JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
Volume 11, Number 2 (January 2024):5475-5483, doi:10.15243/jdmlm.2024.112.5475
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

Utilization of banana waste biochar to reduce heavy metal contamination in soil and maize plants

Ni Made Wedayani, I Nyoman Rai[*], I Gede Mahardika, I Made Sara Wijana

Postgraduate Program in Environmental Science, Udayana University, Jl. Raya Kampus Unud, Bukit Jimbaran, Kuta Selatan, Badung-Bali 80361, Indonesia

[*]corresponding author: rainyoman@unud.ac.id

Article history:

Received 12 September 2023
Revised 23 November 2023
Accepted 10 December 2023

Keywords:

banana wastes
biochar
dosages and types
heavy metals

Abstract

There are indications of heavy metal contamination in soil and agricultural products on paddy fields in Subak Kerdung, Bali. Soil amendments are needed to reduce heavy metal content in contaminated soil to minimize heavy metals in plants. Biochar that contains high organic carbon material and is highly resistant to decomposition is claimed to inhibit and reduce the content of heavy metals in soil and plants. Banana wastes containing cellulose and lignin are considered good as biochar raw materials. This research that aimed to observe the ability of banana waste biochar to reduce heavy metals in soil taken from Subak Kerdung, Bali, was conducted in a greenhouse using maize plants as control plants. The treatments tested consisted of two factors. The first factor was the type of banana waste as biochar-making material consisting of banana stem biochar, banana peel biochar, banana fruit bunch biochar, and mixed biochar (banana stem + banana peel + banana fruit bunch). The second factor was the biochar dosage, which consists of four contents, namely 0 t/ha, 5 t/ha, 10 t/ha, and 15 t/ha. All treatment combinations were arranged in a two-factor, randomized block design with three replications. The results showed that mixed biochar (banana stem + banana peel + banana fruit bunch) effectively reduced Pb and Cu in maize plants. In contrast, banana peel biochar could optimally reduce Cd content in soil and its content in plants. Based on the dose, 15 t/ha of mixed biochar reduced Pb and Cd contents, while 10 t/ha of mixed biochar reduced Cu content.

To cite this article: Wedayani, N.M., Rai, I.N., Mahardika, I.G. and Wijana, I.M.S. 2024. Utilization of banana waste biochar to reduce heavy metal contamination in soil and maize plants. Journal of Degraded and Mining Lands Management 11(2):5475-5483, doi:10.15243/jdmlm.2024.112.5475.

Introduction

There is not enough agricultural land in Denpasar City due to the urbanization process (Zhang et al., 2020) and residential development. However, one of the agricultural lands that still survives in this city is Subak Kerdung, Bali. The research conducted by Murjaya et al. (2019) stated that there are indications of heavy metal contamination of Cu, Pb, Cd, Fe, and Cr caused by screen printing liquid waste that contaminates agricultural soil in Subak Kerdung. Heavy metal contamination from irrigation water can harm aquatic ecosystems, plants, and human health (Ahmad and Danish, 2018). In addition, heavy metal contaminants can come from the basic ingredients of making fertilizers that are added or from the environment (Mahendra et al., 2018; Ali et al., 2020).

Agricultural productivity in Subak Kerdung remains high despite containing heavy metal contamination. Besides rice, Subak Kerdung also produces maize as food for consumption by the surrounding society. Residents also use maize biomass to feed their livestock, so it becomes an important commodity in Subak Kerdung, other than rice. Based on the heavy metal content test conducted in September 2022, the content of cadmium (Cd) in the soil is the highest pollutant content, which is 1.096 mg/kg. Meanwhile, the heavy metal content of Cu and Cd reached 24.54 mg/kg and 2.5 mg/kg in the root of maize plants. The contents of heavy metals in the root are feared to affect the maize kernels produced. Therefore, efforts are needed to reduce heavy metal content in plants.

In maize, heavy metal contamination can result in serious metabolic, physiological, and morphological changes, with the extent of yield loss depending on the related heavy metal, the content of contamination, the combined presence of different metals, and the level of genetic tolerance (Rizvi and Khan, 2018). The content of heavy metals (Fe, Zn, Cu, Cd, Pb, and As) in maize (*Zea mays* L) plants grown at varying distances in the heavy metal-containing soil in Taxco City showed that there was high bioaccumulation of heavy metals in the roots, stems, leaves, and seeds of maize. It caused abnormalities in its organs, such as abnormalities in reproductive structures (tassels and ears), decreased phyllomeres, and plant height (Ruiz et al., 2022). In addition, Romdhane et al. (2021) reported that heavy metal contamination of Zn, Cu, Co, Cd, and Pb can reduce soil pH, reduce fresh and dry weight of shoot and root, and reduce root length. These studies show that maize plants are very sensitive to various metal pollution and have the potential to be used as a test crop to evaluate contaminated soil.

Farmers make efforts to fertilize the soil and plants by adding organic materials and adjusting the cropping pattern. Based on the interview that had been done with the farmers, they think that as long as their rice and maize are pest-free and yields remain high, all is well. Farmers in Subak Kerdung are not interested in the content of heavy metals in the soil or their agricultural production as long as it does not directly impact the amount of agricultural production. In fact, economic yield and biological yield contain dangerous contents of heavy metals. No researchers have focused on the contents of heavy metals in the soil or agricultural products in Subak Kerdung, so the current research cannot be compared to the previous ones. If traced further, the water flow that irrigates Subak Kerdung has the potential to contain excessive contents of heavy metal contamination, which then has the potential to settle on agricultural land.

