Heavy Metals Accumulations And Health Risk Assessment Of Faba Bean Grow On Soil Amended With Municipal Solid Waste Compost, Biochar And Co-Composted Biochar

Zewdu Abebe Tessfaw (zewdutessfaw@gmail.com)
Jimma University
Abebe Beyene
Jimma University
Amsalu Nebiyu
Jimma University
Krzysztof Pikon
Silesian University of Technology
Marcin Landrat
Silesian University of Technology

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Abstract

Health risk assessment of heavy metals is crucial before large scale applications of municipal solid waste (MSW) as organic fertilizer. This study aimed to estimate Pb, Cd and Cr accumulation and health risk in faba bean (*Vicia faba L.*) grow on soils amended with MSW compost, biochar and co-composted biochars (5%, 15% and 25% w/w). The heavy metal concentrations were measured by flame atomic absorption spectroscopy. Bioaccumulation Factor (BAF), Estimated Daily Intake (EDI), Hazard Quotient (HQ) and Hazard Index (HI) were calculated. Results showed that Pb, Cd and Cr concentrations in the amended soils and faba bean grain were lower than WHO permissible levels. The EDIs of Pb, Cd and Cr in grains for all amendments were much lower than the reference doses established by USEPA and FAO/WHO. HQs and HIs of heavy metals were < 1 for all amendments indicating that consumption of faba bean grow on MSW compost, khat biochar and co-composted biochar collected from Jimma city was safe related to human health risks. Low accumulation of heavy metals in faba bean indicating that the low fraction of e-waste in the MSW. Since faba bean grain is not accumulator, it's potential of heavy metals excluder needs further explorations.

1. Introduction

The management of municipal solid waste is becoming the major challenges in urban community in many developing countries (Karak et al., 2012; Menikpura et al., 2013). The solid waste collection rate is the lowest and even the collected solid waste is disposed to open landfills. The organic component of the urban waste is about 45–60 % the total solid waste generated in developing countries (Pattnaik & Reddy, 2009). Improper management of biodegradable organic waste releases greenhouse gases such as carbondioxide and methane in the environment due to anaerobic digestion from open disposal sites which affects climate change. So, that a sustainable solid waste management scheme is required for the exponential increasing of municipal solid waste generations.

Municipal solid waste application to arable land is a sustainable practice of both soil fertility and waste management. Several studies have showed that MSW compost is common practice to improve the physical, chemical and biological properties of impoverished soils by supplying organic matter (Habib et al., 2015; Haghighi et al., 2016; Srivastava et al., 2016, 2018; Weerasinghe & De, 2017). The organic part of municipal solid wastes is recognized as important source soil organic matter, which can provide essential soil nutrients (Ayilara et al., 2020; Lucchini et al., 2014).

However, a heavy metal contamination is the main challenge to use MSW for agricultural use. MSW could be contaminated by heavy metals from many sources such as house hold dust, electronics, plastics, paints and inks and pesticide (Chimuka & Manungufala, 2009). All types of municipal solid waste (MSW) compost contain more heavy metals than the background concentrations present in soil and will increase their contents in amended soil and the heavy metal transfer into plants (Smith, 2009). Studies have showed that compost amended soils had increased significantly in the contents of Cd, Cr, Cu, Ni, Pb and Zn compared to untreated soils (Ayari, 2010; Carbonell et al., 2011). Consequently, there is evidence of phytotoxic effects, or accumulations of heavy metals in crop tissues that may pose a risk of human health from the applications of MSW compost to the soil (Basta et al., 2004; Paradelo et al., 2020; J. Singh & Kalamdhad, 2011).

High levels of heavy metals in soil, water and food supply adversely affects food chain, human health and soil ecosystems. Therefore, consumption of heavy metal contaminated foods is the major route of human health risk (Guerra et al., 2012; Mahfooz et al., 2020). Heavy metals are non-biodegradable and persistent in the environment, which are known to cause toxic effects on animal and human health. Once they enter into our body, they are converted into more dangerous organic forms and accumulate in fatty organs such as liver, kidney and skin. Organic forms of heavy metals are water insoluble which is difficult to eliminate from our body and damage these organs. Thus, heavy metals especially, lead (Pb), cadmium (Cd), and Chromium (Cr) are the most toxic and affect human health even at low concentration (Khan et al., 2008; Qureshi et al., 2016; Shaheen et al., 2016; Volpe et al., 2009; Wassim et al., 2018). As heavy metals can play a role in the development of carcinogenic and non- carcinogenic diseases (Wassim et al., 2018a), a decreased in mental capacity, kidney damage, blood and bone disorders, and neurological damage are caused from exposure of heavy metals (Li et al., 2015).

