Published in final edited form as:

Sci Total Environ. 2018 September 15; 636: 810–817. doi:10.1016/j.scitotenv.2018.04.299.

The influence of various organic amendments on the bioavailability and plant uptake of cadmium present in mine-degraded soil

Muhammad Amjad Khan^{a,b,c}, Xiaodong Ding^a, Sardar Khan^{b,*}, Mark L Brusseau^c, Anwarzeb Khan^a, and Javed Nawab^d

^aCollege of Resources and Environment, Qingdao Agricultural University, Qingdao 266109, China

^bDepartment of Environmental Sciences, University of Peshawar, Peshawar 25120, Pakistan

^cSchool of Earth and Environmental Sciences, University of Arizona, Tucson, AZ 85721, USA

^dDepartment of Environmental and Conservation Sciences, University of Swat, Swat 19130, Pakistan

Abstract

Mining of minerals and precious elements leads to land degradation that need to be reclaimed using environmentally friendly and cost effective techniques. The present study investigated the potential effects of different organic amendments on cadmium (Cd) bioavailability in mining-degraded soil and its subsequent bioaccumulation in tomato and cucumber. The selected organic geosorbents (hard wood biochar (HWB), bagasse (BG), rice husk (RH), and maize comb waste (MCW)) were added at application rates of 3% and 5% to chromite mine degraded soil containing Cd. Tomato and cucumber plants were then grown in the soil, and the roots, shoots, leaves, and fruits of each plant were analysed for Cd concentration, biomass production, and chlorophyll content. The results indicated that the different organic materials have variable effects on physiochemical characteristics of vegetables and Cd bioavailability. The biochar amendment significantly ($P < 0.01$) increased chlorophyll contents (20–40%) and biomass (40–63%), as did RH to a lesser extent (increase of 10–18% in chlorophyll content and 3–45% in biomass). Among the amendments, HWB was the most effective at reducing Cd bioavailability, wherein significant decreases were observed in Cd uptake by fruits of tomato (24–30%) and cucumber (36–54%). The higher application rate of 5% was found to be more effective for mitigation of Cd mobility and bioaccumulation in plants grown in mine degraded soil. The study results indicate that effective use of organic amendments, especially HWB, can significantly reduce Cd levels in vegetables, improve food quality, and reduce human-health risk while increasing biomass production.

Keywords

Degraded soil; Organic amendment; cadmium availability and bioaccumulation; hard wood biochar; bagasse; maize comb waste; plant uptake

*Corresponding author: sardar.khan2008@yahoo.com Tel: 0092 91 9216742; Fax 0092 91 9218401.

Introduction

The contamination of agricultural soils with cadmium (Cd) has steadily increased during the last few decades due to multiple factors. Firstly, intensive mining, pesticides, chemical fertilizers, and smelting discharge Cd to the environment. Secondly, Cd is widely used in pigments, nickel-Cd batteries, alloys, stabilizers, electronics, electroplating, power generation and vehicle industries (WHO, 2011). Mine degraded soils are generally poorly structured with no or very scarce vegetation due to the presence of high concentrations of toxic metals, particularly Cd (Nawab et al., 2015). Mining activities release a large amount of Cd ranging from 2 to 16.5 mg kg⁻¹ (Khan et al., 2017, 2018). Plants grown on mine impacted soil have the potential to accumulate high concentration of Cd (Zhao et al., 2014). Disposal of waste materials during manufacturing and use of these products and processes results in pathways for Cd entry into the environment, for example land application of biosolids and irrigation with wastewater (Khan et al., 2014; Zhang et al., 2010). Cd is a non-essential and potentially toxic element to all organisms (Benavides et al., 2005). For example, high Cd exposure causes bone and kidney damage, cancer, and haematuria (Han et al., 2013; Satarug et al., 2010). Due to its wide range of sources and ubiquitous occurrence, Cd has become an important environmental pollutant.

The uptake of Cd by vegetables from contaminated soil is a primary starting point of exposure for humans (Khan et al., 2015). The uptake of Cd from soil by roots, and its subsequent translocation in plants is a very complex process. The mobility of Cd in soil and its uptake by plants depend on several factors including its concentration in soil, type of plant, pH, soil organic matter, cation exchange capacity (CEC), and concentrations of iron and zinc (Meeus et al., 2002). The bioaccumulation capacity of Cd is different for different plants. The leafy vegetables accumulate the highest concentration of Cd followed by root vegetables and grains (Khan et al., 2017). High concentrations of Cd in soils pose great risk of dietary intake due to its high toxicity and enhanced uptake by plants (Liu et al., 2003).

Cd uptake by plants and resultant dietary exposure can be alleviated by reducing Cd concentrations in soil or by reducing its bioavailability to food plants (Bashir et al., 2018; Kumpiene et al., 2008; Mulligan et al., 2001). Soil remediation by reducing heavy metals mobility and bioavailability is an efficient and cost effective method to address the issue of metals toxicity (Bashir et al., 2018; Li et al., 2018). Methods for reducing soil concentrations include phytoremediation, soil washing, electrokinetic remediation, and excavation, while methods for reducing bioavailability include stabilization and solidification (Khan et al., 2017, 2018). One of the latter techniques is the in situ stabilization of metals by the addition of materials that exhibit high metal retention capacity. Different types of organic materials such as compost from the food industry, municipal waste solids, and manures and agriculture residues may be used for the remediation of metals contaminated soils (Qi et al., 2018). It is reported that organic materials have the ability to decrease metals availability by increasing the soil pH and by complexation via the reactive groups present in organic materials (Abbas et al., 2017; Karlsson et al., 2007). Similarly, some studies revealed that the increase in soil pH with application of biochar may affect the nutrient availabilities and plant uptakes (Qi et al., 2017).

Biochar derived from industrial, municipal, agriculture and food wastes can also be very beneficial for the remediation of metals-contaminated soils (Khan et al., 2015; Khan et al., 2018; Li et al., 2018; Ahmad et al., 2014; Cao and Harris, 2010). The application of biochar to soil increases the water holding capacity, enhances the calcium (Ca), phosphorous (P), and nitrogen (N) status (Borchard et al., 2012; Lehmann, 2007), and the bioavailability of Mg, Zn, and Ca (Gartler et al., 2013; Major et al., 2010).

Previously, several studies have been conducted to assess the role of biochar and organic materials in remediation of metal degraded soil. However, to authors information no such comprehensive study has been conducted to evaluate the effects of organic amendments including non-biochar materials i.e. bagasse (BG), rice husk (RH), and maize comb waste (MCW), and hard-wood derived biochar (HWB) on uptake of Cd, vegetable growth, biomass production, and chlorophyll content. The present study was conducted to investigate their potential use and compare the efficiency of these amendments for the reclamation of mining degraded soils and Cd availability to vegetables. Greenhouse experiments were conducted to compare the effects of four selected amendments on the availability, uptake, and translocation of Cd by tomato and cucumber grown in different geosorbent-amended mine degraded soils.