Based on this phenomenon, efforts need to be made to minimize heavy metal content in the soil so that they can reduce the content from maize plants. Adejumo et al. (2018) used Mexican sunflower compost (MSC), cassava peel compost (CPC) (applied at 0, 20, and 40 t/ha), and inorganic fertilizer (NPK; 20:10:10 at 100 kg N/ha) in the immobilization and content of metals by maize plants. They stated that the application of those composts can reduce the accumulation of heavy metals in maize plants. However, the raw materials that are specialized in terms of types of raw materials certainly cannot be applied to agriculture in Bali. Another research that offers a way to reduce heavy metal contamination is planting wheat as a hyperaccumulator plant. Zou et al. (2021) stated that wheat usage could reduce soil pH, Cd, and Zn contents along with the increasing density of *S. plumbizincicola* plants. However, the use of wheat as a hyperaccumulator plant cannot be applied due to the absence of storage for wheat products and the unfavorable location in Denpasar City. Therefore, it is necessary to make soil amendment efforts that farmers can apply at a low cost.

The application of organic and inorganic methods, such as the use of compost, manure, poultry manure, biochar and gypsum, elemental sulfur, and diammonium phosphate (DAP) in contaminated soil provides benefits compared to inorganic materials. The higher biodegradability and improved soil properties also become considerations apart from the cost-effectiveness (Sabir, 2015). Munir et al. (2020) reported that the use of biochar and the resulting pulverized fuel ash (PFA) significantly increased soil pH, EC, and soil organic carbon (SOC). The addition of biochar increased the availability of Mg, Mn, and Fe content and also reduced the bioavailability of heavy metals in the soil compared to untreated plants.

Biochar can absorb heavy metal contaminants in soil and plants as a cheap and effective soil amendment. Biochar is a carbon (C) rich product derived from the pyrolysis of organic matter at relatively low temperatures (<700 °C) (Lehmann and Joseph, 2009; Clough et al., 2013). Biochar has the potential to amend soil structure, increase agricultural production, and contribute to climate change mitigation (Glaser et al., 2002; Lehmann et al., 2006). Biochar is considered efficient, cost-effective, and environmentally friendly to reduce heavy metal pollution in soil (Bandara et al., 2020). The requirement for biochar raw materials is the presence of cellulose content that can be converted into carbon. One of the biomasses that contains cellulose and even lignocellulose is found in banana waste.

Banana waste can be found in markets, household garbage, and each fried food vendor. In large quantities, besides disturbing the aesthetics of the environment, banana waste, which is abundantly available and not managed properly, can produce greenhouse gases if disposed of in wet conditions (Ahmad and Danish, 2018). Banana waste can be used as an effective adsorbent raw material due to the large amount of carbon compounds contained in it. The content of lignin and cellulose in banana waste can produce carbon that can be utilized as biochar. Sial et al. (2019) reported that the conversion of banana waste into biochar is an alternative disposal method because its application can reduce greenhouse gas emissions and amend soil biochemical properties. In its application, banana waste biochar is also claimed to be more effective in improving soil fertility compared to banana waste, which is not processed into biochar (Sial et al., 2019).

Without specifying the type of banana used, biochar made from banana waste was tested on maize plants with planting media in the form of Inceptisol soil from Subak Kerdung. This aimed to determine the effectiveness of banana waste biochar in absorbing and reducing heavy metal content contained in Subak Kerdung soil.

The application of banana waste biochar with different doses and types of banana waste was carried out to test the effectiveness of absorption on heavy metals Pb, Cu, and Cd. These three types of metals are identified as the most polluting agricultural lands and contaminating agricultural products (Ahadiyat et al., 2023). Subak Kerdung, which is fed by Tukad Badung water, has the potential to experience heavy metal contamination of Pb, Cu, and Cd. Apart from the presence of small industries, such as screen printing and motorcycle washing along the riverbank, the condition of the river, which often smells, changes color, and foams, also indicates heavy metal contamination.

The purpose of this research was to determine the correct type of banana waste biochar to reduce the content of Pb, Cu, and Cd metals in soil and plants. The application of banana waste biochar is expected to reduce heavy metal content in maize plants so that agricultural products are healthier for consumption.

Materials and Methods

Biochar preparation

Banana stem waste, banana peel waste, and banana fruit bunch waste obtained from markets, fried food vendors, and household garbage were collected, cut into small pieces, and then dried in the sun to reduce their moisture content. After drying, these banana wastes were burned in a furnace at a temperature of 400 ºC or on a large scale. The banana wastes could be burned by a simple pyrolysis method using an iron tube for eight hours with constant fire without oxygen. Once in charcoal form, they were crushed and activated by using a $CaCl_2$ activator solution and then dried. Based on the proximate test conducted using ASTM D7582 MVA biomass on each banana waste biochar, the value of water content, fly substance content, ash content, and bound carbon content can be known, as shown in Table 1. Meanwhile, the physical characteristics of each biochar are presented in Table 2.

Experimental design

This research was conducted in a greenhouse in the experimental field of the Faculty of Agriculture, Udayana University, using maize planted in an Inceptisol from Subak Kerdung. Soil weighing 5 kg was placed in each polybag and then treated with biochar. The research method used in this research was a two-factor nested randomized block design with three replications. The factors tested were the type of banana waste as biochar-making material consisting of four contents, namely banana stem biochar (Bt), banana peel biochar (Kl), banana fruit bunch biochar (Tn), and mixed biochar (banana stem + banana peel + banana fruit bunch) (Cam), and also biochar dosage. The treatments of biochar dose variations were 0 t/ha (D_0), 5 t/ha (D_1), 10 t/ha (D_2), and 15 t/ha (D_3). The soil in each polybag was added with compost and then planted with sweet maize (*Zea mays saccarata* L.) with two seedlings in each polybag. The addition of urea to nourish the plants was done after the maize was one month old. Watering intensity was done in the morning and afternoon to prevent the plants from drying out. After entering the harvest period (approximately three months), the maize was ready to be harvested. Then, soils, roots, shoots, and maize kernels were sampled.

