Jurnal Al Ulum LPPM Universitas Al Washliyah Medan
Vol. 14 No. 2 Tahun 2026
P-ISSN 2338-5391 | E-ISSN 2655-9862

RICE-HUSK AND CORN WASTE BIOCHARS IMPROVE RICE GROWTH UNDER LEAD STRESS

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ABSTRACT

Lead (Pb) contamination in agricultural soils threatens rice production by reducing plant growth and increasing the risk of heavy-metal accumulation in edible tissues. Biochar has emerged as a sustainable soil amendment capable of immobilizing heavy metals while improving soil properties. This study evaluated the comparative effectiveness of rice-husk biochar and corn-residue biochar applied at rates of 0%, 10%, and 20% in reducing Pb availability and enhancing the early growth of upland rice (Oryza sativa L.). A factorial completely randomized design with three replications was employed under controlled pot conditions. Soil pH, residual Pb concentration, rice growth parameters, biomass production, root development, and Pb accumulation in plant tissues were measured and analyzed using analysis of variance followed by Duncan's Multiple Range Test at the 5% significance level. Biochar application significantly reduced soil Pb concentration, with the 20% application rate decreasing Pb by approximately 23% compared with the untreated control. A parallel reduction in Pb accumulation was observed in rice tissues, indicating lower Pb bioavailability. Root length increased markedly from 6.35 cm in the control to 16.50 cm at the highest biochar rate, while shoot length also improved significantly. Corn-residue biochar generally promoted greater root development and biomass production than rice-husk biochar, likely because of its higher concentrations of exchangeable potassium, calcium, and magnesium. Although soil pH increased following biochar application, the differences were not statistically significant, suggesting that Pb immobilization resulted primarily from adsorption, ion exchange, surface complexation, and mineral precipitation rather than pH modification alone. Overall, biochar application rate exerted a stronger influence on Pb immobilization than feedstock type, whereas biochar feedstock more strongly affected plant growth. These findings demonstrate that agricultural-residue biochars represent promising, low-cost amendments for mitigating Pb contamination and improving early rice establishment, although long-term field validation is required before practical recommendations can be made.

*Keywords**:** biochar; lead contamination; rice husk; corn residue;* Oryza sativa*; heavy metal immobilization; upland rice*

INTRODUCTION

Rice is a primary staple food for more than half of the global population and is central to food security, especially in Asia. Sustainable rice production is therefore essential to meet the increasing demand associated with population growth. However, rice cultivation is increasingly threatened by environmental degradation, particularly the accumulation of heavy metals in agricultural soils. Among these contaminants, lead (Pb) is of major concern because it is persistent, non-biodegradable, and toxic to both plants and humans (Notohadiprawiro, 2006; Tangahu *et al*., 2011). Unlike many organic pollutants, Pb cannot be biologically degraded and may remain in soil for long periods. Its persistence creates continuing risks for soil quality, crop productivity, grain safety, and human health.

Lead enters rice-growing environments through both direct and indirect anthropogenic pathways. Major sources include mining, ore processing, metal smelting, industrial discharge, traffic emissions, wastewater irrigation, excessive agrochemical use, sewage sludge, and improper waste disposal. Irrigation with contaminated river water, groundwater, or municipal wastewater can gradually increase Pb concentrations in the root zone because repeated irrigation deposits metals in the soil over time (Ali *et al*., 2022). Atmospheric deposition from industrial facilities and transportation corridors may also contribute Pb to paddy soils and plant surfaces (Zhu *et al*., 2022). Runoff and erosion can further transport Pb-contaminated particles from mining and industrial areas into irrigation networks. These multiple pathways make Pb contamination difficult to control and increase the vulnerability of agricultural land located near urban and industrial zones.

Recent studies have shown that Pb contamination adversely affects rice growth, productivity, grain quality, and food safety. Rice seedlings exposed to Pb-contaminated soil commonly develop shorter roots, reduced shoot growth, smaller leaf areas, and lower biomass accumulation (Ashraf *et al*., 2015). Root growth is often more severely affected because roots are directly exposed to contaminated soil and retain most of the absorbed Pb (Tan *et al*., 2022). Lead also reduces chlorophyll concentration, damages the photosynthetic apparatus, and lowers photosynthetic efficiency (Salavati *et al*., 2021). These effects weaken seedling vigor and restrict early crop establishment. When Pb stress continues during later growth stages, impaired vegetative development can reduce tiller formation, panicle development, grain filling, and final yield.