2 Materials and methods

2.1 Soil and amendment characteristics

Soil samples were collected from the 0–20 cm interval of agricultural fields at multiple mine-impacted sites in the Heroshah area of Malak and Agency, Pakistan. Each sample was thoroughly mixed in the laboratory to obtain a homogenized sample, and then air dried and passed through a 2-mm mesh. The soil was analysed for the total metal concentration of Cd using standard methods (Nezhad et al., 2014). Briefly, 0.5 g sample was digested with aqua regia using an automatic controlled digestion block. After completion of digestion, the extracts were cooled to room temperature and then filtered into 50-ml corning tubes and diluted with deionized water and the metal concentrations were determined using ICP-OES (Perkin-Elmer OPTIMA-2000, USA). The concentrations of phosphorous (P) and potassium (K) were determined using UV-spectrophotometer and flame photometer, respectively. The total nitrogen (N) concentration was measured using the Kjeldahl method (Khan et al., 2016).

Organic materials including bagasse (BG), rice husk (RH), maize comb waste (MCW), and hard-wood derived biochar (HWB) were selected as amendment materials. The organic amendments used in the experiments were ground and passed through a 2-mm mesh before application to the soil. HWB was prepared through pyrolysis technique at 500 °C in the absence of oxygen (Khan et al., 2013).

Greenhouse experiments

The four amendments were applied to the soil at 3% and 5% ratios (afterward referred as BG3, BG5, RH3, RH5, MCW3, MCW5, HWB3 and HWB5) and thoroughly mixed. Plastic pots were filled with 4 kg of the soil (dry weight, d.w). NPK doses were applied at

concentrations of 60, 35, and 40 mgkg⁻¹ using NH₄NO₃, and K₂HPO₄ fertilizers, respectively. Each amendment and control were prepared in triplicate. Two sets of the selected treatments were prepared. All pots were evenly irrigated with deionized water when needed. The positions of the pots were changed from time to time to ensure the availability of equal amount of light to each pot.

Seeds of tomato (Cherry tomato (*Lycopersicon esculentum*)) and cucumber (*Cucumis sativus*) were obtained from Tarnab botanical garden, Peshawar. The seeds of tomato were washed using H₂O₂ first and then with deionized water. After washing, the seeds were germinated in petri dishes. The seedlings were provided a controlled environment of 23±2°C and 12/12 photoperiod (light/dark). After germination, healthy and uniform seedlings were transferred in equal number to each pot. Cucumber seeds were directly germinated in the selected pots. The pots were kept in the greenhouse under controlled environment. The physiological characteristics and leaf chlorophyll content were measured periodically at different stages of plant growth. The chlorophyll content was measured using a SPAD chlorophyll meter. (at LEAF, PN: 0131, USA) (Ling et al., 2011). For the measurement of chlorophyll content, five leaves in each pot were randomly selected and SPAD readings were recorded in triplicate.

Vegetable sample preparation and metals extraction

After maturation (130 days) the plants were harvested, while the fruits were collected time to time on maturation. The roots were washed with tap water to remove soil particles and then thoroughly washed with deionized water. Other parts of the plants were also rinsed with deionized water. After rinsing roots, shoots, leaves and fruits were separately oven dried at 70 °C to constant weight. The oven dried samples were powdered and 0.5 g of powdered sample was digested with 5 ml concentrated HNO₃ for 1 h at 80 °C and further heated for 20 h at 120–130 °C. After digestion, the extracts were transferred to clean corning tubes and the volume was adjusted to 50 ml by adding deionized water. The Cd concentration was quantified using ICP-OES (Perkin-Elmer OPTIMA-2000, USA).

Concentration index (CI)

Concentration index (CI) for the fruits was calculated with equation (1), as given below:

$$CI = \frac{\text{Concentration of Cd in treated plant (fruit)}}{\text{Concentration of Cd in control plant (fruit)}} \quad (1)$$

Daily dietary intake of metals

The effects on daily dietary intake of Cd by the amendments were calculated using the equation (2)

$$DIM = \frac{C_{\text{metal}} \times C_{\text{factor}} \times D_{\text{food intake}}}{BW_{\text{average weight}}} \quad (2)$$

where C_{metal} is the concentration of Cd in vegetables, C_{factor} is the conversion factor, $D_{\text{food intake}}$ is the daily intake of vegetables and BW is the average body weight. A conversion factor of 0.0085 was used to convert d.w into fresh weight (Khan et al., 2008). The average daily consumption of vegetables for children was considered as 0.232 and for adults as 0.345 kg person⁻¹ day⁻¹ (Khan et al., 2010).

Health risk index and target hazard quotient

Health risk index (HRI) and target hazard quotient (THQ) were assessed for the consumers of the vegetables grown in contaminated soil amended with different organic materials by the following formulae (Eq. 3 and Eq. 4)

$$\text{HRI} = \frac{\text{DIM}}{\text{RfD}} \quad (3)$$

$$\text{THQ} = \frac{\text{MC} \times \text{FI} \times \text{EFr} \times \text{ED}}{\text{RfD} \times \text{BW} \times \text{AT}} \times 10^{-3} \quad (4)$$

Where DIM is daily intake of Cd, RfD represents reference oral dose, MC is metal concentration, FI is frequency of ingestion (255 g person⁻¹ day⁻¹), EFr represents exposure frequency (350 days/year), ED is total exposure duration (70 years), BW represents average body weight, and AT is non carcinogen's averaging time (ED 365 day/year).

Quality control

The plant (GBW07603-GSV-2) and soil (GBW07406-GSS-6) certified reference materials were used to determine the accuracy of the extraction and subsequent measurements. The Cd recovery was good, 93±5.7 and 91.7±4.3 for plants and soil respectively.

Statistical analysis

Statistical analyses of the raw data were carried out using SPSS 21.0 software. Significance levels ($P < 0.01$ and $P < 0.05$) were used to show the differences between different amendments and the control. Graphs were prepared using Sigma plot 10.0.

Results and discussion

Soil physicochemical characteristics

The soil selected for pot experiments was sandy loam with wilting point of 0.092 cm³ water per cm³, field capacity of 0.181 cm³ water per cm³ soil, and bulk density of 1.56 gcm⁻³. High Cd concentration was present in the soil (Table. 1). The soil was slightly alkaline in nature (pH 8.04), with an EC of 0.19 ms/cm, and organic matter content of 2.2%. The soil was rich with essential nutrients such as N, P, Mg, and Ca (see Table. 1).