Table 1. Composition of banana waste biochar.

Composition	Banana Stem Biochar	Banana Peel Biochar	Banana Fruit Bunch Biochar	Mixed Biochar
Moisture (%)	53.12	41.90	46.30	52.17
Ash (%)	27.92	26.45	31.29	14.93
Fixed Carbon (%)	26.00	35.53	25.98	29.62

Table 2. Physical characteristics of banana waste biochar.

Physical characteristics	Banana Stem Biochar	Banana Peel Biochar	Banana Fruit Bunch Biochar	Mixed Biochar
Number of pores	6.586	7,952	5,460	5,248
Total area (µm)	359,492	546,396	555,347	719,281
Average pore size (µm)	54.58	68.71	101.71	137.06
Porosity value (%)	43.91	44.82	45.91	58.93

Soil samples were taken at a 0-5 cm depth using conventional methods based on a regular soil sampling design. Chemical analysis using Atomic Absorption Spectrophotometry with the Flame Atomic Absorption Spectrophotometry methods was carried out on soil samples, roots, shoots, and maize kernels in the laboratory. After obtaining the test results, data processing was continued using SPSS.

Results and Discussion

Effect of banana waste biochar on heavy metal content in maize plants

Pb, Cu, and Cd contents in maize plant root samples in Subak Kerdung showed Pb content of 16.69 ppm, Cu 24.54 ppm, and Cd 2.5 ppm. The Pb, Cu, and Cd contents in maize plants based on the application of different types of banana waste biochar are shown in Figures 1, 2, and 3. Figure 1 shows that the lowest Pb content (0.05 ppm) was in the roots of plants treated with banana stem biochar, while in the shoots (0 ppm) was in the control treatment. In maize seeds, the lowest value was shown in the control treatment and mixed biochar (0 ppm). Moreover, in the soil, the lowest value was found in biochar-treated plants. Figure 2 shows that the lowest Cu content was 47.96 ppm in the roots of maize treated with banana fruit bunch biochar. The lowest Cu content was 19.83 ppm in shoots and 105.14 ppm in seeds in maize treated with mixed biochar. Meanwhile, the lowest Cu in the soil was 0.76 ppm in maize treated with banana fruit bunch biochar. The lowest Cd content was 0 ppm in maize roots treated with banana peel biochar and 1.67 ppm in maize shoots treated with mixed biochar (banana stem + banana peel + banana fruit bunch). Meanwhile, the lowest Cd values were 1.84 ppm in seeds and 0.55 ppm in maize soil without biochar. Based on Figure 3, the banana peel biochar application can maximally reduce Cd contents in roots, seeds, and soil.

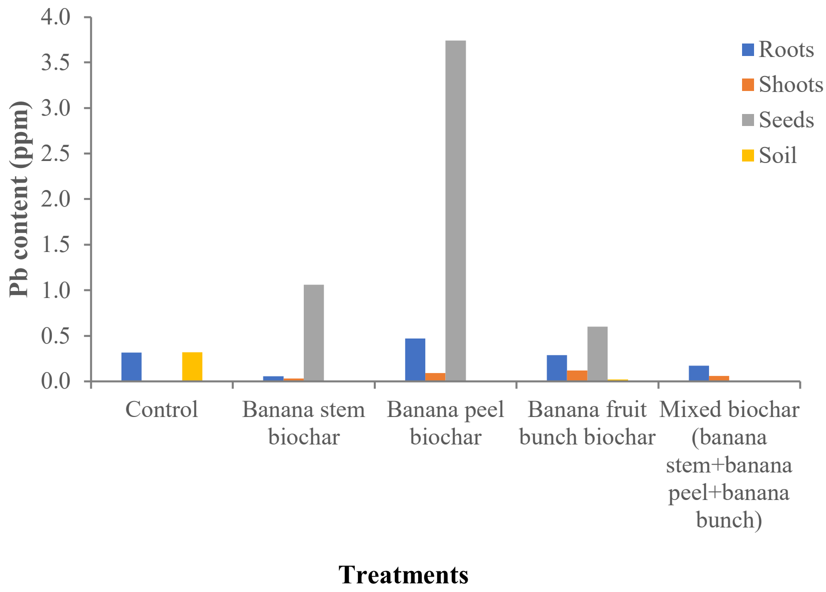

Figure 1. Pb content in maize plants and soil based on the biochar type.

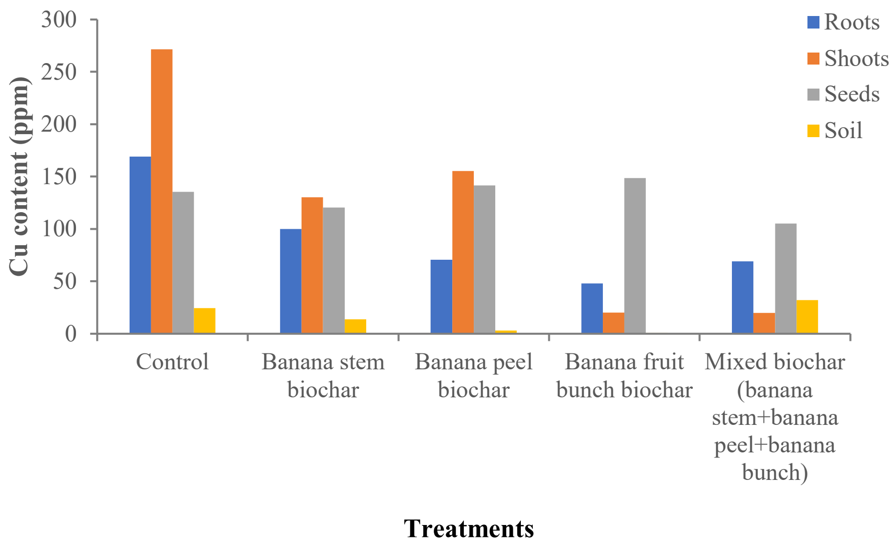

Figure 2. Cu content in maize plants and soil based on the biochar type.

