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S. I. BIOCHAR

Effect of garden waste biochar on the bioavailability of heavy metals and growth of *Brassica juncea* (L.) in a multi-contaminated soil

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Abstract

Metal-contaminated soils are considered a global concern due to their adverse effects on ecosystem vitality. This study was conducted to assess the efficiency of garden waste biochar (GB), as a modern remediation tool of soils contaminated with heavy metals (HMs), compared with the other *Paulownia* biochar (PB) and bamboo biochar (BB), on the growth of *Brassica juncea* (L.). The experiments and analyses were carried out at the Institute of Agricultural Resources and Environment, Guangdong Academy of Agricultural Sciences (Guangzhou, China), during the year 2018. The studied contaminated soil sample was amended with 0, 2%, 4%, and 6% (w/w) of PB, BB, GB_{400}, and GB_{600} biochar. The experiment was designed in a completely randomized block design with 3 replications for each treatment. Garden waste biochar significantly duplicated the soil organic matter and EC 1.43−2.21 and 1.33−1.51 times, respectively, enhanced soil pH, and improved plant growth. It was more efficient to improve soil properties than PB and BB. DTPA-extractable metals showed the highest reduction at 6% of GB_{400}, which was 29.56, 46.04, and 59.98% for Pb, Cd, and Cu, respectively, while it was 48.29% for Zn at GB_{600} over the control. Moreover, GB treatments increased the nitrogen (N) and phosphorus (P) contents of the plant shoots. Besides, HM contents of soil and plant tissues were significantly reduced after biochar applications and the highest reduction was recorded using 6% of GB. The results obviously pointed out that the metal transfer coefficient (TC) of shoots was decreased compared with the control after biochar applications, and GB showed the optimum response in this regard. The huge amounts of garden waste, after transforming them to biochar (GB) which has been considered more effective in safe crop production, can be used to reduce the availability of toxic metals in the soil and keep them under safe limits, especially with large-scale vegetable crops in China. It will clean the environment and improve resource sustainability. Therefore, GB is recommended to be used in soil HM remediation on a large scale in polluted areas.

Keywords Bioavailability · Biochar · Contaminated soil · Heavy metal · Garden waste

Highlights •The influence of biochar additions to *Brassica juncea* grown on contaminatedsoil was tested.
- The tested biochars reduced the bioavailability and bioaccumulation of heavy metals.
- Garden waste biochar was more efficient in reducing the availability of heavy metals and improvement soil properties and plant growth.

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Introduction

The contamination of heavy metals (HMs) that occurs in agricultural soils as a result of industrial activities, mining, and smelting is considered a critical worldwide environmental problem. It caused destructive disorders in plants and soils and then they move to animal and human food chains (Awad et al. 2007; Yang et al. 2017; Awad et al. 2017). In China, about 19.4% of the total farmland have been contaminated by HMs (Ministry of Environmental Protection P.R.C. and Ministry of Land and Resources P.R.C. 2014), especially in Guangdong Province since a potential health risk of HM contamination has been recorded from vegetable crops (Liang et al. 2018). For instance, Shaoguan City, which is located at north Guangdong Province, is considered a HM-contaminated city due to mining activities (Yang et al. 2003) and low soil pH of some areas that increases HM solubility to be toxic (Zhou et al. 2015).

Globally, China is the largest producer and consumer of vegetables (Yang et al. 2017). Moreover, Guangdong Province is considered the main region of vegetable production (2.55 million tons) and its residents consume more than 300 g of vegetable daily. The vegetable fields in Guangdong are often close to the industrial areas that discharge an amount of their chemical wastes (HMs) into agricultural soils (Zeng et al. 2008). Therefore, HMs negatively affect vegetable safety (Eissa 2016; Liang et al. 2018; Eissa 2019) resulted in fatal human health disorders (Moynihan et al. 2017), especially the fresh edible ones (Yang et al. 2017).

Biochar is a pivotal soil amendment used to enhance the food safety through decreasing the bioavailability of HMs via its ability to absorb and/or adsorb HMs (Reeves and Chaney 2008; Shen et al. 2014; Bian et al. 2014; Chen et al. 2016). Recent studies highlighted the benefits of biochar including carbon imprisonment, green gas alleviation, and improvement of soil properties (Xu et al. 2015; Chen et al. 2016; Lu et al. 2014; Song et al. 2014) due to its high longevity in soils (Laird 2008; Sohi 2012), especially surface area, effective organic groups, and high pH value (Wu et al. 2012), resulting in crop biomass improvement (Kaudal et al. 2015).

Bioavailability of HMs to plants depends on feedstock types and levels of biochar application as well as pyrolysis conditions (Zhang et al. 2016). Increasing the pyrolysis temperature increases the aromaticity, whereas the massiveness of oxygenated functional groups decreases (Harvey et al. 2011). Lu et al. (2014) found that the applications of rice straw biochar produced at 500 °C were more effective than bamboo biochar produced at 750 °C in decreasing the level of soil extractable copper (Cu), lead (Pb), and zinc (Zn). Moreover, Song et al. (2014) postulated that the biochar of sewage-sludge, pyrolyzed at 450 °C, reduced the plant uptake of HMs compared with biochar produced at 400 °C, 500 °C, and 550 °C.

Paulownia is a high-yield woody tree naturally grown in China (Basu et al. 2015) especially *P. elongata* (PE) and *P. fortune* species (Yadav et al. 2013). However, there is little information about using *Paulownia* woods as biochar (PB), while bamboo biochar (BB) has been used early as a remediation tool of HMs in China (Lu et al. 2014; Liu et al. 2011; Lu et al. 2017).