The additions of different amendments had variable effects on soil pH, EC, and available Cd concentrations. After harvesting, an increase in soil pH was observed for HWB3 (8.21) and HWB5 (8.22). HWB increased soil pH because of its alkaline nature and high contents of Ca and Mg and the dissolution of their respective carbonates and oxides which are responsible for increasing the amended soil pH. The RH amendment samples showed no changes in soil pH, while the other amendments resulted in decreases (MCW = 7.61 and BG = 7.39). Generally, it is assumed that an increase in soil pH reduces the mobility and bioavailability of heavy metals (Hargreaves et al., 2008; Liu et al., 2015). In our previous study, an increase in pH (4.0 to 5.4) and significant increase in EC (38.7 to 992 $\mu\text{S}/\text{cm}$) was reported with the addition of biochar to contaminated soil (Khan et al., 2013).

Effects of amendments on plant physiological parameters

The selected amendments had variable effects on plant growth, biomass production, and chlorophyll contents (Fig. 1). The results indicate that the amendments had both synergistic and antagonistic effects on plant physiological properties depending upon type of plant species and amendments used (Fig. 1). Organic matter may have negative effects on plant growth (Cline et al., 2012), while biochar amendments favour plant growth and productivity (Jones et al., 2016). Shoot length of cucumber was significantly increased ($P < 0.01$) with HWB3 and HWB5, while the effect was less significant for RH3 ($P < 0.05$). Other amendments had negative impacts on shoot length, among different treatments the effects of MCW5 (50%), BG3 (43%), MCW3 (41%) and BG5 (40%), were more significant ($P < 0.01$) than RH5 (7%). Similarly, tomato showed significant increase in shoot length with amendment addition, except for MCW3 and MCW5, where a decrease was observed. The present study revealed that HWB3 and HWB5 significantly increased the biomass of cucumber and tomato. The increase in biomass might be attributed to various mechanisms that altered the availability of essential nutrients and the basic physicochemical characteristics of soil. As mentioned earlier an increase in soil pH was observed with application of HWB. As evident from Table 1, HWB have higher concentration of essential nutrients like Ca, Mg, N and P. The high concentrations of essential nutrients in HWB are responsible for increases in plant biomasses under high soil pH conditions.

Biomass per pot also showed variation with different amendments. HWB3 and HWB5 significantly ($P < 0.01$) increased the biomass of cucumber per pot. These results are in agreements with the findings of Waqas et al. (2014), who also observed an increase in cucumber biomass under different biochar amendments. An increase in dry biomass of maize with the application of biochar was previously observed by Al-Wabel et al. (2015). RH3 showed a small increase (3%) and RH5 showed a slight decrease (12%) but these changes were not consistent. Similarly, BG3 (24%) and BG5 caused decreases (27%) in biomass of cucumber per pot and a significant ($P < 0.01$) decrease in biomass was observed with the application of MCW3 and MCW5.

The application of HWB3 and HWB5 caused a significant ($P < 0.01$) increase in biomass per pot for tomato. The increase in tomato biomass with application of different biochar has been reported (Hossain, 2010). In our previous study a significant increase in rice biomass was observed with application of sewage slug biochar (Khan et al., 2014). The increase in

growth of cabbage and maize in Cd contaminated soil amended with biochar was reported by Mohamed et al (2015). Similar results were also reported by several other studies used biochar as soil amendment (Usman et al., 2016; Hossain et al., 2015; Akhtar et al., 2014). Similarly, RH3 and RH5 also caused increases (25 to 47%) in biomass per pot in tomato, while the remainder of soil amendments showed a negative effect on tomato biomass. The decrease in biomass per pot with fresh organic amendments was in agreement with the findings of de la Fuente et al (2011).

HWB3 and HWB5 significantly increased the biomass of cucumber and tomato. The increase in plant growth and biomass production can be attributed to various mechanisms that alter the availability of essential nutrients like N, P, K, Na, and S and the basic physicochemical and biological characteristic of soil (Khan et al., 2014). The possible reason of increasing biomass may be the high concentrations of essential nutrients like N, P, Mg and Ca in HWB as compared to other amendment applied (Table 1). Similarly, the application of HWB significantly reduced the uptake of Cd by these vegetables which might be another reason for enhancing biomass production as compared to control (Fig. 2).

Great variation was observed in chlorophyll content of both plant species grown in different amended soils. The plant species showed a significant ($P < 0.01$) increase in chlorophyll content with the application of biochar, however, the cucumber ($P < 0.05$) showed higher effects than tomato. Similarly, the application of RH3 and RH5 also increased (10–12 and 26–41%) the chlorophyll content of both species but these increases were not significant. The remainder of the amendments showed negative effects on chlorophyll content of both plants but the more significant effects were observed for MCW3 and MCW5.

The application of fresh organic amendments may pose a negative effect on plant growth. These negative impacts on plant growth may be due to the decrease in soil pH thus allowing potential toxic metals to interact with essential nutrients and reduce nutrient uptake, which in turn enhances the bioaccumulation of toxic metals in plants. A decrease in maize seedling emergence and corn yield was also observed with fresh manure by Loecke et al (2004). Similar results were also observed by Eremina et al (2003) with the application of raw (un-composted) straw for sugar beets. The one possible reason for decrease in biomass and chlorophyll content may be the production of toxins or the immobilization of N by the crop residues (Singh & Agrawal, 2007). It can also be attributed with the increase in chlorophyll degradation or decrease in chlorophyll synthesis (Santos, 2004). Khaliq et al (2011) reported a reduction in seed germination and shoot length of wheat with the amendments of crop residues. The other possible reason may be the enhanced uptake of Cd. It is also well documented that high Cd accumulation has adverse effects on plant growth, chlorophyll content, and biomass production by causing cytotoxic effects, inducing necrosis, chlorosis, retarding root and shoot growth, and reducing nutrient uptake (Hediji et al., 2010, Júnior et al., 2014; Khan et al., 2016; Mohamed et al., 2012).

Effects of amendments on Cd bioaccumulation

The effects of different organic amendments on Cd bioaccumulation in the selected plant species were also studied. The results showed that different amendments have different effects on Cd uptake depending upon the plant species (Fig. 2 and 3). The effects observed

also varied among the roots, shoots, leaves, and fruits of the same plant species. A decrease in Cd uptake by the roots of tomato plant was observed with all the selected amendments except MCW which showed a minor increase (3.9–5.9%). The highest decrease was observed with HWB3 (22%) and HWB5 (27%) followed by rice husk at RH3 (17.6%) and RH5 (15.7%). BG3 and BG5 also showed decreases (10–26%). In case of cucumber, all the amendments resulted in a decrease in Cd uptake by roots. Among different amendments HWB significantly ($P < 0.01$) reduced the Cd uptake by cucumber roots followed by RH. The translocation of Cd to shoots of both plants varied with amendments. The highest decrease in translocation of Cd to shoot of tomato (32%) and cucumber (49%) was observed with HWB5. The decrease was followed by RH for tomato (26%) and cucumber (37%) at RH5. The application of BG and MCW enhanced the translocation of Cd to shoots of both the vegetables but the increase was not consistent. Decreases in Cd in the leaves of both plant species with biochar amendments were significant ($P < 0.05$), while RH3 (tomato) and RH5 (cucumber) showed almost the same concentration as observed in the controls. Similarly, the leaf Cd concentration decreased significantly ($P < 0.05$) for the RH5 (tomato) amendment.