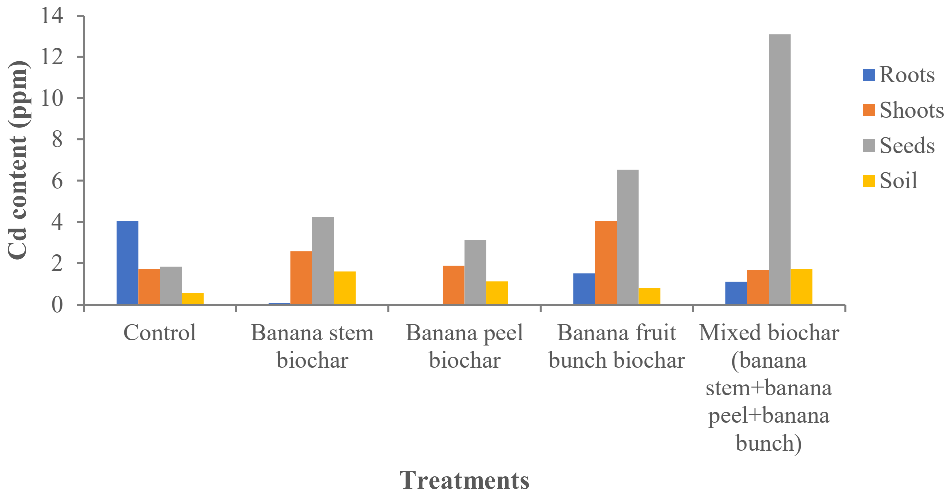

Figure 3. Cd content in maize plants and soil based on the biochar type.

The application of banana waste biochar with different dosages is shown in Tables 3, 4, and 5. The critical threshold for Pb content in plants is 50 ppm, in soil is 100 ppm, and in seeds is 1.0 ppm. Based on Table 3, the application of mixed biochar is included in the safe limit related to the threshold of Pb metal in plants, soil, and seeds. Specifically, the most effective dose to reduce Pb was from the application of mixed biochar at a dose of 15 t/ha. The threshold value of heavy metal Cu in plants is 20-100 ppm, in soil 60-125 ppm, and in seeds is 10 ppm. Based on Table 4, when Cu content is compared with the threshold value of heavy metal Cu in soil and plants, the candidate treatments that can be applied to reduce Cu contents are banana fruit bunch biochar and mixed biochar (banana stem + banana peel + banana fruit bunch).

Table 3. Pb content in soil and maize due to the application of different biochar dosages.

Treatment		Pb content (ppm)			
		Roots	Shoots	Seeds	Soil*)
Banana stem biochar (Bt)	0 t/ha (D_0)	0.32	0	0	0.32
	5 t/ha (D_1)	0	0	1.50	0
	10 t/ha (D_2)	0.16	0	0.74	0
	15 t/ha (D_3)	0	0.09	0.93	0
Banana peel biochar (Kl)	0 t/ha (D_0)	0.32	0	0	0.32
	5 t/ha (D_1)	1.30	0.26	8.74	0
	10 t/ha (D_2)	0.12	0	0.31	0
	15 t/ha (D_3)	0	0	2.17	0
Banana fruit bunch biochar (Tn)	0 t/ha (D_0)	0.32	0	0	0.32
	5 t/ha (D_1)	0.21	0	0.56	0
	10 t/ha (D_2)	0.49	0	0	0
	15 t/ha (D_3)	0.16	0.35	1.25	0.07
Mixed biochar (banana stem + banana peel + banana fruit bunch) (Cam)	0 t/ha (D_0)	0.32	0	0	0.32
	5 t/ha (D_1)	0.26	0	0	0
	10 t/ha (D_2)	0.14	0.14	0	0
	15 t/ha (D_3)	0.12	0.03	0	0

Specifically, the type and dose that was accurate in reducing Cu contents in seeds was mixed biochar with a dose of 10 t/ha, while in soil, it was banana fruit bunch biochar with doses of 5 t/ha and 10 t/ha. The threshold value for Cd heavy metal content in plants is 3-30 ppm, in soil is 0.50 ppm, and in seeds is 0.5 ppm. Based on Table 5, it can be seen that mixed biochar application at a dose of 15 t/ha effectively reduces Cd contents in seeds and soil. However, the reduction of contents in the soil has not been maximized.

Discussion

Laboratory test results for Pb, Cu, and Cd content in root samples of maize plants in Subak Kerdung showed the contents of Pb 16.69 ppm, Cu 24.54 ppm, and Cd 2.5 ppm. These contents can change at any time, depending on the weather and season. Based on the research conducted, maize plants treated with biochar, especially mixed biochar, have significantly lower contents of heavy metals Pb, Cu, and Cd in the soil and seeds compared to those without biochar. Figure 1 shows that maize plants treated with mixed biochar had 0 ppm Pb in the roots, while those without biochar had 0.32 ppm Pb. In maize seeds, both plants treated with mixed biochar and those that did not show the same value of 0 ppm Pb.

Figure 2 shows that Cu content in soil treated with mixed biochar was 32.16 ppm, while in soil that was not treated with biochar was 24.56 ppm. Cu contents in maize seeds treated with mixed biochar was 105.14 ppm, while that not treated with biochar was 135.45 ppm.