Garden waste is one of the less use resources derived from the green space (defined as an area of grass, plants, or other vegetation set apart for recreation) and continually increases due to the extension of urban and green zones (MacFarlane 2009; Niinemets and Penuelas 2008). In China, 1.8 million hectares of green spaces produce 14.4 million tons of garden waste biomass (Shi et al. 2013; Sun et al. 2017). Guangdong Province is the largest producer (2.5 MT annually) of garden waste biomass in China (Shi et al. 2013). The garden waste consists of various plant portions (grass snips, hedge clips, tree clippings, wood wreckage, and falling leaves and branches) that could be of benefit for crop production. Also, the running and handling of green space consume money for labor work and agricultural operations (Boldrin 2009). The garden waste could be utilized for biochar production. It could not only save green space management costs, but also improve soil fertility, enhance plant growth, and remediates HMs in contaminated soils.

The use of garden waste as a biochar for soil amendment has so far not been investigated, whereas a few studies were only focused on its use as biofuel and energy production (Koh et al. 2008; Shi et al. 2013) or as a compost (Chen et al. 2015). Therefore, the current study aims to evaluate the efficiency of garden waste biochar (GB), produced under different pyrolysis, to alleviate HM toxicity in a contaminated soil. Effects of GB compared with those of PB and BB on improving crop production and HM uptake of *Brassica juncea* (L.) will be also tested.

Materials and methods

Soil and biochar

The experiments and analyses were carried out at the Institute of Agricultural Resources and Environment, Guangdong Academy of Agricultural Sciences (Guangzhou, China), during the year 2018 to evaluate the effects of different biochar feedstocks on the remediation of HM-contaminated soil. A sample of HM-contaminated soil (0–20 cm depth) was taken from Shaoquan City, Guangdong Province, China. The soil sample was air-dried, and sieved (5-mm mesh sieve) to be used in the pot experiment. Soil properties (e.g., pH, organic matter, and total cadmium (Cd), lead (Pb), zinc (Zn), and copper (Cu)) were determined by routine analytical methods according to Table 1.

Four biochar types were used to investigate their efficiency on bioavailability of the target metals in the studied HM-contaminated soil. *Paulownia* biochar (PB) and bamboo biochar (BB) were produced by Huanyu Energy Technology Co., Ltd., under 700–800 °C. However, GB was generated at 400 °C and 600 °C (GB_{400} and GB_{600}) for 3 h. Each of the obtained biochar was crushed using a stainless steel mill, and their properties are listed in Table 1.

Pot experiment

Plastic pots (15 × 17 cm) were filled with 1.5 kg of the prepared soil sample amended with 0, 2% (w/w, equivalent to 31.2 t ha^{-1}), 4% (w/w, equivalent to 62.4 t ha^{-1}), and 6% (w/w, equivalent to 93.6 t ha^{-1}) of PB, BB, GB_{400}, and GB_{600} biochar. Also, the recommended dose of NPK mineral fertilizer was added at a rate of 100 mg kg^{-1}, 80 mg kg^{-1}, and 100 mg kg^{-1}, respectively. The experiment was laid out in a completely randomized block design with 3 replicates. Based on the previous studies of Jagtap et al. (2013), *Brassica juncea* (*L.*) plants were chosen as an indicator plant for HM uptake. Five seeds were germinated in each pot, and seedlings were thinned to 2 plants per pot 2 weeks after planting. Then, the plants were left until maturity stage under the greenhouse condition (18–25 °C temperature and 60–70% humidity). The soil moisture content was kept at 7% of its water-holding capacity. Two months after planting, the plants were harvested and separated into shoots and roots, then their fresh weights were registered. Shoots and roots were washed with deionized water then dried at 65 °C for 72 h, ground, and stored for chemical analysis. The soil sample of each pot was air-dried then stirred well, sieved by a 2-mm sieve, and kept for analysis.

Transfer coefficient

The transfer coefficient (TC) of each metal was calculated in order to determine the efficiency of biochar treatments on reducing HM availability to *Brassica juncea* (L.). It represents the plant efficiency to take up the metal from the soil according to the proposed equation by Peijnenburg and Jager (2003) and Karami et al. (2011) as follows:

$$TC = Cp/Cs$$

Where,

TC is the shoot transfer coefficient,
Cp presents the shoot metal concentration (mg kg^{-1}), and
Cs is the soil metal content (mg kg^{-1}).

Chemical analysis

The soil particle size distribution was measured using the pipette method described by Jackson (1973). In stirred

Table 1 Some selected properties of the investigated soil and biochar

Property	Soil	Biochar			
		Paulownia	Bamboo	Garden waste $_{400}$	Garden waste $_{600}$
Clay (%)	25.75	-	-	-	-
Silt (%)	32.01	-	-	-	-
Sand (%)	42.24	-	-	-	-
Texture	loam	-	-	-	-
Organic matter (g kg^{-1})	23.39	840.13	730.64	866.91	860.67
EC (dS m^{-1}) (1:10)	0.54	1.78	0.68	5.35	6.94
pH	5.40	10.28	10.10	10.92	11.35
Total Cd (mg kg^{-1})	2.5	ND	ND	ND	ND
Total Pb (mg kg^{-1})	979.75	4.12	ND	7.52	11.15
Total Zn (mg kg^{-1})	1018.61	40.02	31.70	81.97	108.15
Total Cu (mg kg^{-1})	33.27	16.30	3.88	19.45	27.86
DTPA-extractable metals					
Cd (mg kg^{-1})	1.6	-	-	-	-
Pb (mg kg^{-1})	376.45	-	-	-	-
Zn (mg kg^{-1})	150.01	-	-	-	-
Cu (mg kg^{-1})	10.15	-	-	-	-
Total P (g kg^{-1})	1.32	0.83	0.46	2.53	3.23
Total N (g kg^{-1})	3.02	5.18	3.85	16.95	14.15
Available P (g kg^{-1})	0.20	-	-	-	-

