

Residual effect of biochar from bamboo (*Gigantochloa*) on the growth of *Tithonia diversifolia* as a phytoaccumulator of mercury on ex-gold mining soil

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Abstract. Illegal gold mining harms the environment, notably soil pollution by mercury (Hg), which can be reduced by reclamation with amelioration technology and phytoaccumulator plants. This study examined the residual effect of bamboo biochar (RE-BB) on the growth of *Tithonia diversifolia* in ex-gold mining soil (ex-GMS) contaminated with Hg, that have been fed for one year and six months and planted with corn plants in the previous growing season. This study used a completely randomized design (CRD) with three replicates and five doses (0-40 tons ha⁻¹) of RE-BB. The 40 tons ha⁻¹ RE-BB was significant and still capable of improving the chemical properties of ex-GMS by increasing the pH to 6.37, CEC to 11.07 cmol(+) kg⁻¹, organic C to 1.27%, total N to 0.19%, available P to 24.24 ppm, and Mg-exch to 0.32 cmol(+) kg⁻¹, and reducing the soil of Hg to 2.16 mg kg⁻¹. Additionally, it can increase plant height to 83.67 cm, P to 0.006%, K to 0.13%, and reduce the plant of Hg to 0.04 mg kg⁻¹. Bamboo biochar till the second planting season has been proven to reduce Hg pollution by enhancing the chemical characteristics of ex-GMS. *Tithonia diversifolia* shows potential as a renewable phytoaccumulator of Hg.

1 Introductions

Indonesia is a country rich in mineral resources, such as gold (Au). Indonesia's gold reserves are abundant, according to the World Gold Council (WGC). The average from 2000 to 2025 is 81.78 tons, with the lowest value of 73.09 tons in the fourth quarter of 2006 and the highest value of 96.45 tons in the second quarter of 2000. Indonesia contributed 4% of global gold production in 2025 and ranked eighth among gold-producing countries, up two places from the previous year [1]. Gold deposits in Indonesia are distributed across nearly the entire country, with one significant concentration in West Sumatra Province, particularly in Dharmasraya. However, this abundant gold potential has not been managed effectively, and there remains unregulated gold mining activity that does not comply with legal regulations, such as illegal gold mining (PETI). This situation can have adverse effects on various aspects, particularly the environmental ecosystem, such as soil fertility.

Ex-gold mining soil (ex-GMS) has low soil productivity [2]. In addition to poor soil characteristics, sites are also contaminated with heavy metals such as mercury (Hg). The ex-GMS often has high Hg, as Hg is used as a gold ore refining agent. The ex-GMS in Dharmasraya contains Hg contaminants at levels of 4.42

mg kg⁻¹, classified as very high due to PETI activities [3]. Therefore, ex-GMS requires remediation to enable its reuse, particularly for agricultural productivity. One method of remediation involves adding soil amelioration, such as biochar.

Pyrolysis of organic materials produces biochar. Utilized as a soil ameliorant is biochar. The type of raw material, carbonization process, and application form will affect its chemical and physical characteristics, which in turn determine its effectiveness [4]. The benefit of applying biochar is that its stable form in the soil allows it to last for a long period and serve as a carbon reservoir for the application's aftereffects. The use of biochar can improve the physico-biochemical characteristics of contaminated soil and significantly reduce the absorption of heavy metals by plants.

The first planting period used bamboo biochar (BB) from the *Gigantochloa* genus, which is a fast-growing timber-producing plant [5]. Biochar derived from bamboo can absorb various heavy metals that are toxic to soil and the environment, such as Hg in contaminated soil. The application of 40 tons ha⁻¹ of BB was also proven to reduce Hg by 1.52 mg kg⁻¹ and demonstrated that BB can reduce Hg in soil by 0.39 mg kg⁻¹. This proves that BB can reduce heavy metal levels in soil. The BB has the advantage of a stable form that does not easily decompose

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in soil, allowing it to persist for a long time. This advantage is the primary basis which aims to testing the residual effects of bamboo biochar use on the first planting period. The relatively stable presence of biochar in the soil over an extended period is expected to serve as a long-term soil conditioner, particularly for Hg.