Table 4. Cu content in soil and maize due to the application of different biochar dosages.

Treatment		Cu content (ppm)			
		Roots	Shoots	Seeds	Soil*)
Banana stem biochar (Bt)	0 t/ha (D_0)	168.92 a	271.38 a	135.45 a	24.56
	5 t/ha (D_1)	122.72 b	62.64 d	132.30 b	7.33
	10 t/ha (D_2)	115.41 c	79.37 c	107.21 d	19.28
	15 t/ha (D_3)	61.88 d	248.61 b	121.239 c	14.73
LSD 5%		0.80	0.08	0.31	-
Banana peel biochar (Kl)	0 t/ha (D_0)	168.92 a	271.38 b	135.45 c	24.56
	5 t/ha (D_1)	107.59 b	334.86 a	146.28 b	9.48
	10 t/ha (D_2)	64.79 c	107.42 c	161.89 a	0
	15 t/ha (D_3)	39.4 d	23.43 d	116.49 d	0
LSD 5%		0.80	0.08	0.31	-
Banana fruit bunch biochar (Tn)	0 t/ha (D_0)	168.92 a	271.38 a	135.45 b	24.56
	5 t/ha (D_1)	14.71 d	19.12 c	181.73 a	0
	10 t/ha (D_2)	42.50 c	21.73 b	134.23 c	0
	15 t/ha (D_3)	86.66 b	19.56 c	129.47 d	2.27
LSD 5%		0.80	0.08	0.31	-
Mixed Biochar (banana stem + banana peel + banana fruit bunch) (Cam)	0 t/ha (D_0)	168.92 a	271.38 a	135.45 a	24.56
	5 t/ha (D_1)	37.77 d	16.05 d	90.63 d	26.77
	10 t/ha (D_2)	38.76 c	23.69 b	92.40 c	11.30
	15 t/ha (D_3)	130.77 b	19.76 c	132.38 b	58.41
LSD 5%		0.80	0.08	0.31	-

Notes: Numbers followed by the same letters in the same column indicate no significant difference at the 5% level of the LSD test. *) It was not tested statistically because most of the results could not be detected.

Table 5. Cd content in soil and maize due to the application of different biochar dosages.

Treatment		Cd content (ppm)			
		Roots*)	Shoots	Seeds	Soil
Banana stem biochar (Bt)	0 t/ha (D_0)	4.04	1.71 c	1.84 c	0.55 d
	5 t/ha (D_1)	0.24	2.57 b	4.52 a	1.16 c
	10 t/ha (D_2)	0	3.67 a	3.67 b	1.35 b
	15 t/ha (D_3)	0	1.47 d	4.53 a	2.27 a
LSD 5%		-	0.02	0.08	0.03
Banana peel biochar (Kl)	0 t/ha (D_0)	4.04	1.71 b	1.84 c	0.55 c
	5 t/ha (D_1)	0	1.10 c	4.41 a	0.73 b
	10 t/ha (D_2)	0	3.42 a	1.59 d	0.73 b
	15 t/ha (D_3)	0	1.10 c	3.43 b	1.90 a
LSD 5%		-	0.02	0.08	0.03
Banana fruit bunch biochar (Tn)	0 t/ha (D_0)	4.04	1.71 d	1.84 d	0.55 d
	5 t/ha (D_1)	0.98	3.30 c	8.43 a	0.61 c
	10 t/ha (D_2)	2.57	4.53 a	6.73 b	0.92 a
	15 t/ha (D_3)	0.98	4.28 b	4.40 c	0.86 b
LSD 5%		-	0.02	0.08	0.03
Mixed biochar (banana stem+banana peel+banana fruit bunch) (Cam)	0 t/ha (D_0)	4.04	1.71 d	1.84 d	0.55 d
	5 t/ha (D_1)	3.30	2.08 a	32.19 a	2.32 a
	10 t/ha (D_2)	0	1.59 c	6.11 b	2.08 b
	15 t/ha (D_3)	0	1.35 d	0.98 d	0.74 c
LSD 5%		-	0.02	0.08	0.03

Notes: Numbers followed by the same letters in the same column indicate no significant difference at the 5% level of the LSD test. *) It was not tested statistically because most of the results could not be detected.

Figure 3 shows that Cd contents in soil treated with mixed biochar was 1.71 ppm, while that not treated with biochar was 0.6 ppm. In the seeds, the Cd content of maize treated with biochar was 13.1 ppm. Meanwhile, that of maize seeds not treated with biochar was 1.84 ppm. Based on the dose variation, the most effective biochar to reduce Pb and Cd is the mixed biochar dose of 15 t/ha. Cu contents in maize seeds can be minimized by mixed biochar application with a dose of 10 t/ha and 5 t/ha. Meanwhile, in the soil, a dose of 10 t/ha of mixed biochar is needed.

The application of banana waste biochar to soil from Subak Kerdung, which is indicated to have heavy metal contamination, showed varying values for each treatment. The addition of banana waste biochar to the soil has the main purpose of absorbing or reducing heavy metal content in the soil. This is because the agricultural soil from Subak Kerdung already has a fairly good fertility value; even at some locations, the soil fertility status is classified as high (Sumarniasih et al., 2021). Good soil fertility and stable production results make farmers not interested in the heavy metal content contained in their agricultural products. As a planting medium, if the soil is contaminated with excess heavy metals, it has the potential to be absorbed by plant roots and organs. To reduce the possibility of heavy metals being absorbed into plant roots and organs, efforts need to be made to absorb excess heavy metal content in the soil. In this research, the application of biochar is focused on reducing heavy metal content in Subak Kerdung soil so that it is expected that agricultural products can be healthier and have less heavy metal content.