The translocation of Cd to fruits of both the plant species varied with the amendments and plant species (Fig. 2). Decreases (36–54%) in translocation of Cd were observed for cucumber with HWB application, while in tomato decreases of 24–30% were observed with HWB amendments. In fruits the highest Cd concentration was observed in cucumber (1.84 mg kg^{-1}), while in tomato fruits mean Cd concentration was 1.7 mg kg^{-1} under control treatment. Both the plants have different physiology and different amount of nutrients requirements, therefore differences in Cd uptake were observed. In control treatment, cucumber showed high uptake of Cd than tomato, while with the application of HWB the decreases were higher for cucumber as compared to tomato. The application of HWB3 decreased Cd to 1.1 mg kg^{-1} and 1.3 mg kg^{-1} , while HWB5 decreased Cd to 0.8 mg kg^{-1} and 1.2 mg kg^{-1} in the fruits of cucumber and tomato, respectively. HWB3 and HWB5 showed a significant decrease ($P < 0.05$) in tomato fruits, while for cucumber the decrease was significant at $P < 0.01$. The addition of RH3 and RH5 also decreased Cd translocation ($1.5\text{--}1.7 \text{ mg kg}^{-1}$) in cucumber and in tomato ($1.76\text{--}1.6 \text{ mg kg}^{-1}$), respectively. MCW3 and MCW5 enhanced the translocation of Cd in fruits of both plant species with cucumber ($1.96\text{--}2.1 \text{ mg kg}^{-1}$) and tomato ($2.1\text{--}2.2 \text{ mg kg}^{-1}$), respectively. However, the effects on tomato (21–25%) were comparatively greater than cucumber (7–18%). Similarly, BG3 and BG5 also enhanced Cd translocation to fruits with ($1.96\text{--}2 \text{ mg kg}^{-1}$) in cucumber and (1.9 mg kg^{-1}) in tomato, respectively. The Cd concentrations in both the vegetables under all the treatments were still above the permissible limits of WHO and SEPA, China, while under HWB Cd concentrations were below the Indian safe limit (1.5 mg kg^{-1}). The increase in translocation of Cd to fruits was in agreement with the findings of Pinto et al. (2004a, 2004b), while, in another study Pinto et al. (2005) reported an increase in Cd translocation with organic matter amendment in sorghum. Similarly Yousaf et al. (2017) also reported an increase in translocation of Cd by wheat plant with the application of fresh biowastes. The increase in translocation of Cd might be due to changes in soil pH, because it is a key factor affecting the mobility and bioavailability of Cd, which are negatively correlated with soil pH (Chaudri et al., 2007; Liu et al., 2015). In general, the decreases in soil pH lead to increases

in the amount of dissolved Cd in the soil solution. Subsequently this soluble fraction of metal is readily available for plant uptake.

The results obtained herein indicate that biochar was most effective in restricting Cd uptake by the selected vegetables. Previously, Khan et al. (2015) reported the decrease in Cd accumulation by turnip with biochar amendment. The reduction in bioaccumulation of Cd by the vegetables with biochar application is in agreement with the findings of Bian et al (2013) who reported a significant decrease (20–90%) of Cd in rice grains with biochar amendments. A significant decrease in cabbage (4.7-2.3 times) and maize (5.2-2.7 times) after biochar application was also observed by Mohamed et al (2015). Moreover, Al-Wabel et al (2015) also reported a decrease of 47% of Cd accumulation in maize. These results indicate that biochar application has significant capacity to reduce Cd bioaccumulation.

The application of biochar amendments increased the soil pH, which may have contributed in decreasing the availability of Cd (Lu et al., 2014). In addition, the metal retention capacity of biochar also decreases metals bioavailability. The existence of exchange sites on biochar surfaces greatly affects the capacity of retaining elements and reducing availability (Fellet et al., 2014). The retention of Cd on the surface of biochar was also reported by Beesley & Marmiroli (2011), who showed that Cd was sorbed on the surface of biochar and that the sorption is not an immediately reversible process. There may be three reasons for the high sorption capacity of Cd on biochar surfaces (i) electrostatic force of attraction between the Cd cations and the negatively charged carbon surface (ii) ionic exchange between Cd and the ionizable portion on biochar surface (iii) sorptive interaction in which the delocalized π electrons of carbon are involved (Sohi et al., 2010).

Concentration index (CI)

The Cd concentration and its bioaccumulation in vegetables showed great variation among different plants species and amendments used. RH significantly affected the CI of Cd for both tomato and cucumber fruits. BG and MCW increased the CI of Cd for both vegetables but the increase was higher with MCW amendments (Table. 2). The application of BG at rate of 3% increased the CI for tomato by 8% and for cucumber 7%. Biochar amendment significantly reduced CI of Cd for both the vegetables, however, the decrease was more prominent for cucumber fruits. With HWB3 the CI was reduced by 25% for tomato and 36% for cucumber. More prominent decrease (30%) for tomato and (55%) for cucumber were with the application of HWB5.

Dietary intake of metal, health risk and hazard quotient

The daily dietary intake of metal values ($\text{mg kg}^{-1} \text{d}^{-1}$) for individual of different age groups by consumption of vegetables grown in soil amended with different organics is given in Table 3. The DIM values of Cd with different amendments showed substantial variation dependent upon plant species, amendments, and age group (Table 3). Among different amendments RH3 had no effects on Cd dietary intake in both plant species, while RH5 reduced the daily intake of Cd, however, the effects were negligible for tomato (1–2%), and similar effects were observed for BG5. MCW3 and MCW5 significantly enhanced ($P < 0.05$) the dietary intake in both tomato and cucumber however these values were different

for different age groups. The calculated daily dietary intake rates of Cd were significantly reduced by application of biochar (Table 3). The application of HWB3 and HWB5 was reduced the DIM by 24–30% for tomato and 36–54% for cucumber, respectively. A similar reduction (21–36%) in DIM of Cd with the application of biochar through the consumption of pea fruits was reported by Nawab et al. (2018). Previously, Khan et al. (2014) also reported a decrease of 42% in DIM of Cd with the addition of biochar in mining impacted soil. HRI values of Cd under different amendments for children, adolescent and adults are given in Table 4. HRI values b1 designate that the material is assumed to pose minimal, acceptable risk. For tomato, the HRI were higher than 1 for all of the amendments including the control except for HWB5, indicating that children are at risk while for adolescent the HRI values were b1 for the amendments including the control.

