From Waste to Resource: Exploring the Double-Edged Benefits of Contaminated Biomass in Biochar Production

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Abstract
Improper disposal of biochar derived from post-remediation waste biomass can lead to secondary contamination and have a harmful effect on the ecosystems. In this research, two types of biomass were tested – with low (308 mg Zn/kg, 23 mg Pb/kg) and high heavy metal content (1580 mg Zn/kg, 1863 mg Pb/kg) – as well as the biochars derived from them, containing 740 mg Zn/kg and 50 mg Pb/kg, and 6230 mg Zn/kg and 9590 mg Pb/kg, respectively. The ecotoxicity study included tests towards soil organisms, utilizing plants *Triticum aestivum*, *Lepidium sativum* and *Cucumis sativus*, as well as earthworms *Eisenia fetida*. Neither of biochar showed adverse effects on plant growth parameters such as stem height and stem dry biomass. In contrast, both biomass types inhibited growth of *Lepidium sativum*. None of the sample adversely impacted earthworms survivability.

Keywords
Biochar; biomass; ecotoxicity; phytotoxicity; vermitoxicity

INTRODUCTION

Owing to its beneficial properties (Igalavithana et al., 2017), biochar has found a number of applications, mainly in the agriculture and environmental sector (Bano et al., 2024). It is claimed to improve the physicochemical properties of the soil, particularly by providing and retaining nutrients (Hossain et al., 2020), increasing water holding capacity (WHC) (Ennis et al., 2012) and immobilizing contaminants (Rajapaksha et al., 2016). It can be used as fertilizer and soil improver in sustainable agriculture and therefore stimulate growth and yield of plants (Schmidt et al., 2016). However, biochar can also contain harmful elements and chemicals, inherent to biomass used, but also those produced through pyrolysis (Raheem et al., 2022). The issue concerns primarily heavy metals, as well as organic compounds. This problem is particularly relevant for phytoremediation biomass, which often accumulates substantial amounts of heavy metals. Although pyrolysis provides a sustainable way for utilization of such biomass, once applied to the soil, the resulting biochar may still pose a threat due to the possibility of secondary contamination. Improper application can lead to negative effects on soil flora and fauna (Godlewska et al. 2021). To ensure a comprehensive understanding, the environmental impact of biochar should be evaluated through ecotoxicity tests.

MATERIALS AND METHODS

In this study two types of biomass and their biochars were examined. Materials, distinguished by heavy metals content (Table 1), were referred to as ‘biomass’ (BM) and ‘contaminated biomass’ (BMC), and their conversion products as ‘biochar’ (BC) and ‘contaminated biochar’ (BCC). Pyrolysis was carried out in ceramic crucibles placed in a laboratory muffle furnace at 700 °C for 10 min. The primary objective was to determine the environmental risk of soil storing the materials based on toxicity-based approach employing:
(a) Terrestrial plants seedling emergence and seedling growth (OECD 208, 2006), utilizing garden cress (*Lepidium sativum*) and cucumber (*Cucumis sativus*) as dicotyledonous plants, as well as common wheat (*Triticum aestivum*) as monocotyledon plant,
(b) Earthworm acute toxicity (OECD 207, 1984) utilizing redworm *Eisenia fetida*.
All toxicity tests were conducted using OECD artificial soil (OECD, 1984), composed of 10 % sphagnum peat (fraction < 2 mm), 20 % kaolin clay, and up to 70 % quartz sand, with 0.3–1 %

calcium carbonate to maintain a pH of 6.0 ± 0.5. Biomass and biochar samples were incorporated into the soil at a concentration of 1 % (w/w, dry weight basis).

Phytotoxicity

In phytotoxicity the pots were filled with 440 g of wet artificial soil. Each pot was sown, with seeds of either garden cress, wheat seeds or cucumber. The pots were incubated in climate chamber for 21 days, under conditions of 23°C and 70% WHC with a 14 h light/10 h dark cycle and were periodically refilled with water to maintain soil moisture. The endpoints of the test were stem growth and stem dry biomass growth.

Table 1. Heavy metals content in biomass and biochar.