The combination of ameliorants and phytoremediation can improve Hg control in ex-GMS. Phytoremediation is a method for reducing pollutant concentrations by using plants capable of absorbing metals, extracting them, and accumulating them in plant biomass [6]. Plants capable of accumulating heavy metals are called phytoaccumulators. A plant can be categorized as a phytoaccumulator if it has a high capacity to absorb heavy metal pollutants, grows rapidly, and is not a food crop, as its products cannot be consumed. However, it can be used effectively in rehabilitating ex-GMS for area tourism.

Tithonia diversifolia is an indicator plant that is expected to be a good phytoaccumulator. *Tithonia* or kembang bulan is a wild plant species (weed) that grows naturally and is a source of organic matter due to its very high biomass production of around 5.6-8.1 t/ha/year [7]. In general, *Tithonia* is a wild plant that can grow anywhere and is often used as green manure in agriculture. *Tithonia* has bioaccumulator capabilities because it can grow on soil contaminated with Pb. The study of concentrations 4 weeks after planting (WAP) showed Pb concentrations of 87.3 mg kg⁻¹ in leaves and 99.4 mg kg⁻¹ in roots [8]. The phytoaccumulator ability of *Tithonia*, which can absorb heavy metals such as Pb, there is a possibility that this plant can also be a phytoaccumulator for other heavy metals, especially Hg. This research is interesting to examine the effect of bamboo biochar residue on the growth of *Tithonia* plants and to test them as Hg phytoaccumulators in ex-GMS.

2 Materials and methods

This research was conducted from February to October 2023, at Wire House and the Soil Chemistry and Fertility Laboratory of the Department of Soil Science and Land Resources, Faculty of Agriculture, Universitas Andalas, Padang.

2.1 Experiment design

This study used a completely randomized design (CRD) with three replicates. The treatment used was the residual effect of the first planting season with a fallow system for one year and six months, which was planted with corn in polybags with the same dose of bamboo biochar (BB) [5], namely: 0 (0g 15 kg soil⁻¹), 10 (75 g 15 kg soil⁻¹), 20 (150g 15 kg soil⁻¹), 30 (225g 15 kg soil⁻¹), and 40 ton ha⁻¹ (300g 15 kg soil⁻¹), respectively.

2.2 Cultivation process

The soil samples used were residual effects from the first growing season with a fallow period of one year and six months, planted with corn in polybags with BB doses (0, 10, 20, 30, and 40 tons ha⁻¹) [5]. However, adjustments

were made to the absolute dry weight of 10 kg of soil per polybag.

The planting process of *Tithonia diversifolia* was carried out with a planting distance of 50 cm x 50 cm, with each polybag containing one *Tithonia diversifolia* seedling that had undergone vegetative propagation (stem cuttings). The cuttings were taken over two weeks to achieve the best results. Two weeks after the cuttings were taken, the plants were selected, and the best ones were then transferred into each polybag. Maintenance activities included watering and weeding. Watering was done once a day in the afternoon, depending on the weather conditions that day. Weeding was done when weeds grew and were kept from damaging or interfering with plant growth. Harvesting was done when the plants were 2 months old, in line with the plant's vegetative stage, and the entire plant was harvested. The harvested plant samples were then dried for 2 x 24 hours in a plant oven at 70°C. They were then finely ground using a 500µm sieve for analysis in the laboratory.

