fertilisers
  - Water for irrigation
  - Crops
- Legislations and risk assessment
  - Regulatory control
  - Risk assessment and monitoring
  - Research and collaboration