Magna Scientia Advanced Biology and Pharmacy
eISSN: 2582-8363
Cross Ref DOI: 10.30574/msabp
Journal homepage: https://magnascientiapub.com/journals/msabp/

(Research Article)

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The effect of providing biochar on planting media with heavy metal contents Pb, Cu, and Hg on the growth, yield, and quality of rice (*Oryza sativa* L.)

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Magna Scientia Advanced Biology and Pharmacy, 2025, 14(02), 043-049

Publication history: Received on 13 January 2025; revised on 26 February 2025; accepted on 01 March 2025

Article DOI: https://doi.org/10.30574/msabp.2025.14.2.0026

Abstract

This research aims to evaluate the effect of biochar types in planting media containing the heavy metals Pb, Cu and Hg on the growth, yield and quality of rice (Oryza sativa L.). The research was carried out at the Experimental Garden of the Faculty of Agriculture, Udayana University from May to October 2024. The method used was a one-factor randomized block design (RAK) with three replications and three treatment levels, namely straw and rice husk biochar (Br), shell and coir biochar. coconut (Bc), and lignohumic biochar (Bl). Biochar Bc has been proven to be able to increase the weight of total grain and grain content, which shows that the use of this biochar contributes positively to rice yields. These findings emphasize the importance of choosing the right biochar raw material to increase rice productivity on contaminated land. It is hoped that this research can contribute to the management of agricultural land affected by heavy metal pollution.

Keywords: Biochar; Heavy Metal; Rice; Yield; Growth

1. Introduction

Heavy metal pollution on agricultural land, especially in the downstream area of the Badung River, is a serious concern because it can threaten plant health and the quality of agricultural products. The heavy metals lead (Pb), copper (Cu), and mercury (Hg) often accumulate in soil due to human activities, including industrial and agricultural waste. According to [5] "Soil pollution due to heavy metals can have a significant impact on plant health and the quality of agricultural products". This shows that heavy metal pollution in the planting medium can inhibit plant growth, reduce yields, and affect the quality of rice crops.

In an effort to overcome this problem, the use of biochar is an alternative that is receiving special attention. Biochar, which is produced from biomass pyrolysis, has the potential to increase soil fertility and reduce the availability of heavy metals that can be absorbed by plants.

[1] research (2015) shows that "biochar can function as a binder for heavy metals, thereby reducing the negative impact of pollution on plants." This research aims to evaluate the effect of biochar types in planting media containing heavy metals Pb, Cu and Hg on rice growth, yield and quality.

Based on this background, a research concept was developed to analyze the use of biochar types in planting media with different heavy metal contents Pb, Cu and Hg on the growth, yield and quality of rice. This is then carried out using several types of biochar, namely straw biochar, rice husks, coconut fiber biochar, coconut shells, and lignohumic biochar made from wood residues. Thus, it was found that there was an interaction between differences in the content of the

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heavy metals Pb, Cu and Hg in the planting media and types of biochar with different raw materials on the growth, yield and quality of rice as well as soil fertility.

2. Material and methods

This research was carried out at the Experimental Garden of the Faculty of Agriculture, Udayana University and the Agronomy and Horticulture Laboratory, Faculty of Agriculture, Udayana University. The materials used in this research included Inpari 32 hybrid rice seeds, coconut fiber, coconut shells, straw, husks, lignohumic biochar, soil, firewood, heavy metals Pb, Cu, and Hg, clean water, and distilled water. The tools used in this research include 27 plastic buckets with a diameter of 40 x 40 cm (7 kg), large drums for burning biochar, small shovels, plastic samples, sacks, hoes, pans, measuring cups, blenders, SPADs, Munsell Plant Tissue Color Chart, portable lux meter, analytical balance, oven, 50 mL volumetric flask, and Scanning Electron Microscope (SEM).

This research used a randomized block design (RAK) with one factor and 3 replications with 3 treatment levels, namely Br (straw and husks), Bc (coconut shells and husks), and Bl (lignohumic). The research was carried out in several stages, starting from taking soil samples in subaks downstream of the Badung River, making biochar from raw materials such as straw, husks, coconut waste through a pyrolysis process, sowing rice seeds in prepared media, preparing planting media and planting with predetermined treatment, watering and fertilizing carried out regularly and according to the needs of the plant, weeding carried out to remove weeds that can interfere with rice growth, and harvesting at the right time for optimal results.

Biochar Br and Bc are made by cutting or chopping the raw materials into small pieces and then drying them in the sun until they are completely dry. After that, biochar is made by pyrolysis at a temperature of 400^0C. The ready biochar is then analyzed using a scanning electron microscope (SEM) test to determine its physico-chemical characteristics, as well as proximate tests (moisture content, ash content, volatile content and carbon content in the biochar).