Many research works were done to investigate the bioavailability and human health risk of heavy metals in soil amended with sewage sludge (Pascual et al., 2004; Singh & Agrawal, 2008), soils and vegetables around waste incinerators (Li et al., 2015), and vegetables grow on soil irrigated with wastewater (Hossain et al., 2015; Mahfooz et al., 2020; Qureshi et al., 2016; Sharma et al., 2016; Woldetsadik et al., 2017). There were also research works on risk assessment of heavy metal on soil treated with organic waste compost (Chaney, 2018; Jiwan & Kalamdhad, 2014; Soobhany et al., 2015). But, there is limited study focusing on risk assessments of heavy metals in

plants grown on soil amended with municipal solid waste compost. Bioavailability of heavy metals in the edible portion of each crops varied significantly according to the type of crops (Chen et al., 2014; Edogbo et al., 2020). Leguminous vegetables were more likely to accumulate Cr, while leaf vegetables tended to show higher levels of concentration of Cd and Pb (Chen et al., 2014). Before large scale agricultural applications of organic fertilizers derived from municipal solid waste, data on accumulation and health risk of heavy metals is very important. So, the applications of all organic wastes to arable land must be regulated with regard to tolerable amounts of nutrients and heavy metals (Seçer et al., 2016). Thus, the aim of this study was to assess the bioavailability and health risk of faba bean grow on soil amended with compost, khat biochar and co-composted biochars derived from municipal solid waste.

2. Materials And Methods

2.1 Study Site and Sample Collection

The field experiment was conducted at Debre Markos University agricultural college field laboratory site (10°20'N 37°43'E) from February, 2019 to July, 2019 to investigate the effects of municipal solid waste compost, co-composted biochar and Khat biochar on the soil physicochemical properties and faba bean yield and physiology. Debre Markos University is located in Debre Markos town, North-westrn, Ethiopia. According to CSA (2010) estimation/forecast of the 2018, the town's population growth would have reached 111,313 (Mekuriaw and Gokcekus, 2019). To assess the health risk and bioavailability of Pb, Cd and Cr on faba bean seeds grow on control compost, 5%, 15%, 25% w/w co-composted biochars, surface soil samples (0–20 cm) and faba bean seeds were sampled from all individual plots to make a bulk composite sample for each treatment

2.2 Amendments

A field experiment was conducted on a randomize complete block design with triplicate to study the effects of municipal solid waste compost, khat biochar and co-composted biochars on soil quality and faba bean grain yield. The treatments consisting of i) control compost ii), 5% co-composted biochar (5% w/w khat biochar + 95% w/w municipal solid waste mix), iii) 15% co-composted biochar (15% of khat biochar + 85% municipal solid waste mix), iv) 25% co-composted biochar (25% of khat biochar + 75% municipal solid waste mix) and v) khat biochar. Faba bean ranks first in its production volume and cultivated land among pulse crops cultivated in Ethiopia and it is valuable as the cheap source of protein in most Ethiopian diet.

2.3 Sample collection

Faba bean seeds (Vicia faba L.) with Dosha variety which is used as a test crop was identified and collected from Adet Agricultural Research Center (AARC).

The necessary field management practices were carried out as per the practices followed by the farming community around the study area. In addition, all the field experiments involving were conducted according the guideline written in Estefan et al., (2013) and the Faba bean growth Guideline in New England (Etemadi et al., 2015). Plant samples were collected according to the procedures described in (Jane M-F Johnson and Jack Morgan, 2010) for aboveground growth parameters analysis. The faba bean plants, about 10% (12 plants) were collected per plot. Sampling was done when the pods became brown to black in color.