The greatest decrease in HRI was observed with the application of biochar with HWB5 being the most effective. The reduction in HRI of tomato for adults was greatest for biochar followed by rice husk. For cucumber, substantial variation in HRI values was found under different amendments. All the amendments including control for children have HRI 1 except biochar. For adolescent the HRI values were b1 for all the amendments, as was the case for adults. The highest decrease was observed with biochar followed by RH. These findings showed that children are the most at risk population as would be expected. The reductions in HRI with the application of HWB are consistent with the findings of Nawab et al. (2015), who reported a reduction of 21–36% for pea fruit and 20–32% for chilli fruit with the application of biochar.

The THQ is often used as a tool for assessment of potential health risks resulting from consumption of metals contaminated food. The THQ values calculated for both plant species are given in Table 5. Both increase and decrease were observed in THQ values of different amendments as compared to the control. The changes in THQ values were depend upon type of amendments used. In control soil, the highest THQ value was observed for children followed by adolescent and adults. For tomato, the highest THQ value was noted for MCW5 (8.44×10^{-2}), while lowest value was calculated for HWB5 (4.73×10^{-2}).

Among different age groups the THQ value was highest for children, for all amendments, than adolescents and adults. Almost similar results were found for cucumber. The higher THQ value for control and different amendments except biochar is the indication of human health risk. However, the addition of biochar to metal contaminated soil significantly ($P < 0.01$) reduced THQ at application rate of HWB5. Similar reduction in HQ values for Cd with the application of biochar to rice was previously reported by Khan et al. (2014)

Food chain is one the most important pathways to Cd exposure through the consumption of contaminated vegetables (Khan et al., 2008). The accumulation of Cd in vegetables grown on contaminated soil can be managed by the application of biochar and thus daily intake, HRI and THQ can be reduced. In the present study, among different amendments, biochar was the most effective treatm

Conclusions

Application of organic amendments to Cd contaminated soil has different effects on Cd availability, uptake and translocation by vegetables depending upon the type of organic amendments used. It is revealed that application of biochar provided the greatest decrease in Cd availability in soil and subsequent plant uptake among the four amendments tested. As a consequence, vegetable growth, chlorophyll content, and biomass production was enhanced. Among the application rates HWB5 was more effective in decreasing Cd uptake and the effect was more prominent for cucumber. The use of untreated plant residues were not effective in the immobilization of Cd but rather they enhanced the uptake of Cd. RH slightly reduced the uptake of Cd with no effect on soil pH. BG and MCW decreased the soil pH, which enhanced Cd availability and reduced plant growth, decreased chlorophyll content, and biomass production. Therefore, the use of untreated plant residues is not favourable for the mitigation of Cd plant uptake in contaminated soil. A significant decrease in concentration index for Cd was observed with biochar. The daily dietary intake, HRI, and THQ of Cd for different age groups were also significantly reduced by the application of biochar amendment. The results of this study indicate that biochar is an effective amendment for reducing Cd plant uptake and dietary exposure.

Acknowledgments

The financial support is provided by Higher Education Commission (HEC) Islamabad, Pakistan under indigenous program (PIN No. 112-23334-2PS1-4221). The contributions of Mark Brusseau were supported by the NIEHS SRP (P42 ES04940), while Xiaodong Ding by soil and cultivation position of modern agriculture technology system innovation team of paddy in Shandong Province (SDAIT-17-05).

References

- Ahmad M, Rajapaksha AU, Lim JE, Zhang M, Bolan N, Mohan D, Vithanage M, Lee SS, Ok YS. Biochar as a sorbent for contaminant management in soil and water: A review. *Chemosphere*. 2014; 99:19–23. DOI: 10.1016/j.chemosphere.2013.10.071 [PubMed: 24289982]
- Akhtar SS, Li G, Andersen MN, Liu F. Biochar enhances yield and quality of tomato under reduced irrigation. *Agricultural Water Management*. 2014; 138:37–44. DOI: 10.1016/j.agwat.2014.02.016
- Al-Wabel MI, Usman ARA, El-Naggar AH, Aly AA, Ibrahim HM, Elmaghraby S, Al-Omran A. Conocarpus biochar as a soil amendment for reducing heavy metal availability and uptake by maize plants. *Saudi Journal of Biological Sciences*. 2015; 22:503–511. DOI: 10.1016/j.sjbs.2014.12.003 [PubMed: 26150758]
- Beesley L, Marmiroli M. The immobilisation and retention of soluble arsenic, cadmium and zinc by biochar. *Environmental Pollution*. 2011; 159:474–480. DOI: 10.1016/j.envpol.2010.10.016 [PubMed: 21109337]
- Benavides MP, Gallego SM, Tomaro ML. Cadmium toxicity in plants. *Brazilian Journal of Plant Physiology*. 2005; 17(1):21–34.
- Bešter PK, Lobnik F, Eržen I, Kastelec D, Zupan M. Prediction of cadmium concentration in selected home-produced vegetables. *Ecotoxicology and Environmental Safety*. 2013; 96:182–190. DOI: 10.1016/j.ecoenv.2013.06.011 [PubMed: 23886800]
- Bian R, Chen D, Liu X, Cui L, Li L, Pan G, Xie D, Zheng J, Zhang X, Zheng J, Chang A. Biochar soil amendment as a solution to prevent Cd-tainted rice from China: Results from a cross-site field experiment. *Ecological Engineering*. 2013; 58:378–383. DOI: 10.1016/j.ecoleng.2013.07.031
- Borchard N, Wolf A, Laabs V, Aeckersberg R, Scherer HW, Moeller A, Amelung W. Physical activation of biochar and its meaning for soil fertility and nutrient leaching - a greenhouse

experiment. *Soil Use and Management*. 2012; 28:177–184. DOI: 10.1111/j.1475-2743.2012.00407.x

Cao X, Harris W. Properties of dairy-manure-derived biochar pertinent to its potential use in remediation. *Bioresource Technology*. 2010; 101:5222–5228. DOI: 10.1016/j.biortech.2010.02.052 [PubMed: 20206509]

Chaudri A, McGrath S, Gibbs P, Chambers B, Carlton-Smith C, Godley A, Bacon J, Campbell C, Aitken M. Cadmium availability to wheat grain in soils treated with sewage sludge or metal salts. *Chemosphere*. 2007; 66:1415–1423. DOI: 10.1016/j.chemosphere.2006.09.068 [PubMed: 17109920]

Clemente R, Paredes C, Bernal MP. A field experiment investigating the effects of olive husk and cow manure on heavy metal availability in a contaminated calcareous soil from Murcia (Spain). *Agriculture, Ecosystems and Environment*. 2007; 118:319–326. DOI: 10.1016/j.agee.2006.06.002

Cline ET, Nguyen QTN, Rollins L, Gawel JE. Metal stress and decreased tree growth in response to biosolids application in greenhouse seedlings and in situ Douglas-fir stands. *Environmental Pollution*. 2012; 160:139–144. DOI: 10.1016/j.envpol.2011.09.012 [PubMed: 22035937]

de la Fuente C, Clemente R, Martínez-Alcalá I, Tortosa G, Bernal MP. Impact of fresh and composted solid olive husk and their water-soluble fractions on soil heavy metal fractionation; microbial biomass and plant uptake. *Journal of Hazardous Materials*. 2011; 186:1283–1289. DOI: 10.1016/j.jhazmat.2010.12.004 [PubMed: 21216095]

Eremina RF, Mashchenko SS, Chuyan OG, Yashchenko NA. Use of winter wheat straw as an organic fertilizer. *Sakharnaya-Svekla*. 2003; 6:22–3.