At the physiological and biochemical levels, Pb disrupts several essential plant processes. It interferes with nutrient acquisition, nitrogen metabolism, water relations, and cellular membrane stability (Tan *et al*., 2022). Lead exposure also promotes the excessive production of reactive oxygen species in rice tissues. This response increases hydrogen peroxide, malondialdehyde, electrolyte leakage, and membrane lipid peroxidation (Tan *et al*., 2022). Rice plants may respond by increasing antioxidant-enzyme activity and accumulating protective osmolytes such as proline. However, these defense mechanisms may be insufficient under severe or prolonged exposure. Although Pb generally accumulates more strongly in roots than in shoots, part of the absorbed metal can be translocated to aerial tissues and grain through the soil–water–plant pathway (Li *et al*., 2024).

The transfer of Pb into rice grain creates a direct food-safety concern. Grain contamination lowers product quality and may cause harvested rice to exceed permissible limits for human consumption. This issue is particularly serious because rice is consumed daily in large quantities across many Asian countries. Even relatively low Pb concentrations may therefore contribute to chronic dietary exposure. Long-term consumption of Pb-contaminated rice has been associated with neurological impairment, renal dysfunction, cardiovascular effects, developmental disorders, and other adverse health outcomes. The extent of Pb accumulation in grain is influenced by soil pH, organic matter, redox conditions, cation-exchange capacity, rice genotype, and the chemical form of Pb in soil (Li *et al*., 2024). Consequently, reducing total soil Pb alone may be less practical than decreasing the fraction that remains mobile and available for plant uptake.

Several soil amendments have been investigated, including lime, phosphate materials, compost, clay minerals, silicon, and organic residues. These materials can decrease Pb availability by raising soil pH, increasing adsorption, promoting precipitation, or modifying soil chemical conditions (Beesley et al., 2010; Cao et al., 2011). Nevertheless, some conventional amendments require repeated application or provide limited improvements in soil fertility. Others may be costly or unavailable to smallholder farmers. These limitations have encouraged greater interest in low-cost and locally available amendments that can both immobilize contaminants and improve soil productivity.

Biochar has emerged as one of the most promising amendments for this purpose. It is a carbon-rich material produced through the pyrolysis of biomass under limited oxygen conditions. Biochar generally has a porous structure, a relatively large surface area, abundant oxygen-containing functional groups, and a variable mineral composition (Lehmann, 2007; Liang *et al*., 2006). These properties enable biochar to retain Pb through surface adsorption, ion exchange, electrostatic attraction, surface complexation, and mineral precipitation (Sachdeva *et al*., 2023). Biochar can also increase soil pH, enhance nutrient retention, improve water-holding capacity, and stimulate microbial activity (Yadav & Ramakrishna, 2023). These combined functions make it attractive for contaminated agricultural soils because it may reduce metal exposure while supporting plant growth.

Previous research has demonstrated that biochar can reduce Pb mobility and plant uptake in contaminated soils. Beesley *et al*. (2010) reported that biochar decreased the mobility and bioavailability of several heavy metals in polluted soil. Cao *et al*. (2011) showed that dairy-manure biochar immobilized Pb through adsorption and precipitation mechanisms. Jiang *et al*. (2012) also found that crop-residue biochar enhanced Pb adsorption in amended soil. More recent research indicates that increasing the biochar application rate generally strengthens Pb immobilization, although the response depends on soil properties, feedstock composition, and treatment level. Chemically modified or phosphate-supported biochars may provide even stronger Pb retention than untreated materials (Gusiatin & Rouhani, 2023). However, biochar normally stabilizes Pb rather than removing it from the soil, and its long-term effectiveness may change as the material ages.

The performance of biochar is strongly influenced by its feedstock and production conditions. Feedstock type determines carbon content, ash composition, nutrient concentration, surface functional groups, and pore structure. Pyrolysis temperature also affects pH, aromaticity, porosity, surface area, and the abundance of carboxyl and hydroxyl groups. Biochars rich in calcium, magnesium, potassium, phosphorus, and silica may enhance Pb immobilization through ion exchange and mineral precipitation. In contrast, materials with abundant oxygen-containing functional groups may favor surface complexation. Rice-husk biochar has been widely examined for soil improvement and heavy-metal adsorption because rice husks are abundant and contain substantial silica and ash (Asadi *et al*., 2021). Corn-residue biochar also has potential because it may contain relatively high concentrations of phosphorus and exchangeable base cations. However, the two materials may perform differently in contaminated rice-growing soils.