2.3 Data analysis

The pH, CEC, nutrient content (organic C, total N, available P, exchangeable K, Ca, and Mg, and mercury (Hg) were analyzed in the soil. Meanwhile, plant height, plant nutrient content (N, P, and K), and mercury were analyzed for *Tithonia diversifolia* [9]. The SPSS 23 and Excel 2023 software were used for all analyses. Analysis of variance (ANOVA) and Duncan's Multiple Range Test (DMRT) were used as statistical techniques to find differences between treatment means. Results were considered significant and marked with [*] if the calculated F value > the table F value at the 5% level; if the calculated F value > the table F value at the 1% level, the results were considered highly significant and marked with [***]. The symbols [*] and [***] indicate how significant the differences were.

3 Results and discussion

The residual effect of bamboo biochar (RE-BB) significantly increased soil pH compared to the control. A significant increase occurred at a dose of 20 tons ha⁻¹, amounting to 1.43 compared to the control (Fig. 1). The highest increase occurred at a dose of 40 tons ha⁻¹, amounting to 1.63. This increase in pH occurred due to the contribution of OH⁻ from biochar, which can reduce soil acidity. Biochar contains alkaline substances and has a very high pH, which can be used as an alternative ameliorant. Biochar has a high pH, such as bamboo biochar (BB) with a pH of 10.68, which increases soil pH due to the application of this biochar. However, when compared to the soil pH during the first planting period, the soil pH affected by the RE-BB during the second planting period decreased. This is suspected to be due to the presence of additional organic material that decomposes and produces organic acid compounds, which are the acidic compounds that cause the soil pH to decrease. The length of the planting rest period is 17 months. Ex-gold mining soil (ex-GMS) has a very acidic

soil pH with a large positive charge (H^+), which is thought to be the cause of the decrease in pH during the second planting season.

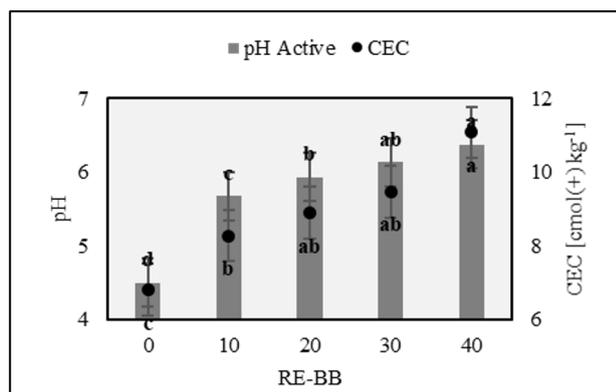


Fig. 1. The residual effect of bamboo biochar on the pH H_2O , and CEC of ex-gold mining soil contaminated with Hg.

The RE-BB on ex-GMS significantly increased the CEC. Increasing the dose gradually from 10 to 40 tons ha^{-1} increased the CEC to 8.27, 8.89, 9.47, and reached 11.07 $cmol(+) kg^{-1}$ at the highest dose (Fig. 1). The increase in the CEC in the soil treated with RE-BB was consistent with the increase in the biochar dosage applied during the first planting season. The higher the bamboo biochar dosage applied during the first planting season, the higher the CEC. The CEC also plays a vital function in guaranteeing the availability of base cations needed by plants. Not only did the CEC rise compared to the control, but the soil CEC with RE-BB also rose compared to the CEC in the first planting season, indicating a substantial difference in impact. The increase in CEC in the second planting season is thought to be due to the contribution of organic carbon from biochar, which increases the negative charge. Biochar contributes negative ions, namely carboxyl ($-COOH$) and phenolic ($-OH$) groups, thus increasing the negative charge [10]. The addition of ameliorants containing high carbon (C) will increase the CEC. Furthermore, as an indicator of soil fertility, the CEC value is directly proportional to pH and organic C (Fig. 2). Biochar, as an organic material, acts as humus, acting as a soil colloid. The more organic matter available, the higher the soil CEC.