Fellet G, Marmioli M, Marchiol L. Elements uptake by metal accumulator species grown on mine tailings amended with three types of biochar. *Science of the Total Environment*. 2014; 468–469:598–608. DOI: 10.1016/j.scitotenv.2013.08.072

Franz E, Römkens P, van Raamsdonk L, van der Fels-Klerx I. A chain modeling approach to estimate the impact of soil cadmium pollution on human dietary exposure. *Journal of food protection*. 2008; 71:2504–13. [PubMed: 19244905]

Gartler J, Robinson B, Burton K, Clucas L. Carbonaceous soil amendments to biofortify crop plants with zinc. *Science of the Total Environment*. 2013; 465:308–313. DOI: 10.1016/j.scitotenv.2012.10.027 [PubMed: 23146312]

Ghosh M, Singh SP. Asian Journal on Energy and Environment A Review on Phytoremediation of Heavy Metals and Utilization of It's by Products. *As J Energy Env*. 2005; 6:214–231. DOI: 10.1007/s10681-014-1088-2

Han SS, Kim M, Lee SM, Lee JP, Kim S, Joo KW, Lim CS, Kim YS, Kim DK. Cadmium exposure induces hematuria in Korean adults. *Environmental Research*. 2013; 124:23–27. DOI: 10.1016/j.envres.2013.04.001 [PubMed: 23642677]

Hargreaves JC, Adl MS, Warman PR. A review of the use of composted municipal solid waste in agriculture. *Agriculture, Ecosystems and Environment*. 2008; 123:1–14. DOI: 10.1016/j.agee.2007.07.004

HE QB, SINGH BR. Effect of organic matter on the distribution, extractability and uptake of cadmium in soils. *Journal of Soil Science*. 1993; :641–650. DOI: 10.1111/j.1365-2389.1993.tb02329

Hédiji H, Djebali W, Cabasson C, Maucourt M, Baldet P, Bertrand A, Boulila Zoghalmi L, Deborde C, Moing A, Brouquisse R, Chaïbi W, Gallusci P. Effects of long-term cadmium exposure on growth and metabolomic profile of tomato plants. *Ecotoxicology and Environmental Safety*. 2010; 73:1965–1974. DOI: 10.1016/j.ecoenv.2010.08.014 [PubMed: 20846723]

Hossain MK, Strezov V, Nelson PF. Comparative Assessment of the Effect of Wastewater Sludge Biochar on Growth, Yield and Metal Bioaccumulation of Cherry Tomato. *Pedosphere*. 2015; 25:680–685. DOI: 10.1016/S1002-0160(15)30048-5

Hossain MK, Strezov V, Yin Chan K, Nelson PF. Agronomic properties of wastewater sludge biochar and bioavailability of metals in production of cherry tomato (*Lycopersicon esculentum*). *Chemosphere*. 2010; 78:1167–1171. DOI: 10.1016/j.chemosphere.2010.01.009 [PubMed: 20110103]

- Järup L, Åkesson A. Current status of cadmium as an environmental health problem. *Toxicology and Applied Pharmacology*. 2009; 238:201–208. DOI: 10.1016/j.taap.2009.04.020 [PubMed: 19409405]
- Jones S, Bardos RP, Kidd PS, Mench M, de Leij F, Hutchings T, Cundy A, Joyce C, Soja G, Friesl-Hanl W, Herzig R, Menger P. Biochar and compost amendments enhance copper immobilisation and support plant growth in contaminated soils. *Journal of Environmental Management*. 2016; 171:101–112. DOI: 10.1016/j.jenvman.2016.01.024 [PubMed: 26850677]
- Nezhad MTK, Mohammadi K, Gholami A, Hani A, Shariati MS. Cadmium and mercury in topsoils of Babagorogor watershed, western Iran: Distribution, relationship with soil characteristics and multivariate analysis of contamination sources. *Geoderma*. 2014; 219–220:177–185. DOI: 10.1016/j.geoderma.2013.12.021
- Karlsson T, Elgh-Dalgren K, Björn E, Skjellberg U. Complexation of cadmium to sulfur and oxygen functional groups in an organic soil. *Geochimica et Cosmochimica Acta*. 2007; 71:604–614. DOI: 10.1016/j.gca.2006.10.011
- Khaledian Y, Kiani F, Ebrahimi S, Brevik EC, Aitkenhead-Peterson J. Assessment and Monitoring of Soil Degradation during Land Use Change Using Multivariate Analysis. *Land Degradation & Development*. 2017; 28:128–141. DOI: 10.1002/ldr.2541
- Khalique A, Matloob A, Farooq M, Mushtaq MN, Khan MB. Effect of crop residues applied isolated or in combination on the germination and seedling growth of horse purslane (*Trianthemportulacastrum*). *Planta Daninha*. 2011; 29(1):121–128.
- Khan A, Khan S, Alam M, Khan MA, Aamir M, Qamar Z, Rehman ZU, Perveen S. Toxic metal interactions affect the bioaccumulation and dietary intake of macro- and micro-nutrients. *Chemosphere*. 2016; 146:121–128. DOI: 10.1016/j.chemosphere.2015.12.014 [PubMed: 26714294]
- Khan S, Cao Q, Zheng YM, Huang YZ, Zhu YG. Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. *Environmental Pollution*. 2008; 152:686–692. DOI: 10.1016/j.envpol.2007.06.056 [PubMed: 17720286]
- Khan S, Chao C, Waqas M, Arp HPH, Zhu YG. Sewage sludge biochar influence upon rice (*Oryza sativa* L) yield, metal bioaccumulation and greenhouse gas emissions from acidic paddy soil. *Environmental Science and Technology*. 2013; 47:8624–8632. DOI: 10.1021/es400554x [PubMed: 23796060]
- Khan S, Rehman S, Zeb Khan A, Amjad Khan M, Tahir Shah M. Soil and vegetables enrichment with heavy metals from geological sources in Gilgit, northern Pakistan. *Ecotoxicology and Environmental Safety*. 2010; 73:1820–1827. DOI: 10.1016/j.ecoenv.2010.08.016 [PubMed: 20810165]
- Khan S, Reid BJ, Li G, Zhu YG. Application of biochar to soil reduces cancer risk via rice consumption: A case study in Miaoqian village, Longyan, China. *Environment International*. 2014; 68:154–161. DOI: 10.1016/j.envint.2014.03.017 [PubMed: 24727070]
- Kobayashi E, Suwazono Y, Dochi M, Honda R, Nishijo M, Kido T, Nakagawa H. Estimation of benchmark doses as threshold levels of urinary cadmium, based on excretion of β 2-microglobulin in cadmium-polluted and non-polluted regions in Japan. *Toxicology Letters*. 2008; 179:108–112. DOI: 10.1016/j.toxlet.2008.04.013 [PubMed: 18515022]
- Kumpiene J, Lagerkvist A, Maurice C. Stabilization of As, Cr, Cu, Pb and Zn in soil using amendments - A review. *Waste Management*. 2008; 28:215–225. DOI: 10.1016/j.wasman.2006.12.012 [PubMed: 17320367]
- Lee TM, Lai HY, Chen ZS. Effect of chemical amendments on the concentration of cadmium and lead in long-term contaminated soils. *Chemosphere*. 2004; 57:1459–1471. DOI: 10.1016/j.chemosphere.2004.08.094 [PubMed: 15519390]
- Lehmann J. A handful of carbon. *Nature*. 2007; 447:143–144. DOI: 10.1038/447143a [PubMed: 17495905]
- Liu J, Li K, Xu J, Liang J, Lu X, Yang J, Zhu Q. Interaction of Cd and five mineral nutrients for uptake and accumulation in different rice cultivars and genotypes. *Field Crops Research*. 2003; 83:271–281. DOI: 10.1016/S0378-4290(03)00077-7