Recent literature does not provide a peer-reviewed study that directly compares rice-husk biochar and corn-residue biochar for Pb accumulation and early rice growth under identical experimental conditions. Most studies assess rice-husk biochar alone (Asadi *et al*., 2021), examine several feedstocks without using rice as the test crop, or review biochar-mediated heavy-metal immobilization broadly (Sachdeva *et al*., 2023; Gusiatin & Rouhani, 2023). Therefore, important uncertainties remain regarding how these two biochars differ in their effects on soil Pb, root development, biomass production, and Pb distribution in rice tissues. The present study aimed to evaluate rice-husk and corn-residue biochars applied at different

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rates to Pb-contaminated soil. It examined soil pH, soil Pb concentration, shoot and root growth, biomass production, and Pb accumulation in rice seedlings. The novelty lies in the direct, side-by-side comparison of two locally available agricultural-residue biochars under the same experimental design. It was hypothesized that higher biochar application would reduce Pb bioavailability and plant accumulation while improving early rice growth, and that differences in feedstock chemistry would produce distinct soil and plant responses. The study was limited to the seedling stage under controlled pot conditions and was intended to provide a basis for subsequent long-term and field-scale evaluation.

METHODOLOGY

Study Site, Materials, and Research Stages

The research was conducted at the Laboratory of the Faculty of Agriculture and the Experimental Field of Universitas Al Washliyah Medan (UNIVA), Indonesia. The study employed a controlled pot experiment and consisted of two consecutive stages. The first stage involved producing and characterizing biochar derived from rice husks and corn residues. The second stage evaluated the effects of the two biochar types and their application levels on soil Pb concentration and the growth and Pb accumulation of upland rice seedlings.

Biochar Production and Chemical Characterization

Rice-husk and corn-residue biochars were produced separately through pyrolysis under restricted oxygen conditions. Each feedstock was placed in a simple pyrolysis unit and thermally processed for approximately two to four hours. After cooling, the resulting biochar was prepared for chemical analysis. Biochar characterization was undertaken to identify compositional differences that could influence soil reactions, nutrient supply, and Pb immobilization. Characterizing each material before application was essential because biochar performance can vary substantially with feedstock composition and production conditions.

Rice-husk biochar contained approximately 60.8% more total carbon than corn-waste biochar, with values of 29.71% and 18.48%, respectively. Its total nitrogen concentration was also almost twice that of corn-waste biochar (0.19 %). Rice-husk biochar showed higher values than corn-waste biochar for all measured properties. It contained more total Na (0.63% vs. 0.41%), total S (1.06% vs. 0.91%), total Al (1.13% vs. 0.97%), organic matter (18.08% vs. 13.62%), electrical conductivity (0.98 vs. 0.84), and ash content (4.98% vs. 3.12%). The higher carbon and organic-matter contents indicated that rice-husk biochar retained a larger carbonaceous fraction after pyrolysis. Corn-waste biochar, however, showed a comparatively stronger mineral-nutrient profile. Its total P, K, Ca, and Mg concentrations were 0.28%, 1.24%, 1.18%, and 0.37%, respectively, compared with 0.21%, 1.18%, 0.96%, and 0.26% in rice-husk biochar. The pH values of both materials were close to neutral, although corn-waste biochar had the higher value of 7.12.

Experimental Design And Treatment Structure

The second stage was arranged as a two-factor factorial randomized block design with four replications. The first factor was the biochar application level, designated as P, comprising no biochar or 0% of the planting medium (P0), 10% biochar (P1), and 20% biochar (P2). The second factor was biochar type, designated as B, comprising rice-husk biochar (B1) and corn-waste biochar (B2).

Soil Incubation, Rice Cultivation, and Variable Measurement

The soil was obtained from a disposal area associated with a tapioca-processing facility. Before the treatments were applied, a composite soil sample was analysed to determine its initial physical and chemical properties. Its initial pH was 6.12, indicating a slightly acidic reaction, while the measured Pb concentration and exchangeable Al was 19.60 ppm and 1.79 me/100 g, respectively. The soil contained 1.87% organic carbon and 0.19% total nitrogen. Exchangeable K(0.15 me/100 g), Na (0.33 me/100 g), and base saturation (35.672 %) were relatively low,

P-ISSN 2338-5391 | E-ISSN 2655-9862

whereas available P (24.17 ppm) exchangeable Ca (6.27 me/100 g), Mg (1.74 me/100 g), and cation-exchange capacity (23.80 me/100 g) were comparatively moderate. The soil contained 8% sand, 78% silt, and 14% clay and was therefore classified as silty loam.

Three kilograms of soil were placed in each polybag and mixed thoroughly with the assigned biochar treatment. The amended soil was watered with sterile water and incubated for 14 days. Following incubation, soil samples were collected from each experimental unit for the determination of soil pH and Pb concentration. The initial soil analysis served as the baseline for evaluating changes associated with biochar application.

After incubation, four upland rice seeds were planted in each polybag. At two weeks after planting, the seedlings were thinned to two uniform plants per polybag to reduce competition and maintain a consistent plant density. The plants were maintained until four weeks after planting, when they were harvested. Roots and shoots were separated, cleaned as required, and measured before drying. The plant fractions were subsequently placed in an oven until suitable for dry-weight determination.

