HUMAN HEALTH RISK ASSESSMENT DUE TO CADMIUM ACCUMULATION THROUGH CONSUMPTION OF CHINESE CABBAGE GROWN IN CADMIUM-CONTAMINATED SOIL

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Abstract

Heavy metal like Cadmium (Cd) is a common pollutant present in the soils of urban and industrial areas. Vegetables are preferably grown in these soils than other crops. Of the vegetables, Chinese cabbage (*Brassica campestris var. pekinensis*) is gaining its popularity among farmers for its high market value. Therefore, an experiment was conducted where cabbage was grown on Cd treated soil. Bioaccumulation of Cd in Chinese cabbage was determined and Target Hazard Quotient (THQ) model was used to assess potential health risk of human. Results showed that with increasing concentration of added Cd (0.00 to 4.00 ppm) in soil, bio-concentration factors of Cd of Chinese cabbage also increased except at 4 ppm. The chinese cabbage grown in Cd contaminated soils up-to 1.00 ppm might be safe. However, cabbage grown in the soils contaminated with Cd above this level would probably be risky and may cause serious health hazard to human body.

Key words: Cadmium, Chinese cabbage, THQ model, Bio-concentration factors, Human health risk assessment.

INTRODUCTION

Bioaccumulation is the process in which persistent toxins are passed along the food chain and accumulate in progressively higher concentrations. When a relative accumulation of pollutants gets up the food chain in more complex organisms, at least for the toxins that are stored in some way, the way may be called bioaccumulation (Bashar 2004). It is a general rule that as pollution increases, the physiological and genetic health of animal populations decline and eventually the number of species in the polluted ecosystem declines. In this process the plants that are affected, for example, may be eaten by small animals with little adverse effect, but as the relative pollution levels rise toxins become concentrated higher up the food chain, where the effects can be magnified, it is not quite that simple, because higher up a food chain, larger creatures may have a greater resistant or ability to deal with poisoning (Woodwell 1967).

Cadmium (Cd), one of the most environmental hazardous heavy metals, has been released into the environment by different human activities; for example, leather processing, electroplating, metal-containing sewage sludge and fertilizers (Zhou *et al*. 2002, Zhou 2003). Rapid uptake and bio-accumulation of Cd in food chain makes this element a potential environmental hazard (De 1989). Cadmium is extremely toxic to animals and causes severe problem in kidneys, liver, gastrointestinal tract, heart, testes, pancreas, bones and blood vessels (Conway and Pretty 1991). The food plants grown in Cd contaminated soils may have possibility of high Cd uptake (Mengal and Kirkby 1987).

Vegetables cultivated in the soils, polluted with toxic and heavy metals, take up such metals and accumulate them in their edible and non-edible parts in quantities high enough to cause clinical problems both to animals and human beings consuming these metal-rich plants as there is no good mechanism for their elimination from the human body (Alam *et al.* 2003, Bhuiyan *et al.* 2011). But by the help of enrichment factor, estimation of metal entry in plant body from metal contaminated soil can be made. Enrichment factor is defined as the ratio of particular element content in a plant to the soil. This was first proposed for the source diagnosis of atmospheric particulate matter in the Antartic (Zoller *et al*. 1974). Recently, enrichment factor is used in the soil, water and sediment research as transfer factor, bio concentration factor (BCF) and plant uptake factor. This ratio is also used for the assessment of heavy metal pollution in environmental geochemistry (Khan *et al*. 2010, Delgado *et al*. 2012, Brioschi *et al*. 2013). BCF is used as indicator for estimating the metal transfer from soil into plant (USEPA 2005). In leafy vegetables, tubers and fruit vegetables, BCF-based research shows that the extent of metal enrichment in vegetables is highest (Liu *et al*. 2012, Pandey and Pandey 2009). Regarding metal concentrations, cadmium (Cd) commonly occurs at high levels in leafy vegetables (Ngole 2011).