- Liu K, Lv J, He W, Zhang H, Cao Y, Dai Y. Major factors influencing cadmium uptake from the soil into wheat plants. *Ecotoxicology and Environmental Safety*. 2015; 113:207–213. DOI: 10.1016/j.ecoenv.2014.12.005 [PubMed: 25499054]
- Loecke TD, Liebman M, Cambardella CA, Richard TL. Corn response to composting and time of application of solid swine manure. *Agronomy Journal*. 2004; 96(1):214–23. DOI: 10.2134/agronj2004.2140
- Júnior CAL, Mazzafera P, Arruda MAZ. A comparative ionomic approach focusing on cadmium effects in sunflowers (*Helianthus annuus* L.). *Environmental and Experimental Botany*. 2014; 107:180–186. DOI: 10.1016/j.envexpbot.2014.06.002
- Lu K, Yang X, Shen J, Robinson B, Huang H, Liu D, Bolan N, Pei J, Wang H. Effect of bamboo and rice straw biochars on the bioavailability of Cd, Cu, Pb and Zn to *Sedum plumbizincicola*. *Agriculture, Ecosystems and Environment*. 2014; 191:124–132. DOI: 10.1016/j.agee.2014.04.010
- Meeus C, Eduljee G, Hutton M. Assessment and management of risks arising from exposure to Cd in fertilisers. *Science of the Total Environment*. 2002; 291:167–187. DOI: 10.1016/S0048-9697(01)01098-1 [PubMed: 12150436]
- Major J, Rondon M, Molina D, Riha SJ, Lehmann J. Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol. *Plant and Soil*. 2010; 333:117–128. DOI: 10.1007/s11104-010-0327-0
- Mohamed AA, Castagna A, Ranieri A, Sanità di Toppi L. Cadmium tolerance in *Brassica juncea* roots and shoots is affected by antioxidant status and phytochelatin biosynthesis. *Plant Physiology and Biochemistry*. 2012; 57:15–22. DOI: 10.1016/j.plaphy.2012.05.002 [PubMed: 22652410]
- Mohamed I, Zhang G shi, Li Z guo, Liu Y, Chen F, Dai K. Ecological restoration of an acidic Cd contaminated soil using bamboo biochar application. *Ecological Engineering*. 2015; 84:67–76. DOI: 10.1016/j.ecoleng.2015.07.009
- Mulligan CN, Yong RN, Gibbs BF. Remediation technologies for metal-contaminated soils and groundwater: An evaluation. *Engineering Geology*. 2001; 60:193–207. DOI: 10.1016/S0013-7952(00)00101-0
- Nwachukwu OI, Pulford ID. Comparative effectiveness of selected adsorbant materials as potential amendments for the remediation of lead-, copper- and zinc-contaminated soil. *Soil Use and Management*. 2008; 24:199–207. DOI: 10.1111/j.1475-2743.2007.00141.x
- Pinto AP, Mota AM, De Varennes A, Pinto FC. Influence of organic matter on the uptake of cadmium, zinc, copper and iron by sorghum plants. *Science of the Total Environment*. 2004a; 326:239–247. DOI: 10.1016/j.scitotenv.2004.01.004 [PubMed: 15142779]
- Pinto AP, Vilar MT, Pinto FC, Mota AM. Organic matter influence in cadmium uptake by Sorghum. *Journal of Plant Nutrition*. 2004b; 27:2175–2188. DOI: 10.1081/LPLA-200034681
- Santos CV. Regulation of chlorophyll biosynthesis and degradation by salt stress in sunflower leaves. *Scientia Horticulturae*. 2004; 103:93–99. DOI: 10.1016/j.scienta.2004.04.009
- Satarug S, Garrett SH, Sens MA, Sens DA. Cadmium, environmental exposure, and health outcomes. *Environmental Health Perspectives*. 2010; 118:182–190. DOI: 10.1289/ehp.0901234 [PubMed: 20123617]
- Singh RP, Agrawal M. Effects of sewage sludge amendment on heavy metal accumulation and consequent responses of *Beta vulgaris* plants. *Chemosphere*. 2007; 67:2229–2240. DOI: 10.1016/j.chemosphere.2006.12.019 [PubMed: 17289111]
- Sohi S, Krull E, Lopez-Capel E, Bol R. A Review of Biochar and Its Use and Function in Soil. *Advances in Agronomy*. 2010; :47–82. DOI: 10.1016/S0065-2113(10)05002-9
- Usman ARA, Al-Wabel MI, Ok YS, Al-Harbi A, Wahb-Allah M, El-Naggar AH, Ahmad M, Al-Faraj A, Al-Omran A. Conocarpus Biochar Induces Changes in Soil Nutrient Availability and Tomato Growth Under Saline Irrigation. *Pedosphere*. 2016; 26:27–38. DOI: 10.1016/S1002-0160(15)60019-4
- Waqas M, Khan S, Qing H, Reid BJ, Chao C. The effects of sewage sludge and sewage sludge biochar on PAHs and potentially toxic element bioaccumulation in *Cucumis sativa* L. *Chemosphere*. 2014; 105:53–61. DOI: 10.1016/j.chemosphere.2013.11.064 [PubMed: 24360844]

- Yousaf B, Wang R, Imtiaz M. Investigating the uptake and acquisition of potentially toxic elements in plants and health risks associated with the addition of fresh biowaste amendments to industrially contaminated soil. *Land Degradation & Development*. 2017; :2596–2607. DOI: 10.1002/ldr.2821
- Zhang S, Chen M, Li T, Xu X, Deng L. A newly found cadmium accumulator-Malva sinensis Cavan. *Journal of Hazardous Materials*. 2010; 173:705–709. DOI: 10.1016/j.jhazmat.2009.08.142 [PubMed: 19767144]

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Fig. 1. Changes (%) in biomass (Fresh) per pot, chlorophyll content and length/height of tomato and cucumber under organic amendments

Fig. 2.
Changes (%) in Cd uptake by plants under different amendments

Table 1

Basic characteristics of soil and organic geosorbent materials used in this study.