The independent variables were biochar application level and biochar type. The dependent soil variables were pH and Pb concentration after incubation. Plant-response variables included shoot length, root length, shoot fresh weight, root fresh weight, shoot dry weight, root dry weight, and Pb concentration in plant tissue.

Statistical Analysis

Data from the factorial pot experiment were analysed using analysis of variance to test the effects of block, biochar level, biochar type, and the interaction between biochar level and type for each response variable. The analysis was performed using JASP version 0.95.3.0.

When the analysis of variance indicated a significant or highly significant treatment effect, treatment means were separated using Duncan's Multiple Range Test at the 5% significance level, corresponding to a 95% confidence level. Statistical significance was therefore established at $p<0.05$.

RESULTS

Soil Characteristics and Post-Incubation Changes

The analysis of variance showed that biochar application level, biochar type, and their interaction did not significantly affect soil pH after the 14-day incubation. Nevertheless, the numerical means showed that soil receiving biochar generally had a higher pH than unamended soil.

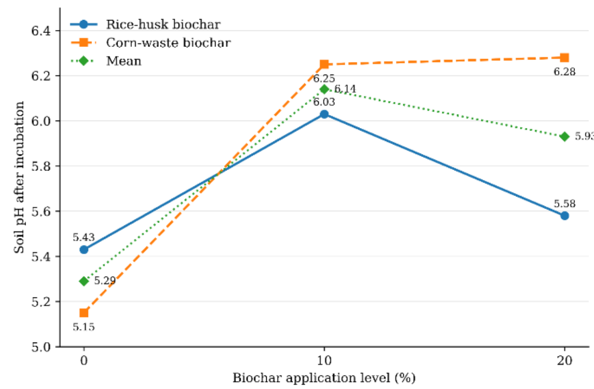

Figure 1. The effect of biochar type and application level on soil pH after the incubation period.

As we seen in Figure 1, biochar application generally increased soil pH relative to the untreated control. Mean soil pH rose from 5.29 at 0% biochar to 6.14 at 10%, then declined slightly to 5.93 at 20%. Corn-waste biochar produced higher pH values than rice-husk biochar at both application rates, with the highest value of 6.28 recorded at 20% corn-waste biochar. The overall mean pH was 5.89 for corn-waste biochar and 5.68 for rice-husk biochar. Although the differences were not statistically significant, both biochars tended to reduce soil acidity, with corn-waste biochar showing the stronger liming effect.

Unlike soil pH, Pb concentration after incubation was significantly affected by biochar application level. Biochar type and the interaction between level and type were not significant.

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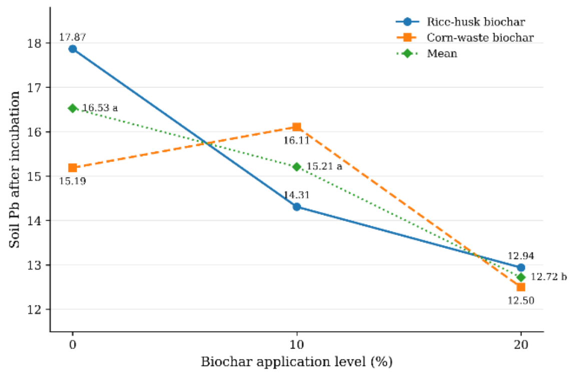

Figure 2. The effect of biochar type and application level on soil Pb concentration after the incubation period.

As we seen in Figure 2, Biochar application significantly reduced soil Pb concentration as the application rate increased. Mean soil Pb declined from 16.53 ppm in the control to 15.21 ppm at 10% biochar and 12.72 ppm at 20%. The 20% treatment was significantly lower than both the control and 10% treatment, representing a 23.1% reduction relative to the untreated soil. Corn-waste biochar produced a slightly lower overall Pb concentration than rice-husk biochar, but the difference was not significant. Thus, biochar application rate was more influential than feedstock type in reducing soil Pb during incubation.

Rice-Seedling Growth Responses

Biochar application significantly affected several indicators of upland rice-seedling growth. The application level significantly influenced shoot length, root length, root fresh weight, shoot dry weight, and root dry weight. Biochar type significantly affected root length, shoot dry weight, and root dry weight. The interaction between application level and biochar type was significant only for shoot fresh weight. Shoot fresh weight did not differ significantly among the treatments. Shoot length at four weeks after planting was significantly affected by biochar application level, whereas biochar type and the interaction were not significant.