2.4 Analysis of soil and faba bean seed samples

For determination of total heavy metal content of the amended soils and faba beans grain, 1 gm oven dried soil /faba bean seed powder solution was digested by 5 ml Di acid (HNO_3& $HClO_4$) at 100^oC for 2 hrs (Upadhyay & Sahu, 2012). Then after 3 ml hydrogen peroxide was added to the remaining mixture and heated at 300^oC for 2 hrs. After cooling the digested solution, it was filtered through Whatman filter paper 42 and diluted with distilled water on 100 ml volumetric flask. 10 ml soil and bean extracted solution of Cd, Cr and Pb were determined by atomic absorption spectroscopy (with model NOVA 400P AAS) (Anderson, and Ingram, 1993; Jackson, 1958).

2.5 Methods of health risk assessment heavy metals

The risk of human health by intake of heavy metal contaminated crops is described by some concepts such as bio-accumulation factor (BAC), estimate daily intake (EDI), hazard quotient (HQ) and hazard index (HRI).

2.5.1 Bioaccumulation factor (BAF)

Bioaccumulation factor (BAF) is defined as the heavy metal accumulated in each plant tissue to that in soil solution and was calculated according to (Saleem et al., 2020) by equation, Eq. (1);

$$BAF = C_{plant}/C_{soil} \qquad eq\ (1)$$

Where, Cplant is heavy metal concentration in vegetable tissue (mg/100 g), and Csoil is metal concentration in soil (mg/100 g dry soil).

2.5.2 Estimated daily intake (EDI) of heavy metals

Estimated daily intake (EDI) is defined as the maximum amount of a chemical that can be ingested daily over a lifetime with no appreciable health risk. It is expressed in terms of milligrams per kilogram of body weight. The EDI value of each metal of interest was determined by the equation used by (Khan et al., 2008) with slight modification as presented in Eq. (2).

$$EDI = \frac{D \times C_M \times E_F \times E_D \times 0.001}{B_W \times AT} \qquad Eq\ (2)$$

where

D is the daily faba bean consumption (17.7 mg day^{-1}) per adult person;

C_M is the mean concentration of metal in contaminated faba bean (mg kg^{-1} dry weight);

E_F is exposure frequency (365 day/year);

E_D is the exposure duration (66.7 years), average life time of Ethiopian from Human Development Report, 2019 (UNDP, 2019),

B_W is reference body weight for an adult during survey assessment, which is 62.3 kg;

AT is the average exposure time during a lifespan (66.7 yrs x 365 days) and 0.001 is unit conversion factor. The overall data employed for the calculation of EDI is as compiled in Table 3.

The daily faba bean consumption (D) was obtained through a formal survey conducted in the study area. Interviewer of 383 persons in the range 50–75 kg body weight regarding their daily consumption rate of the faba bean tested was conducted. An average consumption rate of faba bean per person per day was calculated with an average body weight of 62.3 kg. So, the daily intake of faba bean seed is 17.7 mg/day. A common formula for calculating sample size in survey studies from a finite population (countable population) is given below according to Etikan and Babatope, (2019).

$$n = \frac{N*p*q*Z^2}{e^2(N-1)+Z^2*p*q}$$

Where, n = Sample size; p = 0.5 (Proportion of population to be included in the sample i.e 50%); e = 0.05, margin of error or acceptance error; N = Population size = 111,313; Z = 1.96, for a confidence interval level of 95%, α is 0.05); q = 0.5, none occurrence of events = 1-0.5 = 0.5.

2.5.3 Hazard Quotient (HQ)

A hazard quotient is the ratio of the potential exposure to a substance and the level at which no adverse effects are expected. An estimate of the non-carcinogenic potential hazard to human health (HQ) is calculated as a fraction of determined dose to the reference dose. The health risks of the heavy metals were also determined by calculating their hazard quotients (HQ) according (Sharma et al., 2016) as shown in Eq. (3);

$$HQ = \frac{EDI}{R_fD} = \qquad Eq.\ (3)$$

Where, EDI is the mean vegetables intake per day (mg kg^{-1}) and R_fD is the oral reference dose of the metal (mg kg^{-1} per day). R_fD is an estimate of a daily oral exposure for the human population, which does not cause deleterious effects during a lifetime, generally

used in EPA's noncancer health assessments. The R_fD values were set to be as follows (mg kg^{-1} bw-day): Cd (0.001 mg kg^{-1} per day), Cr (1.5 mg kg^{-1} per day) and R_fD for Pb (0.004 mg kg^{-1} per day) was taken from WHO (1993) (*Joint FAO/WHO, 1993*).