Heavy metal	Material			
	BM	**BMC**	**BC**	**BCC**
Zn [mg/kg]	308	1580	740	6230
Pb [mg/kg]	23	1863	50	9590

Vermitoxicity

In earthworms toxicity testing only animals with visible clitellum and weighing between 250 and 600 mg were used. Each repetition utilized ten suitable animals. In each test container 750 g of wet artificial soil was placed. Test containers were incubated under constant illumination. After 7 and 14 days the mortality of organisms was assessed.

RESULTS AND DISCUSSION

Effects of biomass and biochar on stem growth and stem biomass growth of common wheat, garden cress and cucumber, are shown in Figures 1 and 2, respectively. Both types of biomass inhibited the growth of garden cress, with respect to both stem growth (31.44% and 32.59%), for BM and BMC, respectively) and stem weight growth (52.66% and 57.36%). In case of cucumber, no stem growth inhibition was observed for any of the samples, while there was nearly 30% inhibition of stem weight growth for the BMC. Wheat was the least sensitive plant – neither sample negatively affected the stem and stem weight growth. Bonanomi et al. (2006) in their study showed a high toxic effect of decomposing plant-derived organic matter on cress germination. In subsequent study (Bonanomi et al., 2011), the authors pointed to the allelopathic properties of many organic compounds produced during biomass decomposition, as the reason for such phenomenon.

In this study, neither of the biochar showed any adverse effects towards plants. Biochar application is often associated by a hormesis effect – low doses have a stimulating effect on plants, while high doses, due to the increase in contaminants levels, have an inhibitory effect (Joseph et al., 2021). In this study, biochar was incorporated into a peat-based soil with high nutrient content, which likely diminished the potential positive effects of its application. At the same time, it might have buffered the toxic effects of low concentrations of heavy metals introduced with the applied dose. Nevertheless, it is accepted that doses of biochar <1% (w/w, dry weight basis) usually do not cause plant toxicity (Godlewska et al., 2020).

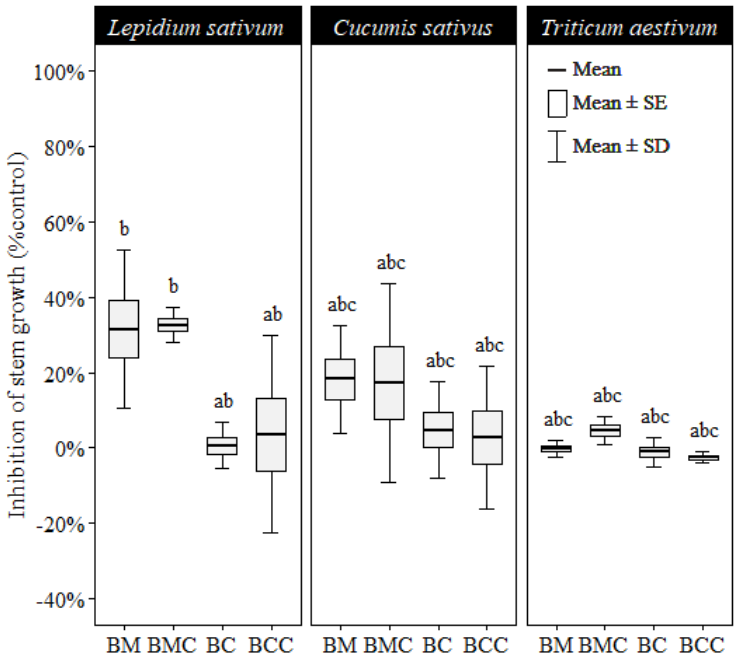


Figure 1. Toxicity of biomass and biochars towards *L. sativum*, *C. sativus* and *T. aestivum* stem growth. (a) statistically significant differences between samples counterparts (BM vs BMC or BC vs BCC) (LSD comparison, $\alpha = 0.05$); (b) statistically significant differences between biomass and biochar (BM vs BC or BMC vs BCC) (LSD comparison, $\alpha = 0.05$).