The RE-BB on ex-GMS significantly affected organic C and total N (Fig. 2). The increase in soil C can also be seen in the RE-BB, which is still able to increase the organic C in ex-GMS. At a dose of 0 tons ha^{-1} , the organic C was only 0.27% C, reflecting the low organic matter from post-mining land degradation. Applying 10 tons ha^{-1} RE-BB nearly doubled the organic C to 0.58% C, then increased to 0.86% at a dose of 20 tons ha^{-1} , 1.11% C at a dose of 30 tons ha^{-1} , and reached a peak of 1.27% C at a dose of 40 tons ha^{-1} . This is due to the input of organic matter from the remaining bamboo charcoal. Biochar can boost soil fertility, particularly by increasing soil organic carbon. The organic C of bamboo biochar utilizing the Kon-Tiki combustion process achieved 15.70%, so that biochar can contribute organic C to the soil [11]. Biochar production using an imperfect combustion process. Biochar, a combustion product that is difficult to

decompose, allows it to contribute organic carbon over a long period of time. Biochar can produce 50% of the carbon, and after 5-10 years, there is still undecomposed carbon. This shows that biochar may supply carbon and remain in the soil for a long period.

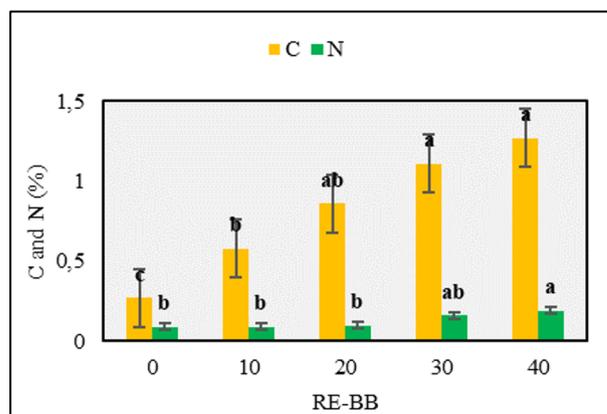


Fig. 2. The residual effect of bamboo biochar on the organic C and total N of ex-gold mining soil contaminated with Hg.

Organic C increased more dramatically in the second growing season compared to the first growing season. Carbon in biochar remains active in the soil. Biochar, with its difficult-to-decompose carbon structure, indicates that its residual effects can still improve soil chemical quality over a long period. The long incubation period during the second growing season contributes to an increase in organic carbon due to the addition of organic matter from living plant biomass or biomass remaining during the dormancy period. In the first planting season, corn plants left behind plant biomass, such as corn roots and weeds that grew and then decayed. These plant parts then became sources of additional carbon-producing organic matter in the soil. The control soil did not receive any carbon contribution from biochar, and no plant growth occurred in the first planting season, resulting in no increase in carbon content from any aspect of the control soil.

The RE-BB can absorb N and reduce N leaching due to its high-water holding capacity, thus reducing N leaching in the soil. The application of biochar can accelerate the process of mineralization and immobilization of N by decomposing microbes present in organic material, thereby increasing total N. At doses of 0 and 10 tons ha^{-1} , the total N remained low at 0.09% N, indicating that without or with a small amount of bamboo biochar, the soil did not receive a significant nitrogen boost. Increasing the dose to 20 tons ha^{-1} only slightly increased the total N to 0.10% N, but a more significant increase occurred at the 30 tons ha^{-1} dose, with a value of 0.16% N, and the highest at the 40 tons ha^{-1} dose, at 0.19% N (Fig. 2). The increase in total soil N with the addition of biochar is due to biochar's ability to increase N fixation in the soil. Furthermore, the presence of microorganisms and biomass that grow, such as wild plants during the planting rest period, also contributes to soil N availability. Compared to the first planting season, the total N in the second planting season experienced a significant increase. Biochar has a porous surface that can become a habitat for microorganisms. Biochar has the potential to maintain

bacterial growth (viability) for a long period of time (± 12 months), especially heterotrophic bacteria that function in mineralizing organic N into a form available for plant growth [12]. The longer the presence of biochar in the soil, the greater the potential for an increase in the number of microorganism habitats in mineralizing N. The addition of NPK fertilizer in the first planting season is also an additional factor in increasing soil N in the second planting season.