Parameters	Soil	HWB ^a	RH ^b	BG ^c	MCW ^d
pH	8.04	7.81	4.01	6.46	5.49
EC (mS _{cm} ⁻¹)	0.19	0.636	1.75	0.358	1.69
	Sand (%)	75.3			
Texture	Silt (%)	13.7			
	Clay (%)	11.0			
OM (%)	2.20				
N (%)	0.45	4.4	5.6	1.2	6.73
P (mgkg ⁻¹)	128	2500	386	46.4	673
Cd (mgkg ⁻¹)	4.55	0.13	0.3	0.1	0.16
Mg (mgkg ⁻¹)	127	2700	5.5	4.6	410
Ca (mgkg ⁻¹)	12.3	10500	2.45	46	290

^a hardwood biochar,

^b rice husk,

^c bagasse,

^d maize comb waste

Table 2

Concentration index (CI) of Cd under different organic amendments

Amendments	Tomato	Cucumber
RH3	1.00	0.85
RH5	0.98	0.93
BG3	1.08	1.07
BG5	0.98	1.09
MCW3	1.21	1.07
MCW5	1.25	1.18
HWB3	0.75	0.64 *
HWB5	0.70	0.45 *

* significantly different at P<0.01 level.

Table 3

Daily dietary intake of Cd via ingestion of selected vegetables

Amendments	Tomato		Cucumber	
	Adults>19	Children	14–18 y	Children
Control	6.82×10^{-4}	1.39×10^{-3}	5.44×10^{-4}	1.45×10^{-3}
RH3	6.82×10^{-4}	1.39×10^{-3}	5.44×10^{-4}	1.24×10^{-3}
RH5	6.69×10^{-4}	1.37×10^{-3}	5.34×10^{-4}	1.34×10^{-3}
BG3	7.33×10^{-4}	1.50×10^{-3}	5.85×10^{-4}	1.55×10^{-3}
BG5	6.69×10^{-4}	1.37×10^{-3}	5.34×10^{-4}	1.58×10^{-3}
MCW3	8.23×10^{-4}	1.68×10^{-3}	6.57×10^{-4}	1.55×10^{-3}
MCW5	8.49×10^{-4}	1.74×10^{-3}	6.78×10^{-4}	1.71×10^{-3}
HWB3	5.14×10^{-4}	1.05×10^{-3}	4.11×10^{-4}	9.20×10^{-4}
HWB5	4.76×10^{-4}	9.73×10^{-4}	3.80×10^{-4}	6.57×10^{-4}
				2.57×10^{-4}

Health risk index for Cd in tomato and cucumber grown under different organic amendments

Table 4

Amendments	Tomato			Cucumber		
	Children	Adolescent	Adults	Children	Adolescent	Adults
Control	1.39×10^0	5.44×10^{-1}	6.82×10^{-1}	1.45×10^0	5.65×10^{-1}	7.07×10^{-1}
RH3	1.39×10^0	5.44×10^{-1}	6.82×10^{-1}	1.24×10^0	4.83×10^{-1}	6.05×10^{-1}
RH5	1.37×10^0	5.34×10^{-1}	6.69×10^{-1}	1.34×10^0	5.24×10^{-1}	6.56×10^{-1}
BG3	1.50×10^0	5.85×10^{-1}	7.33×10^{-1}	1.55×10^0	6.06×10^{-1}	7.59×10^{-1}
BG5	1.37×10^0	5.34×10^{-1}	6.69×10^{-1}	1.58×10^0	6.16×10^{-1}	7.72×10^{-1}
MCW3	1.68×10^0	6.57×10^{-1}	8.23×10^{-1}	1.55×10^0	6.06×10^{-1}	7.59×10^{-1}
MCW5	1.74×10^0	6.78×10^{-1}	8.49×10^{-1}	1.71×10^0	6.68×10^{-1}	8.36×10^{-1}
HWB3	1.05×10^0	4.11×10^{-1}	5.14×10^{-1}	9.20×10^{-1}	3.59×10^{-1}	4.50×10^{-1}
HWB5	9.73×10^{-1}	3.80×10^{-1}	4.76×10^{-1}	6.57×10^{-1}	2.57×10^{-1}	3.22×10^{-1}

Table 5

Target hazard quotient as affected by different amendments

Amendments	Tomato			Cucumber		
	Children	Adolescent	Adults	Children	Adolescent	Adults
Control	6.78×10 ⁻²	1.02×10 ⁻³	1.28×10 ⁻⁵	7.03×10 ⁻²	1.05×10 ⁻³	1.33×10 ⁻⁵
RH3	6.78×10 ⁻²	1.02×10 ⁻³	1.28×10 ⁻⁵	6.01×10 ⁻²	9.00×10 ⁻⁴	1.14×10 ⁻⁵
RH5	6.65×10 ⁻²	9.96×10 ⁻⁴	1.26×10 ⁻⁵	6.52×10 ⁻²	9.77×10 ⁻⁴	1.23×10 ⁻⁵
BG3	7.29×10 ⁻²	1.09×10 ⁻³	1.38×10 ⁻⁵	7.54×10 ⁻²	1.13×10 ⁻³	1.43×10 ⁻⁵
BG5	6.65×10 ⁻²	9.96×10 ⁻⁴	1.26×10 ⁻⁵	7.67×10 ⁻²	1.15×10 ⁻³	1.45×10 ⁻⁵
MCW3	8.18×10 ⁻²	1.23×10 ⁻³	1.55×10 ⁻⁵	7.54×10 ⁻²	1.13×10 ⁻³	1.43×10 ⁻⁵
MCW5	8.44×10 ⁻²	1.26×10 ⁻³	1.60×10 ⁻⁵	8.31×10 ⁻²	1.25×10 ⁻³	1.57×10 ⁻⁵
HWB3	5.11×10 ⁻²	7.66×10 ⁻⁴	9.67×10 ⁻⁶	4.47×10 ⁻²	6.70×10 ⁻⁴	8.46×10 ⁻⁶
HWB5	4.73×10 ⁻²	7.09×10 ⁻⁴	8.94×10 ⁻⁶	3.20×10 ⁻²	4.79×10 ⁻⁴	6.04×10 ⁻⁶