suspension (for 30 min) of 1:10 (w/v) biochar:water, the electrical conductivity (EC) and the reaction (pH) were measured. Soil reaction (pH) was measured in 1:2.5 (w/v) soil:water suspension, while the electrical conductivity (EC) was measured in 1:10 (w/v) soil:water extract. The total soil nitrogen (N) was estimated using the semi-micro Kjeldahl method, while the available phosphorus (P) was determined spectrophotometrically using 0.5 M $NaHCO_3$ (Lu 1999). The total P was estimated using H_2SO_4–$HClO_4$ digestion method described by Lu (1999). The soil organic matter (SOM) content was measured using the method of Walkley-Black as described by Jackson (1973). Diethylenetriaminepentaacetic acid (DTPA) was used to assess HM bioavailability (Lindsay and Norvell 1978). Total soil metal content was extracted using the digestion of soil sample with concentrated acids of HF, HNO_3, and HCl (Shuman 1979). The total and DTPA-extractable Pb, Zn, and Cu were measured using the atomic absorption spectrometer (AA 800, Perkin Elmer Co., USA), while the total and extractable Cd were determined using (AS 800, Perkin Elmer, Co., USA). Plant samples were digested using nitric acid, and the metals were analyzed via the atomic absorption spectrometer (Zarcinas et al. 1987). The total plant N and P were estimated using the H_2SO_4–H_2O_2 digestion method according to Lu (1999).

Analysis of variance (ANOVA) and Duncan's multiple range tests were used to determine the statistical significance of the biochar treatment effects using CoStat software, and $p <$ 0.05 was considered to be statistically significant.

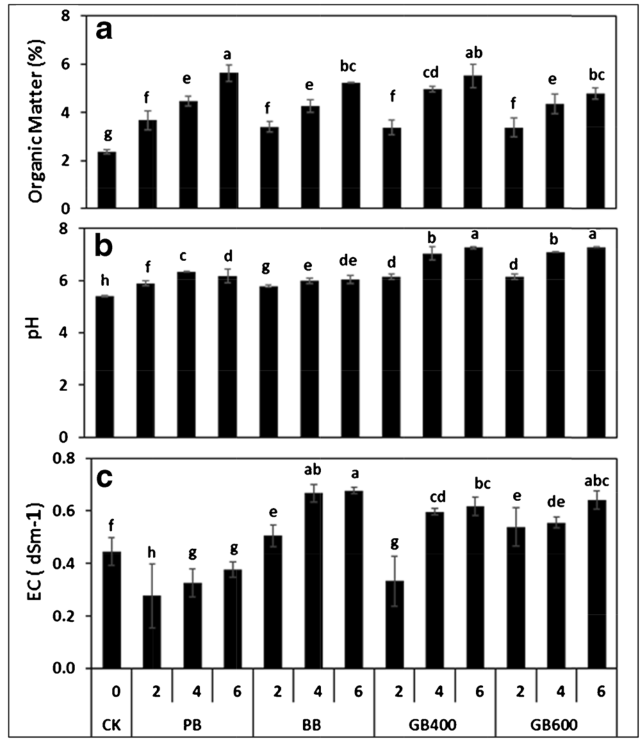

Fig. 1 Effect of biochar application on soil organic matter (%) (**a**), pH (**b**), and electrical conductivity (EC) (**c**). CK, control (no biochar applied); PB, *Paulownia* biochar; BB, bamboo biochar; GB, garden waste biochar at 400 °C and 600 °C. Error bars are standard deviations of the means (n = 3). Different letters above the columns indicate significant ($p < 0.05$) difference between treatments

Results

Soil properties

Biochar applications significantly increased the SOM 1.43–2.21 times compared with the control treatment (Fig. 1a). Soil pH was significantly raised along with increasing biochar levels compared with the control treatment. The increased magnitude depended on feedstock types since significant differences were obtained among GB, BB, and PB treatments (Fig. 1b). At 6% application level, GB_{400} and CB_{600} exhibited the highest soil pH increase compared with other treatments even though there was insignificant difference of soil pH between GB_{400} and GB_{600} treatments (Fig. 1b). Except PB and GB_{400} treatments, biochar applications at 2% caused significant increases in EC values (1.33–1.51 times) compared with the control treatment (Fig. 1c). However, PB at all levels and GB_{400} at 2% significantly reduced the soil EC, and the reduction varied depending on the biochar level (Fig. 1c). In general, all tested biochar materials at any level significantly increased total soil N and P contents (Fig. 2a, b). The largest increases of total N and P were observed with the highest

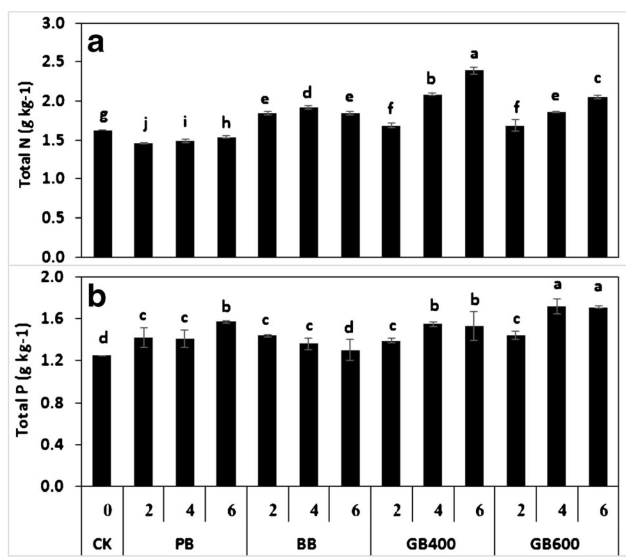

Fig. 2 Effect of biochar application on total soil N (**a**) and total soil P (**b**). CK, control (no biochar applied); PB, *Paulownia* biochar; BB, bamboo biochar; GB, garden waste biochar at 400 °C and 600 °C. Error bars are standard deviations of the means (n = 3). Different letters above the columns indicate significant ($p < 0.05$) difference between treatments

application level of GB while the other biochar types realized slight changes.