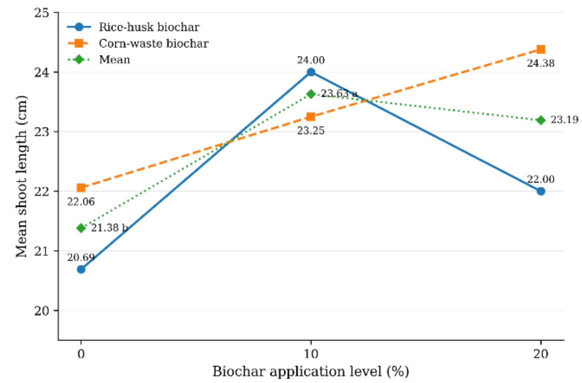

Figure 3. The effect of biochar type and application level on the shoot length of rice seedlings after incubation.

As we seen in Figure 3, Biochar application significantly increased rice shoot length compared with the untreated control. Mean shoot length increased from 21.38 cm at 0% biochar to 23.63 cm at 10% and 23.19 cm at 20%. The 10% and 20% treatments were significantly higher than the control but did not differ from each other. Rice-husk biochar produced the greatest shoot length at 10% (24.00 cm), while corn-waste biochar produced the highest value at 20% (24.38 cm). Overall, corn-waste biochar resulted in a slightly higher mean shoot length than rice-husk biochar.

Root growth showed a stronger response than shoot growth. Both biochar level and biochar type significantly affected root length, while their interaction was not significant.

As we seen in Figure 4, Biochar application significantly increased rice root length. Mean root length rose from 6.35 cm in the control to 13.90 cm at 10% biochar and 16.50 cm at 20%, with all application levels differing significantly. Corn-waste biochar produced significantly longer roots overall than rice-husk biochar, with mean values of 13.50 and 11.00 cm, respectively. The highest root length, 17.50 cm, was recorded with 20% corn-waste biochar, indicating that higher biochar rates strongly promoted root development in Pb-contaminated soil.

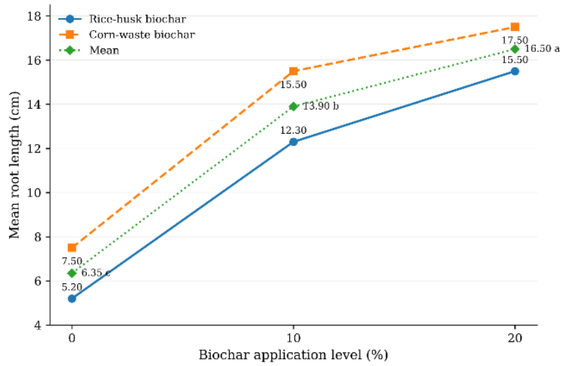

Figure 4. The effect of biochar type and application level on the root length of rice seedlings after the incubation period.

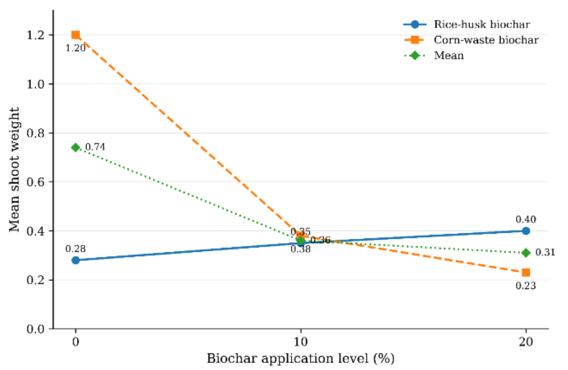

Figure 5. The effect of biochar type and application level on the shoot fresh weight of rice seedlings after incubation.

As we seen in Figure 5, Shoot biomass showed contrasting responses to biochar type and application rate. Mean shoot fresh weight declined from 0.74 g in the control to 0.36 g at 10% biochar and 0.31 g at 20%. Rice-husk biochar gradually increased shoot weight from 0.28 to 0.40 g, whereas corn-waste biochar reduced it from 1.20 to 0.23 g as the application rate increased. Thus, shoot biomass was strongly influenced by the interaction between biochar type and application level and did not increase consistently with biochar application.

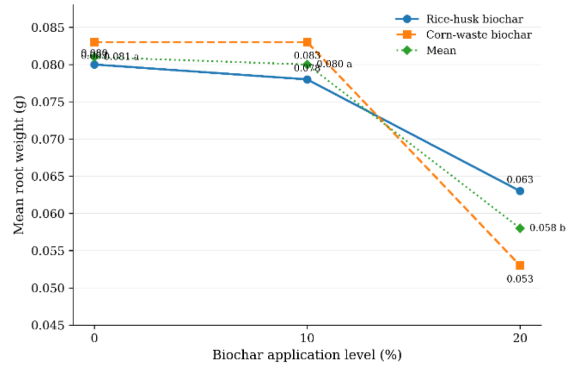

Figure 6. The effect of biochar type and application level on the root fresh weight of rice seedlings after the incubation period.