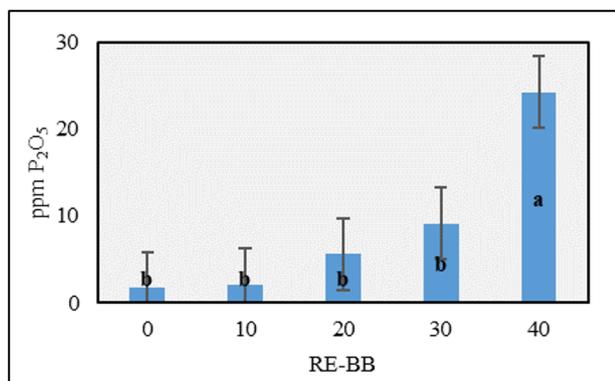


Fig. 3. The residual effect of bamboo biochar on the available P of ex-gold mining soil contaminated with Hg.

Increasing soil pH and organic C (Fig. 1 and Fig. 2) with biochar also increases soil P availability (Fig. 3). At the 0 tons ha⁻¹ dose, available P was only 1.67 ppm, reflecting the P-poor conditions of degraded land. A 10 tons ha⁻¹ application of RE-BB slightly increased available P to 2.11 ppm, but sharper increases occurred at the 20 tons ha⁻¹ (5.62 ppm) and 30 tons ha⁻¹ (9.14 ppm) doses. The highest increase occurred at the 40 tons ha⁻¹ dose, reaching 24.24 ppm, more than 14 times the control (Fig. 3). The increase in P availability in the soil is likely due to the application of P fertilizer during the first growing season. This addition of P fertilizer was intended to support plant growth during the first growing season for corn. Furthermore, the residual effects of biochar are still active. The applied biochar can release metal ions from P because the biochar's functional groups absorb metal ions, preventing them from hydrolyzing. This indicates that there are no elements binding P to make it available to the soil. The amount of biochar applied increased significantly during the second growing season, which was in line with the increase in the applied dose. This is thought to be because the longer biochar remains in the soil, the more phosphorus it contains in ex-GMS. The RE-BB increased the P from 31.08 ppm to 38.18 ppm. The addition of NPK fertilizer also supported corn growth, which is an indicator of the increase in available P in the ex-GMS during the second planting season.

The RE-BB on ex-GMS still affects base cations (K, Ca, and Mg). In exchangeable K, the value was very low in the control [0.003 cmol(+) kg⁻¹] and increased gradually to 0.006 cmol(+) kg⁻¹ at the highest dose (40 tons ha⁻¹), indicating a positive trend, although the increase was relatively small. Exchangeable Ca experienced a more pronounced increase, from 0.35 cmol(+) kg⁻¹ in the control to 0.47 cmol(+) kg⁻¹ at a dose of 40 tons ha⁻¹, indicating a contribution of Ca from bamboo biochar or an increase in Ca retention in the soil.

Exchangeable Mg showed an increase from 0.30 cmol(+) kg⁻¹ in the control to 0.32 cmol(+) kg⁻¹ at all bamboo biochar doses, indicating that biochar was able to maintain Mg availability, although the increase was relatively small (Table 1). Exchangeable base cations in the soil tend to increase, presumably because the oxide composition (K, Ca, and Mg) contained in the biochar is released and can be exchanged in the soil, thereby helping nutrient availability. This increase is relatively unstable, possibly due to the soil pH, which also decreased in the second planting season.

Table 1. The residual effect of bamboo biochar on K, Ca and Mg-exchange of ex-gold mining soil contaminated with Hg.