DTPA-extractable soil metals

The availability of HMs decreased with increasing biochar additions, and the impact was more pronounced at 6% (Fig. 3). In the untreated soil, the DTPA-extractable Cd was more than 60% of the total content which represents a large portion compared with the other metals, while the DTPA-extractable Zn was the lowest one (13.8%). However, those of Pb and Cd were more available than Zn and Cu and their symptoms appeared clearly on the plants grown in the biochar non-treated soil. Although all biochar types decreased the DTPA-extractable metals, GB pyrolyzed at 400 and 600 °C was more effective than BB and PB. The maximum reduction of the DTPA-extractable metals was observed with GB_{400} at 6%, which was 29.56, 46.04, and 59.98% for Pb, Cd, and Cu, respectively, over the control. Also, significant reduction of the DTPA-extractable Zn was obtained with GB_{600} treatment (48.29%).

Brassica juncea biomass yield, and N and P uptake

The fresh and dry biomass productions of *Brassica juncea* (L.) plants were significantly boosted by biochar applications (Table 2), while they were significantly reduced in the untreated soil (Table 1), and even some plants died as a result of HM toxicity. Inversely, the application of different biochar types improved the shoot and root biomass compared with the control (CK) treatment (Table 2). The highest dry biomass yield was obtained using GB_{400} (14.41 g pot^{-1}) and GB_{600} (13.35 g pot^{-1}) at 2%, PB (13.52 g pot^{-1}) at 4%, and BB (5.35 g pot^{-1}) at 6% compared with CK (0.85 g pot^{-1}). Similarly, biochars caused a significant ($p < 0.05$) increase of dry root yield up to 1.73, 0.86, 2.04, and 1.70 g pot^{-1} by using PB at 4%, BB at 6%, and GB_{400} and GB_{600} at 2%, respectively, compared with the CK treatment (0.50 g pot^{-1}). Although the shoot and root yields significantly ($p <$ 0.05) increased by applying 2% of GB_{400} and GB_{600}, they decreased again with increasing the applied levels up to 6%.

Applications of GB_{400} caused more N accumulation in the plant shoots compared with the other treatments (Fig. 4a). Increases in the N uptake resulted in N increases in the shoot dry biomass (Fig. 4b). After biochar treatments, both the shoot P content (Fig. 5a) and uptake (Fig. 5b) were significantly higher than those of the CK treatment. Maximum increases in shoot P content (81.25 and 79.54%) were recorded by applying GB_{600} and GB_{400} at 2%, respectively, while the highest shoot P content using PB treatment (59.47%) was found at the 4% application level. Furthermore, although the 4 and 6% of biochar additions were highly significant than the control, the insignificant differences were noticed among biochar types,

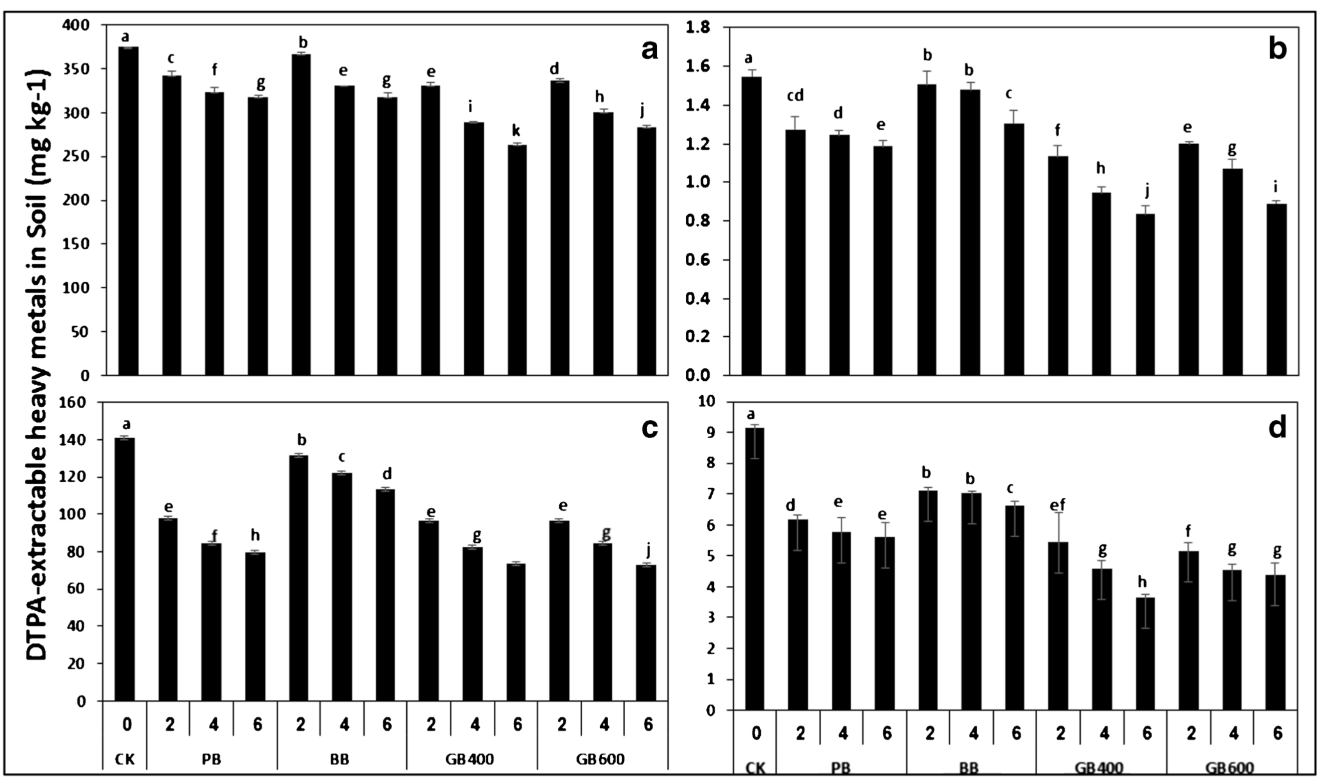

Fig. 3 Effects of biochar treatments on soil DTPA-extractable heavy metals Pb (a), Cd (b), Zn (c), and Cu (d) values. CK, control (no biochar applied); PB, *Paulownia* biochar; BB, bamboo biochar; GW, garden waste biochar at 400 °C and 600 °C. Error bars are standard deviations of the means (n = 3). Different letters above the columns indicate significant ($p < 0.05$) difference between treatments