Chinese cabbage (*Brassica campestlris var. pekinensis*) belonging to the family Cruciferae is an important leafy, herbaceous vegetable widely grown crop and said to be originated in China (Rashid 1999). It is gaining popularity among farmers for its rapid growth, high yield and economic return. The productions of different cabbages are increasing each year (BBS 2015). In the Dhaka division, Savar agricultural area is extensively used for vegetable production. Due to different anthropogenic activities like textile industry, pharmaceuticals companies, low grade fertilizer application, automobile etc., the soils of Savar, Bangladesh are contaminated with Cd and become very risky to grow leafy vegetable (Aktaruzzaman *et al*. 2013). Thus, the objectives of this study were to evaluate the potential accumulation capacity of Chinese cabbage for Cd. Moreover, bio concentration factor to assess the potential human health risks of Cd metal exposure to the Dhaka city residents through consumption of contaminated Chinese cabbage was evaluated using the Target Hazard Quotient (THQ) (USEPA 2002). The THQ, which is the ratio between the exposure and the reference dose (RfD), is used to express the risk of non-carcinogenic effects. Ratio of less than 1 signifies non-obvious risk. Conversely, an exposed population of concern will experience health risk if the dose is equal to or greater than the RfD. The method for the determination of THQ was provided in the United States EPA Region III risk-based concentration table (USEPA 1989).

MATERIAL AND METHODS

Field site and soil characterization

A pot experiment was carried out in the net house of the Department of Soil Water and Environment, University of Dhaka. Soil samples (0-20 cm depths) were collected from the field near Bangobondhu Shekh Mujibur Rahman Hall, Jahangirnagar University. Some physico-chemical properties of the soil determined are as follows: pH 6.48 (1:2.5 W/V H_2O), sand 10%, silt 62% and clay 28%, textural class – silty clay loam (Piper 1944), CEC 28.71 me/100g soil, soil colour – red and organic carbon 1.24% (Jackson 1958). Total nitrogen 0.30% (Marr and Cresser 1983), total phosphorus 0.04% (Jackson 1967), potassium 0.24%, sulphur 0.01% (Klute 1986) and cadmium (Wei *et al*. 2005) – below detection limit.

Experimental procedure

Three kilogram air-dry soil (passed through 3 mm sieve) was used per plastic pot. Treatments used were Control (without Cd), 0.25 ppm Cd/3 kg soil, 0.50 ppm Cd/3kg soil, 1.0 ppm Cd/3kg soil, 1.5 ppm Cd/3 kg soil, 2.0 ppm Cd/3 kg soil, 3.0 ppm Cd/3 kg soil, and 4.0 ppm Cd/3 kg soil. Cadmium Chloride ($CdCl_2.2.5H_2O$) was applied in the pots as per treatment. Treatment 0.00 ppm stands for unpolluted. Treatment 0.25, 0.50 and 1.00 stands for unpolluted to moderately pollute. Treatment 1.50 and 2.00 ppm stand for moderately polluted and treatment 3.00 ppm stands for moderately to strongly pollute. Lastly, 4.00 ppm stands for strongly polluted (Muller 1969). Eight treatments replicated thrice were arranged in a completely randomized design (CRD). Chinese cabbage seeds were collected from Rajdhani Seed Company, Siddique Bazar, Dhaka. Before sowing, the seeds were sterilized in 2 % (v/v) hydrogen peroxide for 10 minutes, washed several times with distilled water and soaked in water overnight. Five seeds were sown per plot and finally two seedlings were allowed to grow. Seedlings were irrigated with tap water. Intercultural operations, *viz.* weeding, pesticide application etc., were done as and when needed. Plants were harvested as root and leaf after twelve weeks of growth. Heights were recorded at the time of harvest.