As we seen in Figure 6, root fresh weight remained similar between the control (0.081 g) and 10% biochar treatment (0.080 g) but decreased significantly to 0.058 g at 20%. Both biochar types produced the same overall mean root weight of 0.073 g. At the highest application rate, root fresh weight declined to 0.063 g with rice-husk biochar and 0.053 g with corn-waste biochar. Thus, increasing biochar application promoted root elongation but did not increase root biomass.

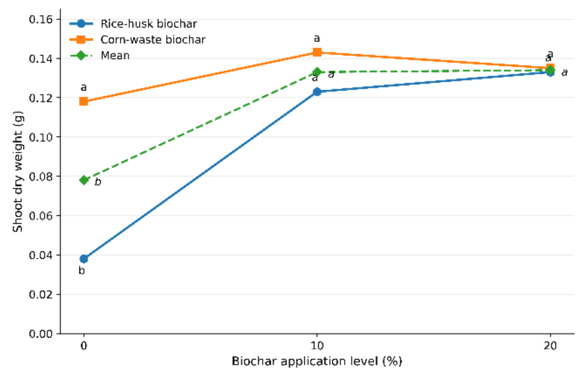

Figure 7. The effect of biochar type and application rate on the shoot dry weight of rice seedlings grown in Pb-contaminated soil.

As we seen in Figure 7, Biochar application significantly increased shoot dry weight from 0.078 g in the control to 0.133–0.134 g at the 10% and 20% rates, with no significant difference between these two application levels. Corn-waste biochar produced a higher overall mean shoot dry weight (0.132 g) than rice-husk biochar (0.098 g). The highest value was recorded with 10% corn-waste biochar (0.143 g), indicating that a 10% application was sufficient to maximize shoot biomass.

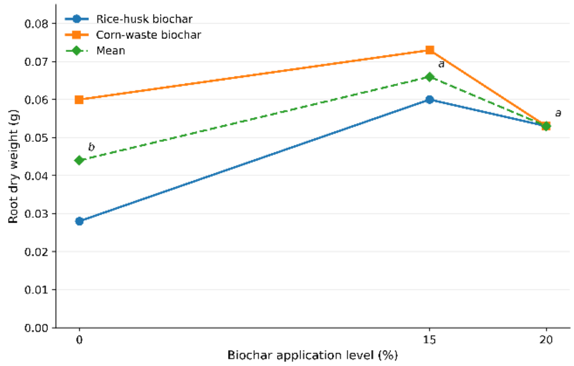

Figure 8. The effect of biochar type and application rate on the shoot dry weight of rice seedlings grown in Pb-contaminated soil.

As we seen in Figure 8, Biochar application increased root dry weight from 0.044 g in the control to 0.066 g at 15% and 0.053 g at 20%. The 15% and 20% treatments were significantly higher than the control but did not differ from each other. Corn-waste biochar produced a higher overall mean root dry weight (0.062 g) than rice-husk biochar (0.047 g), with the highest value recorded at 15% corn-waste biochar (0.073 g).

Accumulation in Rice Tissues

Biochar application level significantly affected Pb concentration in rice-seedling tissues. Biochar type and the interaction between biochar level and type were not significant. Plant-tissue Pb declined progressively as the application rate increased.

Biochar application reduced Pb accumulation in rice tissues. Mean tissue Pb concentration declined from 0.13 in the control to 0.07 at 10% biochar and 0.04 at 20%, with the 20% treatment significantly lower than the other application levels. Both biochars limited Pb uptake, although rice-husk biochar was most effective at 20%, reducing tissue Pb to 0.02. Overall, the results indicate that higher biochar application, particularly 20% rice-husk biochar, was most effective in restricting Pb uptake by rice seedlings.

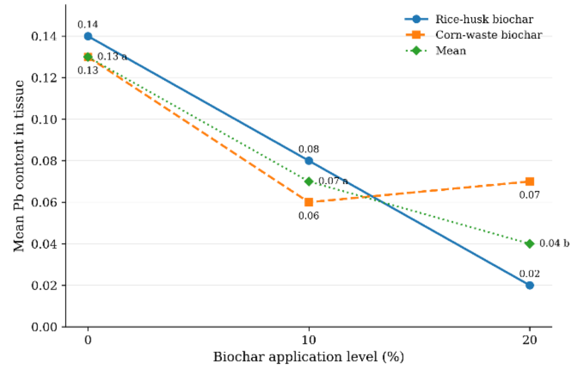

Figure 9. The effect of biochar type and application level on Pb accumulation in rice tissues after the incubation period.