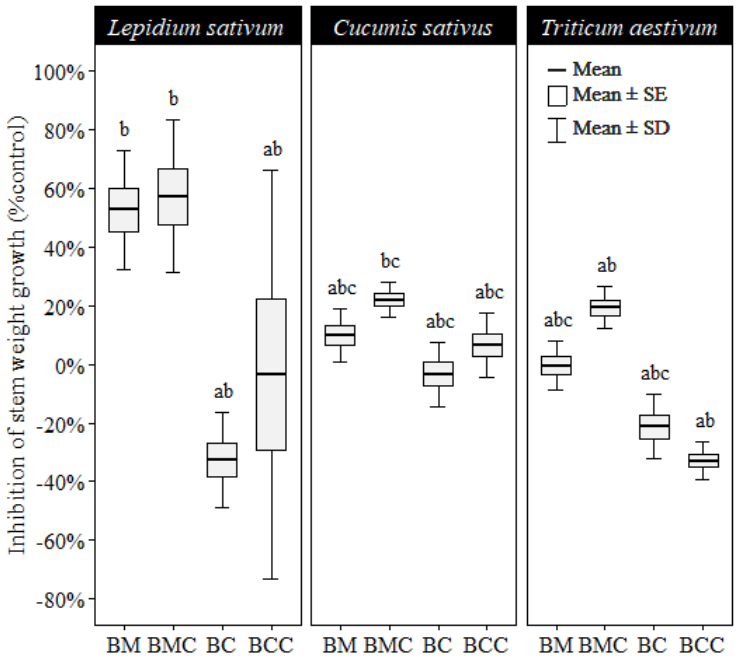


Figure 2. Toxicity of biomass and biochars towards *L. sativum*, *C. sativus* and *T. aestivum* stem weight growth.

The effects of biomass and biochar on *E. fetida* earthworm mortality after 7- and 14-days are shown in Figure 3. The highest mortality rate after either 7 or 14 days, was 6.67%. In neither case was mortality statistically significant. It is recognized that high WHC values of the materials are one of the reasons for the negative effects of biochar against earthworms, because of decrease in the availability of water in the soil (Li et al., 2011). Based on that conclusion, in the present study,

additional water was supplied to offset the amount absorbed by biochar and to isolate other toxic effects of biochar. The toxicity of biochar can also be affected by the material particle size (Prodana et al., 2019), and water-soluble organic compounds and heavy metals (Shi et al., 2021). However, in this study none such toxic effects were observed.

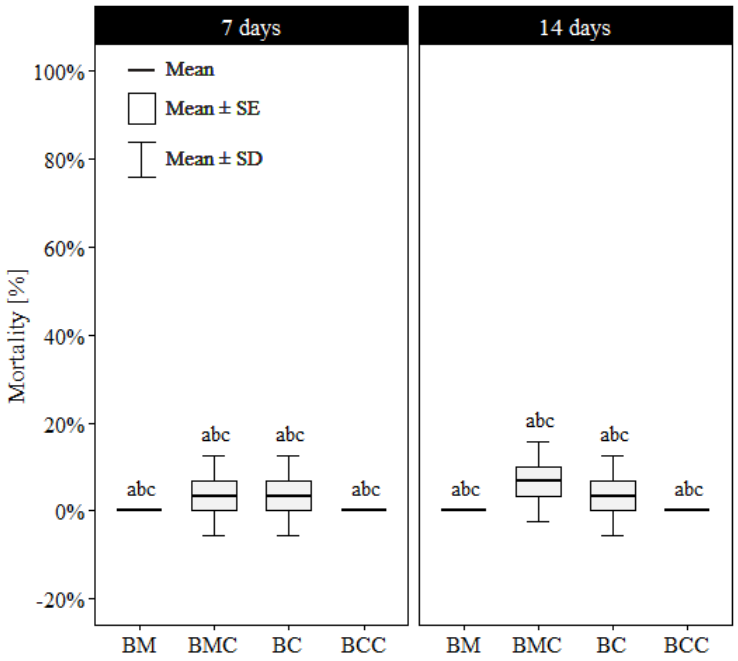


Figure 3. Mortality of *E. fetida* in soil with biomass and biochars after 7 and 14 days of experiment.

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