Plant sample preparation and analysis

Leaf samples were collected and wiped with a piece of white cloth and washed with distilled water. Root samples were washed with tap water and finally with distilled water to remove soil particles. The samples were then dried at 70º C in an oven until completely dry. The dried plant samples were grinded and kept in polyethylene bag for chemical analysis. The leaf sample (0.1 g) was digested with 12 ml solution of concentrated nitric acid (HNO_3) and concentrated per chloric acid ($HClO_4$) (v/v) (Wei *et al*. 2005). The concentrations of heavy metals in digest were determined using an atomic absorption spectrophotometer (VARIAN AA240).

Statistical analysis

Data were analyzed with statistical package Minitab 17 and SPSS 20. The differences among treatment were evaluated by one-way ANOVA ($p<0.05$) according to the Tukey's multiple range test.

RESULTS AND DISCUSSION

Dry matter yield

Plant heights, fresh and dry weight of root and leaf were measured at different treatments (Table 1). Highest values of the height, fresh weight and dry weight of the root and leaf were observed in treatment receiving no Cd (Table 1). For the treatments maximum height (17.6 cm) was recorded in T_2 treatment (0.25 ppm Cd/3 kg soil) 0.25 ppm among the Cd treatments. However, no significant variation was observed among the Cd treated plants. The highest dry matter yield of the root (4.26 g/plant) and leaf (2.00 g/plant) were also achieved in T_2 treatment. Total fresh weights of the root and leaf (6.26 g/plant) were recorded highest also with the same treatment. The highest dry weights of the root (2.38 g/plant) and leaf (0.79 g/plant) were also observed in the treatment having concentrations at 0.25 ppm. Total dry weights of the root and leaf (3.17 mg/kg) were also observed with the same treatment (Table 1).

Table 1. Effects of cadmium on dry matter yield of Chinese cabbage grown in soil.

Treatments	Height (cm)	Fresh weight(g/plant)			Dry weight(g/plant)		
		Root	Leaf	Total	Root	Leaf	Total
(Control) 0.0 ppm Cd/3kg soil	17.9^a	4.58^a	2.02^a	6.6	2.82^a	0.87^a	3.69
0.25 ppm Cd/3kg soil	17.6^a	4.26^b	2.00^a	6.26	2.38^b	0.79^b	3.17
0.50 ppm Cd/3kg soil	16.9^a	3.21^c	2.08^b	5.29	1.96^c	0.74^b	2.70
1.00 ppm Cd/3kg soil	16.6^a	3.17^c	1.90^c	5.07	1.70^d	0.71^b	2.41
1.50 ppm Cd/3kg soil	16.0^a	3.22^c	1.50^d	4.72	1.55^e	0.63^c	2.18
2.00 ppm Cd/3kg soil	15.4^a	3.05^d	1.32^e	4.37	1.60^e	0.46^d	2.06
3.00 ppm Cd/3kg soil	14.7^a	2.83^e	1.04^f	3.87	1.27^f	0.30^e	1.57
4.00 ppm Cd/3kg soil	14.1^a	1.06^f	1.35^g	2.41	0.56^g	0.48^f	1.04
LSD at 5%	0.16	0.06	0.06	-	0.06	0.06	-

Tukey pair test

Highest concentration of Cd was found in the treatment 3.00 ppm. However, the lowest concentration of Cd was found in the treatments 0.25 and 0.50 ppm. The concentration values of Cd varied significantly in the treatments 3.00, 4.00, 2.00, 1.50, 1.00 and 0.50 ppm although treatments 0.00 and 0.25 did not vary significantly (Table 2).

Table 2. Tukey pair wise comparison tests among treatments.

Grouping Information Using the Tukey Method and 95% Confidence

treatment	N	Mean	Grouping
7	3	1.12000	A
8	3	0.87333	B
6	3	0.57000	C
5	3	0.41333	D
4	3	0.26000	E
3	3	0.067333	F
2	3	0.017333	G
1	3	0.000000	G

Means that do not share a letter are significantly different.