Discussion

The findings demonstrate that biochar application altered both Pb behavior in the soil and the early growth of upland rice seedlings, although the magnitude of the response depended more strongly on application level than on biochar feedstock. The significant reduction in soil Pb at the 20% application rate, together with the parallel decline in Pb concentration in rice tissues, indicates that increasing the amount of biochar in the planting medium reduced the fraction of Pb available for plant uptake. The measured soil Pb concentration decreased from 16.53 ppm in the control to 12.72 ppm at the 20% application rate, representing a reduction of approximately 23.1%. This treatment also produced the lowest Pb concentration in rice tissues. These corresponding responses suggest that biochar acted principally by retaining Pb in the soil matrix rather than allowing continued transfer into plant tissues. The result supports previous evidence that biochar can immobilize potentially toxic metals and reduce their mobility, bioavailability, and toxicity in contaminated soils (Beesley *et al*., 2010; Cao *et al*., 2011).

Several mechanisms may explain this reduction. Biochar surfaces contain negatively charged sites and oxygen-containing functional groups, including carboxyl and hydroxyl groups, which can bind Pb through electrostatic attraction and surface complexation. Pb may also be retained through ion exchange, physical adsorption within pores, and precipitation with mineral components derived from biochar ash.

P-ISSN 2338-5391 | E-ISSN 2655-9862

Yuan *et al.* (2011) reported that oxygen-containing functional groups can form surface complexes with Pb(II), thereby increasing Pb adsorption. The mineral fraction of biochar may further facilitate the conversion of soluble or exchangeable Pb into more stable forms. Recent reviews similarly emphasize that the effectiveness of biochar for heavy-metal immobilization is governed by the interaction among surface area, porosity, functional groups, mineral composition, soil pH, and contaminant chemistry (Gu *et al*., 2024; Gusiatin & Rouhani, 2023). The strong response at the 20% rate therefore likely resulted from the greater number of sorption and reaction sites introduced into the soil.

Although biochar application increased soil pH numerically, the treatment effects on pH were not statistically significant. The mean soil pH rose from 5.29 in the untreated treatments to 6.14 and 5.93 at the 10% and 20% application rates, respectively. The absence of statistical significance may reflect variation among experimental units, the relatively short 14-day incubation period, or the near-neutral pH of both biochars. Nevertheless, even moderate increases in pH may contribute to Pb immobilization by decreasing metal solubility and promoting adsorption or precipitation. The slightly higher average pH under corn-waste biochar was consistent with its higher initial pH and greater concentrations of K, Ca, and Mg. Previous studies have shown that feedstock composition and pyrolysis conditions determine the alkalinity and liming potential of biochar (Sohi *et al*., 2009; Steiner *et al*., 2007; Singh *et al*., 2010). However, because pH differences were not significant in the present experiment, the decline in Pb cannot be attributed to pH modification alone. Surface sorption, ion exchange, and mineral interactions were also likely involved.

The contrasting chemical properties of the two biochars help explain their different effects on rice growth. Rice-husk biochar contained more total carbon, nitrogen, sodium, sulfur, aluminium, organic matter, ash, and electrical conductivity, whereas corn-waste biochar contained more phosphorus, potassium, calcium, and magnesium and had a higher pH. Corn-waste biochar produced significantly longer roots than rice-husk biochar, whereas root fresh weight did not differ overall between the two feedstocks. Its higher overall shoot biomass was largely influenced by the unusually high value recorded in the corresponding control treatment. These responses may be associated with its comparatively higher concentrations of nutrients that support root development, cell expansion, osmotic regulation, and biomass formation. Phosphorus is particularly important for early root growth, while potassium, calcium, and magnesium contribute to physiological regulation and tissue development. The results therefore reinforce the principle that biochar performance is feedstock-specific and that chemical characterization is necessary before agronomic recommendations are made.

Root length showed the clearest growth response to biochar. It increased from 6.35 cm in the control to 13.90 cm at the 10% rate and 16.50 cm at the 20% rate. This substantial increase indicates that biochar improved the root-zone environment and alleviated constraints associated with Pb exposure or poor soil fertility. Pb commonly restricts root elongation and alters root branching because roots are the first plant organs exposed to contaminated soil. By reducing Pb availability and modifying nutrient and moisture conditions, biochar may have allowed continued root extension. The longer roots observed under corn-waste biochar also support the interpretation that nutrient composition contributed to improved seedling establishment. These findings are consistent with reports that biochar can stimulate seed germination, root development, and early plant growth by improving soil physical and chemical conditions (Kwapinski *et al*., 2010)

Shoot length also improved significantly following biochar application. Both the 10% and 20% treatments produced longer shoots than the untreated control, although the 10% treatment had the highest overall mean. This pattern indicates that the response was not strictly proportional across all growth variables. The positive regression coefficient reported for shoot length reflects an overall increasing trend, but the treatment means show that the response began to plateau or decline slightly at the highest rate.