Based on the type, mixed biochar contains all three other materials (stems, bunches, and peels) so that it can be more optimal in terms of waste utilization and absorption of heavy metals in soil and plants. The ash content produced by mixed biochar shows the smallest value, so this type has more ability in thermal stability compared to other types of banana waste when tested. It is supported by research conducted by Burachevskaya et al. (2023), who stated that biochar, which has a smaller ash content value, indicates that the raw material is rich in cellulose and easily forms a more stable biochar with high aromatic characteristics (Lin et al., 2022). The high level of lignin in biochar feedstock requires a higher decomposition temperature than cellulose and hemicellulose. Hemicellulose decomposes at 220-315 °C, and cellulose decomposes at 315-400 °C. Meanwhile, lignin decomposition occurs at 400 °C. Therefore, the average activation energy required for breakdown may be greater (Pasangulapati, 2012; Burachevskaya et al., 2023).

Other types of biochar that have been tested to reduce Pb, Cu, and Cd contents in the soil are biochar derived from bagasse, bamboo, rice straw, garden waste, and paulownia. From these five wastes, biochar with sugarcane raw materials significantly increased the concentration of Cu and Pb residual fractions and decreased the concentration of available Cd (Bousdra et al., 2023). However, when compared to banana waste biochar, banana waste biochar is certainly not able to be as optimal as biochar with sugarcane raw materials. This is because the ash and carbon content produced by sugarcane biochar is different from the value of banana waste biochar. Meanwhile, in a similar research, Liu et al. (2022) wrote that banana steam and leaf biochar can effectively reduce Pb and Cd contents in water. However, when tested on soil, banana waste biochar, such as stem, bunch, peel, and mixed biochar, were also able to bind and reduce Pb and Cd contents in the soil. Sial et al. (2019) added that banana waste biochar (in this research in the form of banana peels) can significantly increase soil enzyme activity (urease, invertase, and alkaline phosphatase) compared to untreated banana waste. In addition to soil type, heavy metals, biomass, application rate, and pyrolysis temperature, different biochars also have different physicochemical properties and thus exhibit different properties. It depends on the effect of the chemical fraction of heavy metals (Fu et al., 2023; Vuong et al., 2023). For example, biochar produced at 300 °C has a higher soluble phosphate concentration than biochar pyrolyzed at 400 °C. As a result, this biochar is more effective in adsorbing lead in the exchangeable fraction than biochar pyrolyzed at 400 °C.

The number of pores and porosity value of each banana waste biochar affects the absorption of heavy metals by biochar. With a large number of pores and a wide average pore size, it has the potential to bind more heavy metals in the soil so that rhizofiltration can be minimized. The test results of the physical characteristics of the four types of banana waste biochar show that the characteristics of mixed biochar have the largest surface area, namely 104.14 µm. At 1000x magnification for total pore area, average pore size and particle porosity values show that the test value of mixed biochar has the highest value, namely 719281 µm, 137.06 µm, and 58.93%. These values are higher when compared to the three other types of banana waste biochar. The pore size and porosity value of biochar is a variable that needs to be considered because it has a real influence on the size of the biochar absorption capacity (Taer et al., 2015) and the ability to store nutrients in helping the soil maximize its retention properties (Agviolita et al., 2021). The larger the pore size of the biochar particles produced, the better the absorption of particles that can be done by biochar.

Besides the type and dose of biochar, there are several other factors that also affect the effectiveness of biochar application, such as the time application and additional fertilizers or other substances. In the banana waste biochar application as a soil amendment for maize plants, the soil test time interval after its application is three months. This period is quite short and included in the medium-term reaction category. It is due to the interaction between biochar and plant roots that began to be established (Joseph et al., 2021). Meanwhile, the previous research conducted by Chen et al. (2022) showed that it takes almost two years to maximize biochar in reducing Cu and Cd contents. In rice, after four years of biochar application, its effectiveness can only be felt because it can help the work of four bacteria in adding nutrients and immobilizing heavy metals. The related bacteria are Proteobacteria (including the Rhodocyclaceae, Burkholderiaceae, and Nitrosomonadaceae families), Chloroflexi (including the Anaerolineaceae family), Bacteroidetes (including the Ignavibacteriales and Bacteroidales orders), and Nitrospirae (Wang et al., 2019; Deng et al., 2022). Thus, the effectiveness of banana waste biochar in reducing Pb, Cu, and Cd in soil and plants needs to be assessed regularly. Meanwhile, Qiu et al. (2011) wrote that the reduction of Cd contents in plants will be maximized if phosphorus is added periodically. The bonding of phosphate and cadmium ions can effectively clean the soil from the dangers of heavy metal Cd. Salam et al. (2022) also added that by applying biochar, not only will heavy metal content in the soil be reduced, but plant growth on heavy metal-polluted land can gradually increase.

Conclusion

Based on the research that has been conducted, the type of banana waste biochar that is effective in absorbing heavy metals Pb and Cu is the mixed biochar (banana stem + banana peel + banana fruit bunch) because it can reduce heavy metal content in maize seeds to the maximum. Meanwhile, banana waste biochar that effectively reduces Cd contents is banana peel biochar. Based on the dose of each type of banana waste biochar, mixed biochar (banana stem + banana peel + banana fruit bunch) at a dose of 15 t/ha can be recommended to reduce Pb and Cd contents. Meanwhile, a 10 t/ha dose of mixed biochar (banana stem + banana peel + banana fruit bunch) can be used to reduce Cu content in plants.

Acknowledgments

The authors thank the Soil Science Laboratory of the Faculty of Agriculture, the Materials Analysis Laboratory of the Faculty of Engineering, and the Analytical Laboratory of Udayana University for their help in this research. The authors also thank the MERO Foundation for supporting this research. The authors also thank the greenhouse staff who have facilitated the place for conducting this research.