2.5.4 Hazard Index (HI)

An exposure to more than one pollutant results in summation effects. Thus, hazard index (HI) is a vital index that assesses overall likely impacts that can be posed by exposure to more than one contaminant. When the HI is < 1, this suggests that there will not pose health effects from consuming pollutants contained in a foodstuff (*U.S. EPA, 1998*). The HI is calculated as an arithmetic sum of the hazard quotients for each metal as shown in Eq. (3);

$$HI = HQPb + HQ\ Cd + HQ\ Cr = \frac{EDI,Pb\ x\ Cm,Pb}{RfD,Pb} + \frac{EDI,Cd\ x\ Cm,Cd}{RfD\ Cd} + \frac{EDI,Cr\ x\ Cm,Cr}{RfD\ Cr} \qquad \text{eq. (3)}$$

Where HQ is hazard quotient of a heavy metal, EDI is estimated daily intake of a heavy metal, Cm is concentration of a heavy metal, and R_fD is a reference dose of a heavy metal.

Hazard quotient (HQ) assumes that there is a level of exposure known as the reference dose (R_fD). It is estimated that a daily oral intake of the heavy metal at the reference dose will pose no reasonable risk even to sensitive populations, over a 70-year lifetime (Saleem et al., 2020).

2.6 Statistical analysis

Statistical significance of variation in content of heavy metals in soils and faba bean was determined by one-way analysis of variance (ANOVA) and Tukey's HDS test (at the 0.05 significance level) between treatments (Torrie and Steel, 1979). Statistical analysis was performed using the statistical package SPSS (IBM version 20).

3. Result And Discussion

3.1 Heavy metal accumulation in soil

The total concentrations of studied heavy metals in the top 20 cm of the soil layer were presented on Table 2. The concentrations (mg kg^{-1}) of heavy metals in the different amended soils were ranged as Pb (0.96 ± 0.07–1.55 ± 0.06), Cd (0.40 ± 0.06–1.09 ± 0.03) and Cr (1.50 ± 0.13–2.86 ± 0.07). The highest concentrations of heavy metals in the soil from the plot area amended with municipal solid waste compost, biochar and co-composted biochar was found for chromium (Cr), followed by lead (Pb) and cadmium (Cd). Among the amended soils, the concentrations of Pb increased in the order of khat biochar < 25% w/w co- composted biochar < compost alone < 15% co-composted biochar < 5% co- composted biochar. The concentration of Cd in the amended soil increased in the order of khat biochar < compost alone < 15% co-composted biochar < 25% co- composted biochar < 5% co-composted biochar. The Cr concentration among the amended soils also increased in the order of khat biochar < compost alone < 25% co-composted biochar < 15% co-composted biochar < 5% co-composted biochar.

Our results revealed that the concentrations of Pb, Cd and Cr in the amended soils are much lower than WHO (1996) permissible levels, (Pb (85), Cd (0.8) and Cr (100) mg kg^{-1}), which is reported in Onyedikachi et al., (2018). Comparatively, the concentrations of heavy metals are lower in co-composted biochar than control compost and khat-derived biochars amended soils and faba beans. This is due to the organic amendments immobilized the heavy metals through formation of complex in the humic substances. Recently, considerable research has shown that biochar is effective in immobilizing heavy metals, thus reducing their bioavailility and mobility in compost piles. In support of this result, adding 5% biochar to the soils decreases the bioavailability and bioaccessibility of Pb by 75.8 and 12.5%, respectively, compared to the unamended soil (Ahmad et al. 2012).

Table 1
concentrations of Pb, Cd and Cr observed in faba bean grain and soil amended with compost, co-composted biochars and biochar from MSW sources, values in the table are means ± S.D.