RE-BB (Ton ha ⁻¹)	Cation Base		
	K-exch	Ca-exch	Mg-exch
cmol(+) kg ⁻¹			
0	0.003	0.35	0.30 b
10	0.004	0.36	0.32 a
20	0.005	0.43	0.32 a
30	0.005	0.41	0.32 a
40	0.006	0.47	0.32 a
<i>CV - Duncan's Test</i>			
	27.05 ^{ns}	12.41 ^{ns}	3.32*

Notes: Numbers in the same column followed by the same lowercase letter are not statistically different (ns) according to Duncan's test at the 5% (*) and 1% (**) levels; CV = Coefficient of variation; and n = 15 samples.

Height growth of *Tithonia diversifolia* plants after 8 weeks of planting. The RE-BB significantly affected the growth of *Tithonia diversifolia*. *Tithonia* plant height in the control soil reached 64.90 cm and increased according to the treatment dose. In the 10 tons ha⁻¹ dose, plant height increased to 70.33 cm, with the highest increase at the 40 tons ha⁻¹ dose, with plant height reaching 83.67 cm (Fig. 4). This indicates that BB can support the growth of *Tithonia* plants. Observations of plant height at 8 weeks after planting, when *Tithonia* plants had reached the vegetative phase, showed that the plants had reached the vegetative phase. *Tithonia* is a weed that can thrive in nutrient-poor soil, but with the help of active bamboo charcoal residue in the soil, it can increase soil nutrient content and plant development. Biochar can increase pH, CEC, organic carbon, total nitrogen, available phosphorus, and cation base (Figures 1, 2, 3, and Table 1) while also stimulating plant growth.

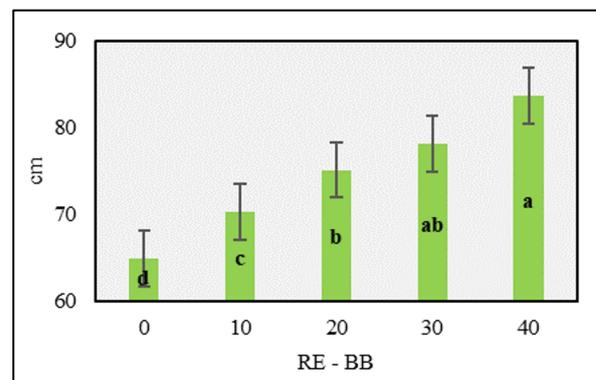


Fig. 4. The residual effect of bamboo biochar on *Tithonia diversifolia* height in ex-gold mining soil contaminated with Hg.

The RE-BB still shows an increase in the levels of N, P, and K in *Tithonia diversifolia* planted on ex-GMS. The RE-BB still provides improvements, where the higher the dose of biochar added during the first planting season, the higher the levels of N, P, and K in *Tithonia* plants. Basically, *Tithonia* is a plant that is often used as a compost fertilizer that helps the availability of nutrients for soil and plants, so that the tithonia plant itself already contains several nutrients needed by the soil and plants. The N element is one of the essential macronutrients that plays a vital role in plant growth. *Tithonia* itself has a high N, up to 3.43%. The increase in plant N is not significant, but tends to increase. At a dose of 0 tons ha⁻¹, the plant N reaches 2.24% and increases in line with the treatment dose, until at the highest dose of 40 tons ha⁻¹ the plant N reaches 4.20%, meaning an increase of up to 1.96% (Table 2).

Table 2. The residual effect of bamboo biochar on *Tithonia diversifolia* nutrient (NPK) level in ex-gold mining soil contaminated with Hg.

RE-BB (Ton ha ⁻¹)	<i>Tithonia diversifolia</i> nutrient level		
	N	P	K
	%		
0	2.24	0.003 c	0.11 b
10	2.61	0.004 b	0.11 b
20	2.99	0.004 b	0.11 b
30	3.27	0.005 ab	0.12 ab
40	4.20	0.006 a	0.13 a
<i>CV - Duncan's Test</i>	9.37 ^{ns}	14.86 ^{**}	5.86 [*]

Notes: Numbers in the same column followed by the same lowercase letter are not statistically different (ns) according to Duncan's test at the 5% (*) and 1% (**) levels; CV = Coefficient of variation; and n = 15 samples.