Table 2 Fresh and dry shoots and roots (g/pot) of *Brassica juncea* plants after application of biochar materials

Biochar type	Biochar rate (%)	Fresh shoot	Dry shoot	Fresh root	Dry root
CK	0	3.76j	0.85g	1.08f	0.50g
PB	2	150.87g	11.54d	11.34d	1.32d
	4	183.95cd	13.52abc	12.96c	1.69b
	6	166.09f	12.86abcd	13.47bc	1.73b
BB	2	5.06j	1.11g	1.66ef	0.66f
	4	12.69i	2.47f	1.74ef	0.67f
	6	61.66h	5.35e	2.09e	0.86e
GB_{400}	2	194.21a	14.41a	14.75a	2.04a
	4	185.29c	13.96ab	14.68a	1.97a
	6	166.12f	13.59abc	14.02ab	1.70b
GB_{600}	2	190.67b	13.35abc	13.71bc	1.70b
	4	182.52d	12.15cd	11.69d	1.63bc
	6	174.37e	12.74bcd	11.15d	1.52c

All values are the means of triplicate analysis. Within each column, values followed by the same letter are not significantly different at $p < 0.05$ level
CK, control (no biochar applied); *PB*, *Paulownia* biochar; *BB*, bamboo biochar; *GB*, garden waste biochar at 400 °C and 600 °C

except BB, at 4 and 6% application levels. Similarly, biochar treatments significantly increased the P uptake which was associated with the plant shoot biomass. The highest P uptake was observed by GB_{400} treatment followed by GB_{600} at 2% level. However, BB treatment exhibited P uptake increases up to 6% applied level (Fig. 5b).

Heavy metal content of plant shoots

The permissible limits of Cd, Pb, Cu, and Zn in soils according to the environmental quality standard of China (SEPA 1995) for vegetable crops are 50, 0.25, 150, and 150 mg kg^{-1}, respectively. The tested soil retained 19, 9, and 7 times of these limits for Pb, Cd, and Zn, respectively, while the Cu

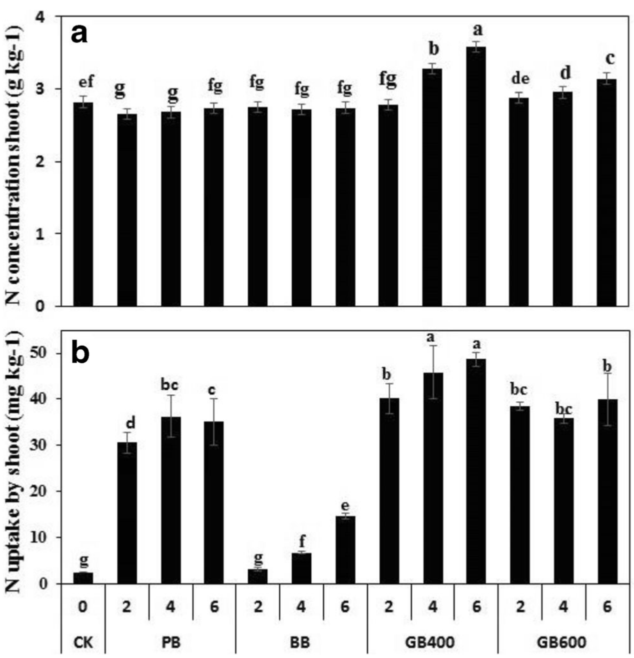

Fig. 4 Effect of biochar application on N concentration (**a**) and total N uptake (**b**) in the shoots of *Brassica juncea*. CK, control (no biochar applied); PB, *Paulownia* biochar; BB, bamboo biochar; GB, garden waste biochar at 400 °C and 600 °C. Error bars are standard deviations of the means (n = 3). Different letters above the columns indicate significant ($p < 0.05$) difference between treatments

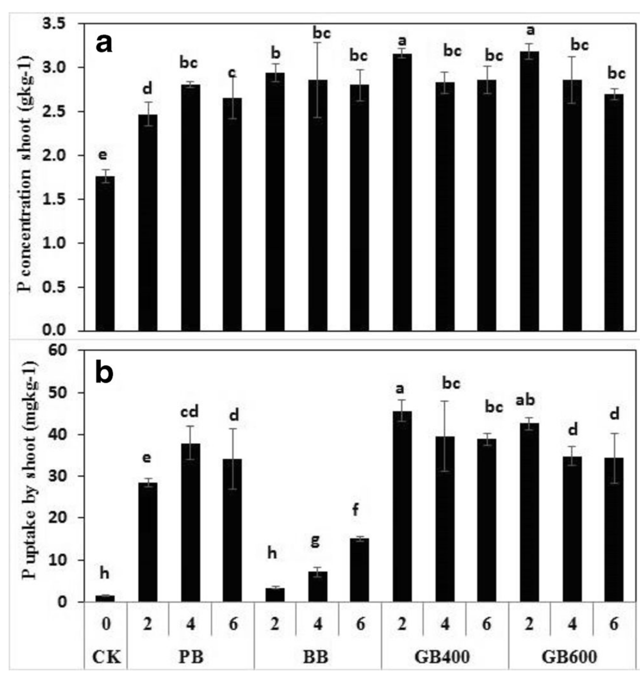

Fig. 5 Effect of biochar application on P concentration (**a**) and total P uptake (**b**) in the shoots of *Brassica juncea*. CK, control (no biochar applied); PB, *Paulownia* biochar; BB, bamboo biochar; GB, garden waste biochar at 400 °C and 600 °C. Error bars are standard deviations of the means (n = 3). Different letters above the columns indicate significant ($p < 0.05$) difference between treatments

was below the permissible limit. All investigated biochars significantly reduced the HM concentrations in both shoots and roots compared with non-amended soil (Table 3). Generally, HM levels of the plant roots were higher than those of the shoots. The highest reduction value of Cd concentration in the plant shoots was observed using GB_{400} (87.97%) at the highest application level, while the lowest one was noticed with BB (13.40%) at 2% application level. Maximum reduction values for Pb, Zn, and Cu shoot concentrations of 98.85, 98.35, and 72.16%, respectively, were recorded for GB_{600} applied at 6% level. On the other side, BB at 2% applied level caused the lowest reduction for Pb, Cd, Zn, and Cu concentrations in the plant shoots. Therefore, GB_{600} was more efficient in reducing Pb, Zn, and Cu content in the shoots than the other tested biochars, while GB_{400} was more effective in lowering the Cd in plant shoots.