Types of organic amendments	**Concentrations in soil mg/kg**			**Concentrations in faba bean grain mg/kg**		
	Pb	**Cd**	**Cr**	**Pb**	**Cd**	**Cr**
Compost alone	1.14 ± .10a	.46 ± .06a	2.17 ± .23a	.37 ± .04a	.04 ± .01a	1.67 ± .14a
5% co- composted biochar	1.55 ± .06b	1.09 ± .03	2.86 ± .07b	.42 ± .04a	.06 ± .01a	1.83 ± .08b
15% co-composted biochar	1.36 ± .06b	.94 ± .09c	2.79 ± .15b	.54 ± .04c	.08 ± .01a	1.84 ± .02a
25% co-composted biochar	1.22 ± .04a	.99 ± .06c	2.61 ± .15b	.59 ± .03c	.10 ± .01a	2.02 ± .14d
Khat-derived biochar	.96 ± .07e	.40 ± .06a	1.50 ± .13e	.37 ± .04a	.04 ± .01a	1.67 ± .14a

Tukey HSD ($p < 0.05$; means within a column followed by different letters are significantly different).

3.2 Heavy metal accumulations in faba bean grain

The concentrations of Pb, Cd and Cr in different faba bean seeds grow on municipal solid waste compost, biochar and co-composted biochar amended soils are presented on Table 1. The mean concentrations of different heavy metals for faba bean seeds were also in decreasing order of Cr > Pb > Cd. Whereas the concentrations of Pb, Cd and Cr in faba bean grain grow on different amendments decreased similarly in the order of khat biochar < compost alone < 5% co-composted biochar < 15% co- composted biochar < 25% co-composted biochar.

In the present study, our results revealed that the accumulations of all heavy metals in faba bean grains significantly decreased in the MSW compost, biochar and co-composted biochars application. And the concentrations of these heavy metals are higher in soils than faba bean grown on the same soils. Literatures suggested that plants growing on toxic heavy metals contaminated soils cannot prevent metal uptake but, only restrict and hence accumulate in their tissues in varying degree. On their associations with soil toxic contaminants, plants can be classified as accumulator, excluders or indicators. This indicated that faba bean is not heavy metals accumulator plant.

The concentrations of Pb, Cd and Cr in faba bean grains for all treatments were less than the JECFA (2011) permissible limits in plant which Pb (0.20), Cd (0.1) and Cr (1.3) mg kg^{-1} (FAO/WHO, 2015; JECFA, 2016). The findings of this study is similar with the study by Nawaz et al., (2020) which the levels of Cr > Pb > Cd in vegetables grown on wastewater irrigated soil.

3.3 Bioaccumulation factor (BAF)

The bio-accumulation factors of Cr, Cd and Pb in faba bean were lower than 1.0 for all the amendments (Table 2). A BAF value higher than one indicates that a plant is a hyper accumulator, whereas a value less than one is indicative of an excluder. Our finding indicated that faba beans grown on all the five amendments are lower or no accumulators of Pb, Cd and Cr. And there were no significant differences in the BAF of Cr, Cd and Pb between faba beans grown on different soil amendments. The values obtained were in increasing order of Cd < Pb < Cr in faba bean grown on all amendments. The BAF values showed that relatively Cr was the highest uptake metal. According to research investigating the nature of metal binding mechanisms to compost show that composted residual derived from MSW has a high affinity for metal sorption due to complexation. Therefore, there is low heavy metal levels in soil solution and hence plant grains.

Table 2
Effects of different organic soil amendments on bio-concentration factor (BCF) in faba bean seeds (Values are means of three replicates expressed on dry matter basis)

Types of soil amendments	Bio - accumulation factor		
	Pb	Cd	Cr
Compost alone	0.33	0.08	0.76
5% co- composted biochar	0.27	0.05	0.64
15% co- composted biochar	0.39	0.08	0.66
25% co- composted biochar	0.48	0.10	0.77
Khat biochar	0.29	0.06	0.76