The N plant increased consistently from 2.24% in the control to 4.20% at the highest dose (40 tons ha⁻¹), indicating that bamboo biochar can increase soil N availability or N uptake efficiency by plants. The P in plants increased from 0.003% in the control group to 0.006% at the maximum dose, although this increase was relatively small, indicating the role of biochar in reducing P fixation in the soil and maintaining its availability. Meanwhile, K in plants also increased gradually from 0.11% in the control group to 0.13% at a dose of 40 tons ha⁻¹. This shows that biochar is not a major source of K, but its presence can increase K retention and minimize loss through leaching. The residual effect of biochar is able to maintain N nutrients from being leached or evaporated, and also, the measured N nutrient levels in plants are obtained from the total N of the soil. The oxide surface of biochar is also effective in absorbing NO₃⁻ so it can potentially reduce N nutrient losses. The high CEC is also able to adsorb ammonia, which affects the biochar functional groups that can increase N retention in the soil.

The P element in plants plays an important role in increasing crop yields, where P elements can trigger flowering and fruit ripening, as well as increase root growth. The amount of P available in the soil is directly proportional to the amount absorbed by plants. Plants can absorb more P in an accessible form, and the amount of P absorbed depends on the availability of P in the soil. The

increase in K uptake by plants varies greatly. Increased K availability in the soil affects K availability to plants. The increase in K exchange in the soil is directly proportional to the increase in K uptake by plants, and this is closely related to the increase in CEC caused by the RE-BB (Table 1). The higher the concentration of K in biochar, the more K elements can be supplied to the soil, thereby increasing its availability in the soil and for plants. In plants, K plays an important role in the production of proteins and carbohydrates, which also help strengthen plant stems. *Tithonia* also contains high K elements, has a total K up to 4.16%.

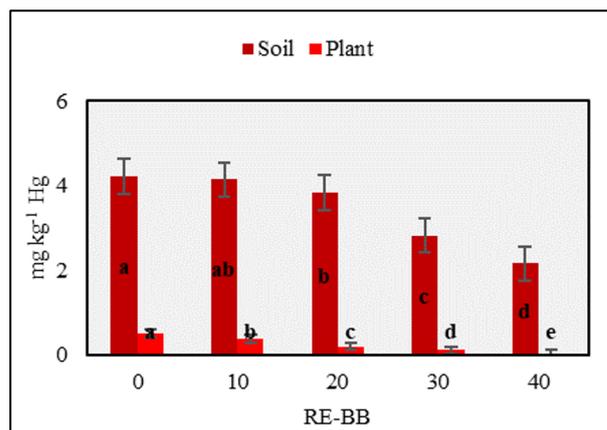


Fig. 5. Residual effects of bamboo biochar on Hg in *Tithonia diversifolia* and ex-gold mining soil.

The RE-BB significantly reduced Hg in ex-GMS. A significant reduction occurred at a dose of 20 tons ha⁻¹, amounting to 0.39 mg kg⁻¹, and at the highest dose of 40 tons ha⁻¹, the Hg decreased to 2.06 mg kg⁻¹ (Fig. 5). However, the Hg in the soil was still considered very high because it exceeded the established critical threshold. The normal limit for Hg in soil is 0.01–0.05 mg kg⁻¹ with a critical threshold of 0.3–0.5 mg kg⁻¹ [13]. This decrease in Hg was in line with the increase in the treatment dose used, which could be evidence that the residual effect of bamboo biochar still contributed to Hg absorption in the soil. This is because Hg elements were still bound by the biochar surface through Hg metal absorption. The decrease in Hg in the second season compared to the decrease in Hg during the first planting phase, apart from the control soil. The properties of Hg, especially in the context of sediments, include binding with proteins, volatility, and producing or releasing harmful mercury vapor even at room temperature. The Hg is easily dissolved and changes its stability from carbonate to hydroxide, which forms particle bonds in water, then settles to form mud. This is suspected to be one of the factors in the decrease in Hg in soil. During the planting period between the first planting period and the second planting period, Hg evaporation into nature and Hg leaching by rainwater are very likely. This decrease is not only due to external factors such as rainwater leaching, but also due to the influence of bamboo biochar in the soil.