The highest HM concentrations in shoots and roots were obtained with BB treatment, except the root Pb which was less than that of the PB indicating that BB was the least effective treatment in remediating the HMs of this soil. According to SEPA (2005), the permissible limits of Pb, Cd, Zn, and Cu in vegetables and fruits are 9, 0.1–0.2, 100, and 20 mg kg^{-1}, respectively. The shoot and root HM contents of the plants grown in the untreated soil exceed SEPA limits except those of Cu (Table 3). However, the Pb shoot concentrations varied between 21.09 and 1.17 mg kg^{-1} in the plants grown in biochar-treated soils, which was lower than the SEPA limit for Pb, except in the BB-treated one. Although the biochar treatments reduced Cd in plant shoots compared with the CK, it was still higher than the permissible limit (0.1–0.2). However, Zn content was lower than its SEPA limit when the GB was added at different pyrolyzed temperatures and levels except at 2%. In addition, Cu level was under the SEPA limit in all plants grown in all biochar-treated soils. The highest relative reductions in HM contents of the edible parts (shoots) which amounted to 98.85, 98.35, and 72.16% for Pb, Zn, and Cu, respectively, were observed at 6% application level of GB_{600}, while the highest relative reduction of Cd (87.97%) was observed at 6% of GB_{400}.

Soil to plant metal transfer coefficient

The application of the tested biochars significantly decreased the metal transfer coefficient from the soil to the shoots compared with CK treatment. The GB_{400} and GB_{600} treatments showed the optimum response in this regard compared with the other biochars (Table 4). Generally, HMs could be ranked according to their TC values of *Brassica* shoots in the order of Pb < Zn < Cu < Cd. Although the least metal content in the studied soil was Cd, its TC in the control and some biochar-treated plants was higher than 1 indicating that it has higher solubility than other HMs.

Table 3 Lead (Pb), cadmium (Cd), zinc (Zn), and copper (Cu) concentrations (mg kg^{-1}) (dry weight basis) in shoots and roots of the *Brassica juncea* plants grown in contaminated soils treated with biochar materials

Biochar type	Biochar rate	Pb		Cd		Zn		Cu	
		Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
CK	0	101.59a	337.23a	6.07a	12.61a	664.63a	1078.88a	15.59a	23.73a
PB	2	8.24d	247.32d	3.27d	3.53d	287.22e	404.68d	8.44d	15.07d
	4	4.35e	237.75e	1.91g	2.49e	143.15g	279.60f	5.52f	11.58gh
	6	2.28f	222.07g	1.29h	2.21e	49.75i	194.28h	4.64fg	9.58j
BB	2	21.09b	325.20b	5.26b	9.57b	553.63b	820.43b	11.30b	19.89b
	4	11.58c	304.02c	5.19b	6.47c	517.47c	605.43c	10.35c	18.14c
	6	11.60c	172.78i	3.61c	4.69d	424.90d	600.77c	10.11c	13.88e
GB400	2	4.18e	232.08f	2.19f	1.81f	117.63h	395.43d	6.91e	13.39ef
	4	1.51f	160.95k	1.12hi	1.66fg	31.10j	205.65h	4.94fg	10.23ij
	6	1.63f	146.14l	0.73j	1.16h	22.57k	204.22h	4.88fg	9.93ij
GB600	2	3.63e	228.35f	2.61e	2.40e	155.98f	376.53e	7.41e	12.46fg
	4	1.64f	185.28h	1.42h	1.74f	12.55l	242.18g	4.55fg	10.43hij
	6	1.17f	166.97j	0.93ij	1.32gh	10.95l	231.72g	4.34g	11.20hi
SEPA limits[a]		9.0	-	0.1- 0.2	-	100	-	20	

All values are the means of triplicate analysis. Within each column, values followed by the same letter are not significantly different at $p < 0.05$ level

CK, control (no biochar applied); *PB*, *Paulownia* biochar; *BB*, bamboo biochar; *GB*, garden waste biochar at 400 °C and 600 °C

[a] Safe limits for human consumption according to SEPA (2005)

Table 4 Transfer coefficient (TC) of Pb, Cd, Zn, and Cu by *Brassica* plants after biochar application

Biochar type	Biochar rate	Pb	Cd	Zn	Cu
CK	0	0.104a	2.49a	0.65a	0.47a
PB	2	0.022b	2.22b	0.54b	0.25d
	4	0.012c	2.15b	0.51c	0.17f
	6	0.012c	1.48c	0.42d	0.14fg
BB	2	0.008d	1.34d	0.27e	0.34b
	4	0.004e	1.07e	0.15f	0.31c
	6	0.004e	0.90f	0.13g	0.30c
GB400	2	0.004e	0.78f	0.12g	0.21e
	4	0.002f	0.58g	0.05h	0.15fg
	6	0.002f	0.53gh	0.03i	0.15fg
GB600	2	0.002f	0.46gh	0.02i	0.22e
	4	0.002f	0.38hi	0.01i	0.14fg
	6	0.001f	0.30i	0.01i	0.13g

All values are the means of triplicate analysis. Within each column, values followed by the same letter are not significantly different at $p < 0.05$ level

CK, control (no biochar applied); *PB*, *Paulownia* biochar; *BB*, bamboo biochar; *GB*, garden waste biochar at 400 °C and 600 °C