Accumulation of Cd

Treatments caused variable accumulations of Cd in the leaf of Chinese cabbage (Fig. 1). Accumulated cadmium in the leaf was around 0.0, 0.023, 0.067, 0.26, 0.41, 0.57, 1.12, and 0.87 ppm, respectively. Accumulations showed marked variation among the treatments. The values of Cd increased sharply with increasing concentration except the 4 ppm which decreases. The highest uptake was found in the 3 ppm and that of the lowest was found in 0 ppm. There was no significant difference between 0 and 0.5 treatments (Fig. 1).

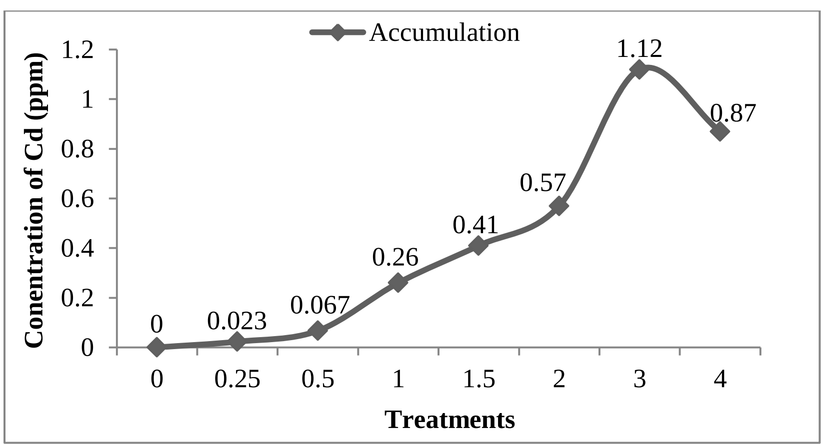

Fig. 1. Accumulation of Cd in the leaf of Chinese cabbage in different treatments.

However, other treatments caused significant variation in the doses of Cd applied. Highest concentration of Cd was found in the 3.0 ppm treatment. However, the lowest concentration of Cd was found in the treatments 0-0.5 ppm. The decline in Cd concentration in the tissue of leaf at the highest concentration dose might be due to the toxic effect of the metal.

Bio-concentration factor (BCF)

Bio-concentration factor (BCF) is a ratio of total cadmium accumulation in plant to soil was calculated where plant were grown

$$BCF = \frac{C_{vegetable}}{C_{soil}}$$

In this study, several bio-concentration factors were found that were associated with the treatments. Bio-concentration factors of the treatments 0 - 4 ppm of cadmium were adjusted and the values were around 0.0, 0.092, 0.134, 0.26, 0.27, 0.29, 0.37 and 0.22 ppm, respectively. The highest amount of BCF was found in the treatment receiving 3.0 ppm of Cadmium whereas the lowest measure of BCF was recorded in the 0.0 ppm treatment of cadmium. The BCF was augmented with the increment of cadmium up to 3 ug/pot and declined thereafter (Fig. 2).

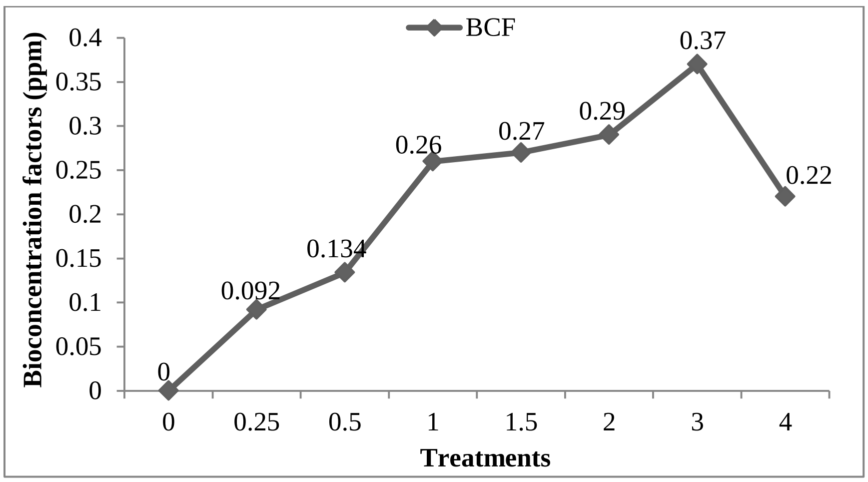

Fig. 2. Bio-concentration factor (BCF) of Cd for different treatments.