The large surface area and rich negative charge of biochar produce electrostatic interactions between carbon anions in biochar and metal cations, resulting in a decrease in Hg in the soil. The decrease in Hg is also

caused by the availability of organic matter in the soil. Organic matter reacts with heavy metals to form complex molecules, which limit their solubility. Because organic matter helps bind and inactivate Hg in the soil, the higher the organic carbon content, the lower the availability of Hg. In addition to organic carbon, the reduction of Hg in the soil is also regulated by soil pH and CEC. High CEC can increase the absorption of heavy metals, and Hg bound to organic matter has a strong binding force with soil pH and organic C. However, despite this, the residual effect of bamboo biochar is still unable to reduce the Hg to below the threshold permitted for agricultural use, which is 0.5 mg kg⁻¹ according to the soil quality standards [13].

Tithonia diversifolia demonstrated that Hg was absorbed by the plant at levels up to 0.52 mg kg⁻¹ in the control group, demonstrating that *Tithonia* plants can play a role in the bioremediation of Hg. Bioremediation is the use of microorganisms or other biological systems to degrade or transform pollutants under controlled conditions. Bioremediation primarily uses bacteria to degrade or transform pollutants into harmless compounds, but can also utilize fungi, algae, and plants. Bioremediation using plants is known as phytoremediation. *Tithonia diversifolia* is a weed species with phytoaccumulator properties because it can grow in polluted locations. The *Tithonia* plant not only grows but also provides benefits as an absorber of heavy metals in contaminated soil. *Tithonia diversifolia* can reduce soil Hg by 0.1838 mg kg⁻¹ [14]. The higher the dose of biochar applied to the soil, the less Hg can be absorbed by the plants. In the control soil, the *Tithonia* plant was able to absorb up to 0.52 mg kg⁻¹ of soil Hg, but at the highest dose of biochar, *Tithonia* plants only absorbed 0.04 mg kg⁻¹ of soil Hg. The long-term effect of bamboo biochar on the phytoaccumulation capacity of *Tithonia* plants is likely due to Hg in the treated soil being absorbed and possibly bound to functional groups in the biochar. Biochar can release metal ions from P because the biochar functional groups absorb metal ions, preventing them from being hydrolyzed in the soil. The biological accumulation coefficient (BAC) value of *Tithonia* plants can be obtained by dividing the concentration of Hg in plant biomass by the concentration of Hg in the soil. Hyperaccumulators are defined as plants that have a biological accumulation coefficient greater than 1 [15]. This indicates that the ability of the *Tithonia* plant to accumulate Hg is relatively low, because the BAC is <1. Thus, it proves that the inactivation technique with residual effect of bamboo biochar can reduce Hg toxicity to the *Tithonia* plant.

4 Conclusions

The residual effect of bamboo biochar (RE-BB) at a dose of 40 tons ha⁻¹ was significant and still capable of improving the chemical properties of ex-GMS by increasing the soil pH to 6.37, CEC to 11.07 cmol(+) kg⁻¹, organic C to 1.27%, total N to 0.19%, available P to 24.24 ppm, and Mg-exch to 0.32 cmol(+) kg⁻¹, and reducing the soil of Hg to 2.16 mg kg⁻¹. Additionally, it

can increase plant height to 83.67 cm, P to 0.006%, K to 0.13%, and reduce the plant of Hg to 0.04 mg kg⁻¹. The application of BB at a dose of 30-40 tons ha⁻¹ until the second planting season has been proven to control Hg contamination by improving the chemical properties of ex-GMS. Meanwhile, *Tithonia diversifolia* has been proven to have potential as a renewable phytoaccumulator of Hg.

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