3.4 Estimated daily intake (EDI)

The estimated daily intake of heavy metals in all the five treatments were increased in the order of Cd < Pb < Cr as presented on Table 3. The EDIs for all heavy metals (Pb, Cd and Cr) were highest in 25% w/w co-composted biochars, while lowest for khat biochar amended faba beans. According to US Environmental Protection Authority USEPA (USEPA, 1998) and Joint FAO/WHO Expert Committee on Food Additives (JECFA, 2003) cited in (Chen et al., 2014), the reference dose (R_fD) for Cr, Cd and Pb were 1.5 and 1×10^{-3} mg kg^{-1} and 3.6×10^{-3} per day respectively. The highest mean estimated daily intake of Pb, Cd and Cr was via dietary consumption of 25 % co-composted biochars amended faba beans, 0.017×10^{-3}, 0.03×10^{-3} and 0.57×10^{-3} mg kg^{-1} of body weight per day, respectively, levels that were much lower than the reference doses. Thus, the consumption of faba bean growth on municipal solid waste compost, biochar and co-composted biochar collected from Jimma city was safe related to human health risks. Similarly, Guerra et al., (2012) observed that the daily ingestion of heavy metals was below the oral dose of reference, therefore, consumption of these vegetables can be considered safe and without risk to human health.

Table 3
Estimated daily intake (EDI) of Pb, Cd and Cr values via consumption of faba bean grown on soil amended with compost, co-composted biochars and biochar from MSW sources (means ± S.D)

Types of soil amendments	EDI (μg/kg)		
	Pb	Cd	Cr
Compost alone	0.10	0.01	0.50
5% co- composted biochar	0.12	0.02	0.52
15% co- composted biochar	0.15	0.02	0.52
25% co- composted biochar	0.17	0.03	0.57
Khat biochar	0.08	0.01	0.33

3.5 Hazard Quotient (HQ) and hazard Index (HI)

Risk of intake of municipal solid waste compost, biochar and co-composted biochar was characterized by hazard quotient (HQ) and hazard index (HI) as shown on Table 4. The hazard quotient for all amendments decreased in the order of Pb > Cd > Cr. Among the amendments the 25% w/w co-composted biochar had the highest value of both hazard quotient and hazard index for all metals. The HQs and HIs values for all heavy metals determined in all treatments were less than one indicated that the studied population considered to be safe from consumption of faba bean grow on municipal solid waste compost, biochar and co-composted biochar.

Table 4
The HQ and HI of Pb, Cd and Cr values in faba bean amended with compost, co-composted biochars and biochar from MSW sources (means)

Types of soil amendments	HQ			$HI=\sum HQ=HQPb+HQ\ Cd+HQ\ Cr$
	Pb	Cd	Cr	
Compost alone	0.029	0.01	0.0003	0.04
5% co- composted biochar	0.034	0.02	0.0004	0.05
15% co- composted biochar	0.043	0.02	0.0004	0.06
25% co- composted biochar	0.050	0.028	0.0006	0.08
Khat biochar	0.023	0.007	0.0002	0.03

4. Recommendation

Accumulation and health risk assessment of heavy metals is very important before recommendation to widely used MSW as organic fertilizer, since MSW could be contaminated with pollutants from industry sources. Data on the heavy metals levels in soil amended with organic fertilizer derived from MSW and crops grow on this soil is a tool for the well-being of population. During the application organic fertilizer derived from municipal solid waste, the risk of transference of heavy metals from soil to humans should be a matter of concern. In the present study, the accumulations of heavy metals in faba bean grow on soil amended with municipal solid waste compost, biochar and co-composted biochar collected from Jimma city waste disposal site was much lower than the WHO (1996) levels. Hence, the EDIs of Pb, Cd and Cr were all far below the R_fDs, suggesting that the consumption of faba bean posed no health risk to the local population.

Declarations

Author contribution statement

Conceptualization, Z.A., K.P. and M.L.; methodology, Z.A., A.B. and A.N.; investigation, Z.A., A.B. and A.N.; resources, Z.A., A.B., A.N., K.P. and M.L.; data curation, Z.A., A.B., A.N., K.P and M.L.; writing—original draft preparation, Z.A., A.B. and A.N.; writing—review and editing, K.P. and M.L.; project administration, M.L.; funding acquisition, K.P. All authors have read and agreed to the published version of the manuscript.

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Competing interest statement

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Additional information

No additional information is available for this paper.

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