Target Hazard Quotient (THQ)

The THQ value determines the potential risk that is associated with the cadmium accumulation. If THQ is less than 1, no risk associated with the consumption but higher than 1 is potentially toxic.

$$Single\ pollutant : THQ = \frac{C \times IR_{vegetable} \times EF \times ED}{BW \times AT \times RfD} \times 10^{-3}$$

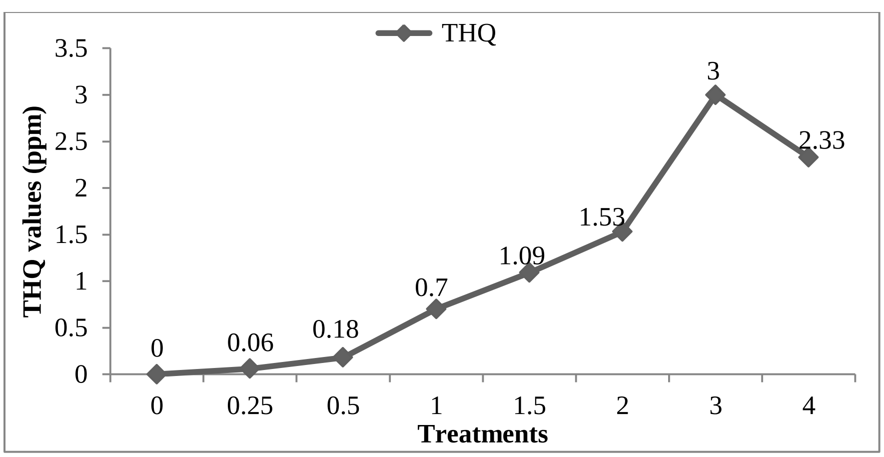

Fig. 3. Target Hazard Quotient (THQ) of different treatments applied Chinese cabbage.

In Bangladesh, exposure frequency per year (days/year), **EF** = 90/365=0.24; in urban area, the vegetable ingestion rate per day (g/day), **IR** = 155 g; exposure duration (year); **ED** = 70.7 years, average weight of local residency, **BW** = 57.7 kg; average exposure time for non-carcinogens, **AT** = EF × 70.7 years = 16.96; oral reference dose, **RFD** = 0.001 mg/kg-day (Finucane *et al*. 2011, BSS 2010, Foulkes 1986).

With increasing concentration of Cd in soil, bio-concentration factors of Cd in Chinese cabbage (*Brassica campestris var. pekinensis*) also increased except at 4 ppm. As far as human health is concerned, Chinese cabbage grown in Cd contaminated soils contenting 1.0 ppm might be safe. However, Chinese cabbage grown on the soils with Cd content 2.0, 3.0 and 4.0 ppms were risky and may cause serious health hazard to human body. From the study, it is clear that Chinese cabbage can be cultivated in Cd contaminated soil containing maximum 1 ppm Cd which will not cause any risk beyond which it is extremely risk for health.

Not only Chinese cabbage, but also all other consumable vegetables are similarly contaminated through the process of bioaccumulation of heavy metals by passing the successive trophic levels in an ecosystem (Woodwell 1967). The present paper deals with only one (Cd) heavy metal. Movement of all heavy metals follows more or less the same pattern but accumulation or/and concentrations in parts per million (ppm) are varied depending on the number of trophic levels are involved. However, these heavy metals as per their movement pathways and rate of concentrations cause manifold impacts on depleting bioresources (including humans) through bioaccumulation almost in all ecosystems. This biological process has been occurring in nature very often by the anthropogenic activities.

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