References

Adejumo, S.A., Ogundiran, M.B. and Togun, A.O. 2018. Soil amendment with compost and crop growth stages influenced heavy metal uptake and distribution in maize crops grown on lead-acid battery waste-contaminated soil. *Journal of Environmental Chemical Engineering* 6(4):4809-4819, doi:10.1016/j.jece. 0727.

Agviolita, P., Yushardi, Y. and Anggraeni, F.K.A. 2021. The effect of differences in biochar on the ability to maintain retention in soil. *Jurnal Fisika Unand* 10(2):267-273, doi:10.25077/jfu.10.2.267-273.2021 (*in Indonesian*).

Ahadiyat, Y.R., Fauzi, A., Herliana, O. and Hadi, S.N. 2023. Mapping heavy metals accumulation in conventional rice farming system at Banyumas Regency of Central Java, Indonesia. *Journal of Degraded and Mining Lands Management* 10(4):4583-4592, doi:10.15243/jdmlm.2023.104.4583.

Ahmad, T. and Danish, M. 2018. Prospects of banana waste utilization in wastewater treatment: A review. *Journal of Environmental Management* 206:330-348, doi:10.1016/j.jenvman.2017.10.061.

Ali, J., Khan, S., Khan, A., Waqas, M. and Nasir, M.J. 2020. Contamination of soil with potentially toxic metals and their bioaccumulation in wheat and associated health risks. *Environmental Monitoring and Assessment* 192(2):138, doi:10.1007/s10661-020-8096-6.

Bandara, T., Franks, A., Xu, J., Bolan, N., Wang, H. and Tang, C. 2020. Chemical and biological immobilization mechanisms of potentially toxic elements in biochar-amended soils. *Critical Review in Environmental Science and Technology* 50:903-978, doi:10.1080/10643389.2019.1642832.

Bousdra, T., Papadimou, S.G. and Golia, E.E. 2023. The use of biochar in the remediation of Pb, Cd, and Cu-contaminated soils. The impact of biochar feedstock and preparation conditions on its remediation capacity. *Land* 12(2):383, doi:10.3390/land12020383.

Burachevskaya, M., Minkina, T., Bauer, T., Lobzenko, I., Fedorenko, A., Mazarji, M., Sushkova, S., Mandzhieva, S., Nazarenko, A., Butova, V., Wong, M.H. and Rajput, V.D. 2023. Fabrication of biochar derived from different types of feedstocks as an efficient adsorbent for soil heavy metal removal. *Scientific Reports* 13(1), doi:10.1038/s41598-023-27638-9.

Chen, L., Guo, L., Liao, P., Xiong, Q., Deng, X., Pan, X., Zeng, Y. and Zhang, H. 2022. Effects of biochar on the dynamic immobilization of Cd and Cu and rice accumulation in soils with different acidity contents. *Journal of Cleaner Production* 372:133730, doi:10.1016/j.jclepro.2022.133730.

Clough, T.J., Condron, L.M., Kammann, C. and Müller, C. 2013. A review of biochar and soil nitrogen dynamics. *Agronomy* 3(2):275-293, doi:10.3390/agronomy3020275.

Deng, X., Long, C., Chen, L., Du, Y., Zhang, Z., Gan, L. and Zeng, Y. 2022. Special microbial communities enhanced the role of aged biochar in reducing Cd accumulation in rice. *Agronomy* 13(1):81, doi:10.3390/agronomy13010081.

Fu, T., Zhang, B., Gao, X., Cui, S., Guan, C.-Y., Zhang, Y., Zhang, B. and Peng, Y. 2023. Recent progresses, challenges, and opportunities of carbon-based materials applied in heavy metal polluted soil remediation. *Sciences of the Total Environment* 856:158810, doi:10.1016/j.scitotenv.2022.158810.

Glaser, B., Lehmann, J. and Zech, W. 2002. Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal - A review. *Biology and Fertility of Soils* 35(4):219-230, doi:10.1007/s00374-002-0466-4.

Joseph, S., Cowie, A.L., Van Zwieten, L., Bolan, N., Budai, A., Buss, W., Cayuela, M.L., Graber, E.R., Ippolito, J.A., Kuzyakov, Y., Luo, Y., Ok, Y.S., Palansooriya, K.N., Shepherd, J., Stephens, S., Weng, Z.H. and Lehmann, J. 2021. How biochar works, and when it doesn't: A review of mechanisms controlling soil and plant responses to biochar. *GCB Bioenergy* 13(11):1731-1764, doi:10.1111/gcbb.12885.

Lehmann, J. and Joseph, S. 2009. Biochar for environmental management: An introduction. In: Lehmann, J. and Joseph, S. (eds.), *Biochar for Environmental Management, Science and Technology*, Earthscan: London, UK; pp. 1-12.

Lehmann, J., Gaunt, J. and Rondon, M. 2006. Biochar sequestration in terrestrial ecosystems - A review. *Mitigation and Adaptation Strategies for Global Change* 11(2):403-427, doi:10.1007/s11027-005-9006-5.

Lin, Q., Tan, X., Almatrafi, E., Yang, Y., Wang, W., Luo, H., Qin, F., Zhou, C., Zeng, G. and Zhang, C. 2022. Effects of biochar-based materials on the bioavailability of soil organic pollutants and their biological impacts. *Science of The Total Environment* 826:153956, doi:10.1016/j.scitotenv.2022.153956.

Liu, X., Li, G., Chen, C., Zhang, X., Zhou, K. and Long, X. 2022. Banana stem and leaf biochar as an effective adsorbent for cadmium and lead in aqueous solution. *Scientific Reports* 12(1):1584, doi:10.1038/s41598-022-05652-7.