Discussions

Soil properties

Compared with the other biochars, garden waste is the combination of plant origin wastes of green spaces. It is considered a valuable, rich material that contains high amounts of plant nutrients and organic matter with unique properties adequate to improving the soil fertility and increasing plant production mainly when it is used as a biochar. The GB additions positively improved OM, pH, and EC of the soil, as well as both N and P in the soil and plants (Table 1, Figs. 1 and 2). The key factor to increasing OM is the increase of biochar level regardless of their types. Consistently, Zeng et al. (2008) found that the increase of SOM remediates Cd contamination through the inhibition of Cd accumulation in the edible parts of the vegetables. Moreover, soil pH is a vital factor for HM remediation since the increase in pH promotes HM adsorption and precipitation and reduces their solubility. The results demonstrated that the level of 6% of GB was better than PB and BB biochars in raising soil pH (Fig. 1B), which directly reduced HM uptake by the plant roots and enhanced plant production (Tables 2 and 3) (Zhang et al. 2013). These findings suggest that GB is more efficient than those of PB and BB as a modern remediation tool. Furthermore, several studies proved the role of biochar in increasing the pH of acidic soils, resulting in enhancement of the adsorption as well as the complexation of metal cations, hence metal mobility reduction on biochar (Beesley and Marmiroli 2011; Ahmad et al. 2012).

The higher application of GB increased the total N and P in the soil, while this relation was unclear on PB and BB (Table 1). These findings agree with those of Mohamed et al. (2015) and Zhang et al. (2016). Moreover, the increase in the soil EC and pH after GB additions reflects their high EC and pH relative to that of the studied soil (Table 1). Although the additions of different biochar materials increased the soil EC by 1.33–1.51-fold, the obtained EC values were less to cause saline conditions. The reduction in soil salinity via biochar amendments may be due to (1) the adsorption as well as the retention of salts on biochar surfaces resulting in the reduction of salt levels in soil solution, and (2) the decrease in the upward movement of saline water that hindered surface soil salinization (Dahlawi et al. 2018).

DTPA-extractable soil metals

We found that although all types of biochar decreased the DTPA-extractable metals, GB at different pyrolysis was more effective than BB or PB, and the reduction was gradually increased with more additions of biochar. This may be due to the increase in soil pH as a result of biochar application leading to less HM phytoavailability, and/or high HM adsorption as well as a fixed complex formation with these metals, causing low mobility of HMs. These results are in agreement with those of Yang et al. (2016). They found that the extractable Cu, Pb, Zn, and Cd decreased with the increase of the rice straw biochar levels that was correlated with the rising soil pH. Furthermore, Chaney (2010) postulated that Cd in the contaminated soil remains phytoavailable due to its presence in the labile pool, and it transforms into low phytoavailable forms and reduces its plant uptake through raising the soil pH.

Plant growth, and N and P uptake

Garden waste biochar pyrolyzed at 400 °C was the superior treatment and it increased both the fresh and dry root and shoot biomass. This may be due to its rich content of nutrients. Also, low pyrolysis temperature produces more negative surface charges that strongly bind metal cations with soil particles that make it a more efficient biochar (Beesley et al. 2015). These findings were also elucidated by the results in Figs. 4 and 5, whereas GB_{400} accumulated more N and P in *Brassica* shoots. Nevertheless, the biochar application improved the growth and yield of *Brassica juncea* (Table 1) and supported the hypothesis that biochar applications improve crop yield in acidic soil. The enhancement impact of biochar material on the dry biomass of *Brassica juncea* is supported by the results of Khan et al. (2015) who found a significant high biomass production in *Brassica rapa* L. up to 49, 44, 29, and 22% after adding 2% of sewage sludge, rice straw, soybean straw, and peanut shell biochars, respectively.

The response of fresh and dry shoot biomass to BB biochar applications is more pronounced by increasing the application level. In contrary, both types of GB slightly decreased the fresh and dry shoot biomass with increasing application level. The slight reduction in growth as a result of adding 4 and 6% levels may be due to rising electrical conductivity values which led to salt stress on the plant and consequently reduced growth. The increase in vegetative production after the application of biochars may be attributed to their high pH value that reduces HM stress through stabilizing these metals leading to optimal conditions for plant growth. These results are in accordance with those of Yamato et al. (2006) who found a significant increase of peanut yield up to 50% after *Acacia* biochar additions to Indonesia soils. Also, Jeffery et al. (2011) proved a 14% increase in crop production toward biochar applications in acidic soils due to various liming effects and increasing the soil nutrient supply. The biochar application to tomato plants grown on metal-contaminated soil increased the availability of N, P, and K by 67, 54, and 43% above that of the control soil (Almaroai and Eissa 2020). The biochar application to metal-contaminated soils not only increases the growth and yield but also improves the quality of the edible parts (Eissa 2019; Almaroai and Eissa 2020). The results showed that the root biomass slightly responded to the increasing biochar application level, especially BB and GB_{400} since the root biomass was not affected by increasing biochar application level. The biochar applications showed no significant impacts on the N content of plant shoots except for GB treatment (Fig. 4A). An enhancement of N accumulation in shoots using the 6% of GB_{400} treatment may be attributed to the increase in the soil N use efficiency (Zheng et al. 2013). Moreover, the biochar treatments significantly increased the shoot concentration and uptake of P (Fig. 5A, B). The increase in shoot N and P uptakes with GB treatments may be due to their relatively higher P and N content (Table 1). Also, increasing soil phosphorus content and consequently its uptake may be attributed to rising acidity near to neutral due to biochar additives which led to precipitation of iron and aluminum oxides; thus, the phosphorus became more available as the optimum pH for phosphorus availability is about 6.8, especially in the absence of calcium ions in the acidic soils. The application of biochar realized a synergistic effect and increased availability and uptake of N and P (Al-Rohily et al. 2013; Eissa 2016; Almaroai and Eissa 2020).