Such a result may indicate that moderate biochar application was sufficient to improve shoot elongation, while further application provided no additional advantage for this specific parameter. Biochar effects are frequently nonlinear because excessive amendment may alter nutrient ratios, salinity, water relations, or substrate density. Therefore, although the 20% rate was most effective for Pb reduction and root elongation, it was not consistently superior for every growth characteristic.

A further distinction occurred between root length and root fresh weight. Root length increased substantially with biochar, whereas the reported regression for root fresh weight showed a decreasing trend. This suggests that biochar affected root architecture and biomass allocation rather than simply increasing all measures of root growth. Seedlings may have developed longer and finer roots with lower fresh mass, or differences in tissue water content may have influenced fresh weight. Because the study did not measure root diameter, root volume, specific root length, or tissue moisture content, the biological basis of this contrasting response cannot be determined conclusively. This limitation should be acknowledged, and future work should include more detailed root-morphology measurements.

Shoot fresh weight was the only variable significantly affected by the interaction between biochar type and application level. This interaction indicates that the effect of application rate differed between rice-husk and corn-waste biochars. The significant interaction reflected contrasting dose responses: shoot fresh weight increased gradually with rice-husk biochar but declined with increasing corn-waste biochar application. Its higher overall shoot biomass was largely influenced by the unusually high value recorded in the corresponding control treatment. The interaction is consistent with the chemical differences between feedstocks and indicates that application rate cannot be evaluated independently from material composition for biomass production. In contrast, the nonsignificant interactions for soil Pb and plant-tissue Pb suggest that both biochars responded similarly to increasing application level in terms of Pb reduction.

The decrease in Pb concentration in rice tissues has direct implications for food-production safety, although the present experiment evaluated seedlings rather than mature plants or harvested grain. Rice-residue biochar has previously been shown to reduce Cd, Zn, and Pb accumulation in rice shoots (Zheng *et al.*, 2012), supporting the pattern observed here. However, reduced Pb in seedlings cannot automatically be interpreted as reduced Pb in grain because metal uptake and translocation may change during later growth stages and under flooded field conditions. The experiment was short term, conducted in polybags, and limited to early vegetative growth. Consequently, the results demonstrate the potential of rice-husk and corn-waste biochars for Pb immobilization but do not establish their long-term field effectiveness.

The high application rates also require practical evaluation. A 20% amendment was the most effective treatment within the tested range, but such a rate may be difficult or costly to apply at field scale. Long-term effects on soil physical properties, nutrient balance, microbial activity, and crop yield were not assessed. Recent literature emphasizes the need to identify soil- and crop-specific biochar rates rather than assume that the highest tested dose is universally optimal. Future studies should therefore compare lower and intermediate rates, evaluate mature rice and grain Pb, examine long-term biochar aging, and conduct field trials under realistic water-management conditions.

Overall, the study demonstrates that biochar produced from locally available rice husks and corn residues can simultaneously reduce Pb availability and improve several indicators of rice-seedling growth. The stronger effect of application level on Pb reduction and the superior growth response to corn-waste biochar highlight two complementary considerations: sufficient biochar quantity is required for effective immobilization, while feedstock chemistry influences agronomic performance. These findings support the use of agricultural residues as value-added soil amendments, but field validation is necessary before recommendations can be made for contaminated rice-production systems.

CONCLUSION

This study demonstrates that biochar derived from rice husks and corn residues can reduce Pb availability in soil while improving several indicators of early upland rice growth. The 20% application rate produced the lowest soil Pb concentration, decreasing it by approximately 23.1% relative to the untreated control, and also resulted in the lowest Pb concentration in rice tissues. Biochar level significantly influenced soil Pb, shoot length, root length, root fresh weight, shoot dry weight, root dry weight, and plant-tissue Pb. Biochar type significantly affected root length and shoot and root dry weights, whereas the interaction between application level and feedstock type was significant only for shoot dry weight. Corn-waste biochar generally promoted stronger root development and biomass production, which was associated with its higher phosphorus, potassium, calcium, magnesium, and pH values. Rice-husk biochar, however, contained more total carbon, nitrogen, organic matter, ash, sodium, sulfur, aluminium, and electrical conductivity. These findings contribute to the existing knowledge by showing that the quantity of biochar is particularly important for Pb immobilization, while feedstock composition more strongly influences plant-growth responses. The conversion of rice husks and corn residues into biochar therefore offers a practical approach to agricultural-waste utilization, contaminated-soil management, and safer rice production. Nevertheless, because the experiment was conducted in polybags and limited to the seedling stage, further research should evaluate intermediate application rates, long-term soil effects, grain Pb accumulation, economic feasibility, and field-scale performance under realistic rice-cultivation conditions.

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