Mahendra, R., Siaka, I.M. and Suprihatin, I.E. 2018. Bioavailability of heavy metals Pb and Cd in land for cultivating cabbage in Kintamani Area Bangli. *Ecotrophic: Jurnal Ilmu Lingkungan* 12(1):42-49, doi:10.24843/EJES.2018.v12.i01.p06 (*in Indonesian*).

Munir, M.A.M., Liu, G., Yousaf, B., Ali, M.U., Abbas, Q. and Ullah, H. 2020. Synergistic effects of biochar and processed fly ash on bioavailability, transformation and accumulation of heavy metals by maize (*Zea mays* L.) in coal-mining contaminated soil. *Chemosphere* 240:124845, doi:10.1016/j.chemosphere.2019.124845.

Murjaya, I.M., Sujana, P. and Suryana, M. 2019. The effect of giving biochar to kangkung plants in land contaminated with liquid waste (in Subak Cuculandesa Kepaon). *Agrimeta* 9(17):27-31 (*in Indonesian*).

Pasangulapati, V. 2012. Effects of cellulose, hemicellulose and lignin on thermochemical conversion characteristics of the selected biomass. *Bioresource Technology* 114:663-669, doi:10.1016/j.biortech.2012.03.036.

Qiu, Q., Wang, Y., Yang, Z. and Yuan, J. 2011. Effects of phosphorus supplied in soil on subcellular distribution and chemical forms of cadmium in two Chinese flowering cabbage (*Brassica parachinensis* L.) cultivars differing in cadmium accumulation. Food and Chemical Toxicology 49(9):2260-2267, doi:10.1016/j.fct.2011.06.024.

Rizvi, A. and Khan, M.S. 2018. Heavy metal-induced oxidative damage and root morphology alterations of maize (*Zea mays* L.) plants and stress mitigation by metal tolerant nitrogen fixing *Azotobacter chroococcum*. *Ecotoxicology and Environmental Safety* 157:9-20, doi:10.1016/j.ecoenv.2018.03.063.

Romdhane, L., Panozzo, A., Radhouane, L., Dal Cortivo, C., Barion, G. and Vamerali, T. 2021. Root characteristics and metal uptake of maize (*Zea mays* L.) under extreme soil contamination. *Agronomy* 11(1):178, doi:10.3390/agronomy11010178.

Ruiz-Huerta, E.A., Armienta-Hernández, M.A., Dubrovsky, J.G. and Gómez-Bernal, J.M. 2022. Bioaccumulation of heavy metals and As in maize (Zea mays L) grown close to mine tailings strongly impacts plant development. *Ecotoxicology* 31(3):447-467, doi:10.1007/s10646-022-02522-w.

Sabir, S. 2015. Approach of cost-effective adsorbents for oil removal from oily water. *Critical Reviews in Environmental Science and Technology* 45(17):1916-1945, doi:10.1080/10643389.2014.1001143.

Salam, A.K., Rizki, D.O., Santa, I.T.D., Supriatin, S., Septiana, L.M., Sarno, S. and Niswati, A. 2022. The biochar-improved growth-characteristics of corn (*Zea mays* L.) in a 22-years old heavy-metal contaminated tropical soil. *IOP Conference Series: Earth and Environmental Science* 1034(1):012045, doi:10.1088/1755-1315/1034/1/012045.

Sial, T., Khan, M., Lan, Z., Kumbhar, F., Ying, Z., Zhang, J., Sun, D. and Xiu Li, X. 2019. Contrasting effects of banana peels waste and its biochar on greenhouse gas emissions and soil biochemical properties. *Process Safety and Environmetal Protection* 122:366-377, doi:10.1016/j.psep.2018.10.030.

Sumarniasih, M.S., Simanjuntak, D.D. and Arthagama, I.D.M. 2015. Evaluation of paddy soil fertility status at the Subak Kerdung and Subak Kepaon, South Denpasar District. *Agrovigor: Jurnal Agroekoteknologi* 14(2):123-130, doi:10.21107/agrovigor.v14i2.10899 (*in Indonesian*).

Taer, E., Aiman, S., Sugianto, S. and Taslim, R. 2015. Variations in coconut shell carbon size as a humidity control tool. *Proceedings of the National Physics Seminar (E-Journal) SNF 2015* IV:89-92 (*in Indonesian*).

Vuong, T.X., Pham, T.T.H., Nguyen, T.T.T. and Pham, D.T.N. 2023. Effects of biochar and apatite on chemical forms of lead and zinc in multi-metal-contaminated soil after incubation: a comparison of peanut shell and corn cob biochar. *Sustainability* 15(15):11992, doi:10.3390/su151511992.

Wang, R., Wei, S., Jia, P., Liu, T., Hou, D., Xie, R., Lin, Z., Ge, J., Qiao, Y., Chang, X., Lu, L. and Tian, S. 2019. Biochar significantly alters rhizobacterial communities and reduces Cd concentration in rice grains grown on Cd-contaminated soils. *Science of the Total Environment* 676:627-638, doi:10.1016/j.scitotenv.2019.04.133.

Zhang, R., Chen, T., Zhang, Y., Hou, Y.H. and Chang, Q.R. 2020. Health risk assessment of heavy metals in agricultural soils and identification of main influencing factors in a typical industrial park in northwest China. *Chemosphere* 252:126591, doi:10.1016/j.chemosphere.2020.126591.

Zou, J., Song, F., Lu, Y., Zhuge, Y., Niu, Y., Lou, Y., Pan, H., Zhang, P. and Pang, L. 2021. Phytoremediation potential of wheat intercropped with different densities of *Sedum plumbizincicola* in soil contaminated with cadmium and zinc. *Chemosphere* 276:130223, doi:10.1016/j.chemosphere.2021.130223.