Heavy metal content of plant shoots

The biochar levels play a critical role in decreasing HMs in plant tissues. The levels of GB_{400} and GB_{600} were better than those of PB or BB (Table 3). Biochar promotes mycorrhizal fungi, changes soil chemical and physical properties, increases the nutrient retention, and raises the soil pH which impact the retention and release of HMs, and provide more negatively charged surfaces ($^{-}$OH and $^{-}$COOH) (Karami et al. 2011; Lehmann et al. 2011; Beesley et al. 2015). The tested biochar had high pH values (Table 1) which increased soil pH (Fig. 1) that reduce the HM availability (Fig. 3). Since the HMs accumulated in roots more than in shoots, it is recommended to grow vegetables with aboveground edible parts in HM-contaminated soils, and avoiding growing those with underground edible parts. Management of metal-contaminated soils needs to find out the optimum plant species, as well as the appropriate organic amendments, which would improve soil conditions and reduce the uptake of toxic metals in the edible plant parts (Eissa 2016; Almaroai and Eissa 2020).

Furthermore, Lu et al. (2014) recorded that the feedstock type and the grain size of biochar had a critical impact on the concentration of Cd and Pb on *Brassica juncea* (L.). Also, they recorded 49% of Cd reduction in the plant via bamboo biochar. Biochar adsorbs HMs on its surfaces via complexing them with the dissolved organic carbon and HCO_3, which reduces their mobilization and concentrations in the soil and inhibits their translocation in plants (Lucchini et al. 2014; Shen et al. 2015). Moreover, the results indicated that GB_{600} and GB_{400} treatments were more effective in reducing HMs in the plant tissues than PB and BB that pyrolized at high temperature (700–800), supporting the hypothesis that feedstock type, pyrolysis temperatures, and biochar properties have a positive effect on HM availability to *Brassica juncea* in acidic soils. These results are in harmony with the fact that lower temperature pyrolysis resulted in internal and external complex formations in the short term. Therefore, the higher temperature during biochar production may produce negative surface charges that should make the metal stable longer but weakly absorbed to biochar surfaces, while the lower temperature has more negative surface charges that strongly bind the metals but decreases with time (Beesley et al. 2015).

Otherwise, the levels of HMs in *Brassica juncea* shoots must be below the permissible limits since they are edible parts which are used as human food. Compared with SEPA (2005) limits, we found that PB, GB_{400}, and GB_{600} were efficient to maintain Pb under the permissible limit. Garden waste biochar continued to show a super impact in reducing Zn below the SEPA limit especially at 4% and 6% levels, while all biochars maintained Cu below the permissible limit, but PB at 6%, GB_{400}, and GB_{600} were the best. Except for Cu, all HMs exceeded the permissible limits in the non-treated soil (Table 3). Due to the fact that *Brassica juncea* is considered a metal hyperaccumulator plant especially for Cd (Jagtap et al. 2013), GB can reduce Cd uptake and accumulation in the aboveground parts of vegetable plants since it tends to accumulate lower and medium amounts of Cd.

Metal transfer coefficient of plant shoots

The transfer coefficient (TC) describes the total concentration of HM proportion in soil, which is transported into the edible parts of the plant. A lower metal TC value indicates lower HM plant uptake, thereby lower health risks to the consumers consequently (Karami et al. 2011). All values of TC of *Brassica* shoots were low after biochar application than those of the CK treatment. However, the TC of Cd in the soils treated with PB and BB at all levels was > 1 and < 1 in the CK treatment. Using 5 and 50 mg kg^{-1} levels of artificial Cd-contaminated soil, Mohamed et al. (2015) found that the biological concentration factor (BCF) values for Chinese cabbage and maize were > 1 in the untreated soil. The lower TC values of Zn, Cu, Cd, and Pb using GB_{400} and GB_{600} indicate that *Brassica* plants prevent the accumulation of these metals in their tissues confirming the effectiveness of GB in reducing the toxic metal uptake. These results are compatible with those obtained by Mohamed et al. (2015) who indicated that the applications of biochar had a higher positive efficiency in reducing HM uptake by ryegrass resulting in significant decreases in TC. Additionally, the higher TC values of Cd, resulting from adding PB and BB levels, ensure a greater ability to absorb Cd from soils. *Brassica juncea* is considered a higher biomass product with a high ability to accumulate HMs in its cells, especially Zn and Cd (Salt et al. 1998; Kumar et al. 1995). In addition, in pot and field experiments, *Brassica juncea* plants were reported to be a hyperaccumulator for cadmium, chromium, and nickel (Jagtap et al.2013). The results confirmed that about 60% of the total content of Cd was available to be taken up by root plants due to acidic conditions.

Conclusions

Biochar application showed positive significant changes regarding soil quality. Garden waste biochar (GB) caused a significant increase in the soil pH, OM, EC, total N, and total P. The investigated biochars were able to potentially in situ remediate the soil contaminated with Pb, Cd, Zn, and Cu by immobilizing these metals in the soil and reducing their uptakes by *Brassica juncea*. The enhancement of pH of the biochar-treated soil may contribute in reducing HM toxicity, and therefore increasing *Brassica juncea* growth and development. In addition, GB_{600} was more effective in decreasing the bioavailability of soil Pb, Cu, and Zn than the other tested biochar. GB_{400} was more efficient in reducing the availability of Cd. DTPA-extractable HMs decreased with increasing biochar level. Enhancing the precipitation and adsorption of HMs on the studied biochar resulted in the decrease of their solubility and bioavailability. Therefore, the efficiency of biochar in reducing the bioavailability of HMs in acidic soil was dependent not only on the biochar materials and its application level but also on the type of metal. Generally, GB was the most effective in improving the soil fertility and crop production through reducing HM availability and keeping them below the safe limits, except Cd. Further studies on the remediation of Cd by GB in other plant species using different levels are required. Moreover, the impact of biochar in the remediation of soil HMs should be studied under field conditions. Finally, the huge amounts of garden wastes along with the high levels of soil HMs in China can give a push to using garden waste biochar to solve these problems, clean the environment, and improve the resource sustainability.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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