Rice seeds are sown before sowing, soaked for 48 hours (2 days) in a water solution mixed with 3 cloves of shallots and micin, then drained and left to rest for 2 days. After being cured, the seeds are sown in a nursery box for 14 days until they are ready to be transferred to the planting medium. The research was carried out in plastic buckets in the greenhouse of the Experimental Garden, Faculty of Agriculture, Udayana University, Pegok, Denpasar. 27 7 kg plastic buckets with a bucket size of 40 × 40 cm in diameter. The 7 kg plastic bucket is filled with 7 kg of planting media with a composition ratio of soil and biochar of 7 kg of soil mixed with 52.5 g of biochar (Br and Bc) and 7 g of biochar (Bl) (recommended use of biochar for rice is 10-15 tons /ha), then given a code according to the combination of soil planting media treatments with different heavy metal contents and types of biochar with different raw materials. Fertilization is carried out according to recommendations for fertilizing rice. The recommended fertilizer dose for rice plants based on Minister of Agriculture Number 22 of 2022 is a package of Phonska Plus 15-15-15 compound fertilizer doses at a dose of 400 kg/ha and urea at a dose of 100 kg/ha.

The variables observed in this research include growth, yield and quality of rice, as well as analysis of heavy metal content in soil and plants. Data obtained from observations were analyzed using analysis of variance (ANOVA) to determine the effect of the treatment given. If there is a significant difference, continue with further tests to determine the differences between treatments.

3. Results and discussion

Based on the analysis presented in Table 1, heavy metal pollution in the lower reaches of the Badung River detected the heavy metals Pb, Cu and Hg. The analysis results show that irrigation water used on agricultural land contains heavy metals Pb (0.20 mg/L), Cu (0.16 mg/L), and Hg (0.020 mg/L). The heavy metal levels obtained indicate that irrigation water originating from the lower reaches of the Badung River has been contaminated with heavy metals and could potentially damage rice plants and human health. Heavy metal levels in irrigation water that exceed the quality standard threshold can cause the accumulation of heavy metals in the soil and plants. This has the potential to disrupt the growth of rice plants and reduce the quality of rice crops.

Heavy metal levels show that farmers' land downstream of the Badung River has been contaminated with heavy metals by industrial waste and heavy metal pollution from the river. If the availability of heavy metals in the soil increases, then the heavy metals have the potential to be absorbed by plants, thus having a negative effect on human health [1]. The results of analysis on rice plant roots showed an accumulation of the heavy metal Pb of 21.60 mg/kg and Cu of 29.49

mg/kg, this shows that Cu is more easily absorbed by plant roots than the heavy metal Pb. In rice plant stover only 5.45 mg/kg of the heavy metal Cu was detected, and in rice plant seeds only 1.95 mg/kg of Cu was detected.

Table 1 Results of Analysis of Heavy Metal Content Pb, Cu, and Hg in Soil, Irrigation Water, Roots, Stoves, and Seeds of Rice Plants Before Research

No.	Heavy metal type	Unit	Results			
			Sample 1	Sample 2	Sample 3	Average
Land						
1.	Pb	mg/kg	73.47	80.15	72.59	75.43
2.	Cu	mg/kg	63.50	70.66	61.11	65.09
3.	Hg	mg/kg	18.28	18.98	15.89	17.71
Rice plant roots						
1.	Pb	mg/kg	35.38	18.31	11.08	21.59
2.	Cu	mg/kg	34.59	31.11	22.76	29.49
3.	Hg	mg/kg	nd	nd	nd	-
Rice plant stems and leaves						
1.	Pb	mg/kg	nd	nd	nd	-
2.	Cu	mg/kg	5.15	4.88	6.33	5.45
3.	Hg	mg/kg	nd	nd	nd	-
Rice seeds						
1.	Pb	mg/kg	nd	nd	nd	-
2.	Cu	mg/kg	2.21	1.72	1.93	1.95
3.	Hg	mg/kg	nd	nd	nd	-
Irrigation Water						
1.	Pb	mg/L	0.18	0.13	0.31	0.21
2.	Cu	mg/L	0.12	0.10	0.27	0.16
3.	Hg	mg/L	0.02	0.03	0.01	0.02

Information : nd = not detected

The use of biochar in planting media has been proven to increase grain yield by 12% moisture content. The results of the analysis show that the grain yield on Bc biochar is higher compared to other types of biochar. Biochar functions to increase soil moisture retention, so that plants can obtain sufficient water during their growth phase. Biochar also has a positive effect on the number of productive seedlings, because biochar increases nutrient availability and improves soil structure that supports root and vegetation growth. In this study, biochar Bl did not show a significant increase in the number of tillers, but biochar Bc and Br still showed a positive effect on plant growth. Analysis data is presented in Table 2.

Biochar contributes to increasing the total weight of grain per hill, research shows that biochar Bc is able to increase the total weight of grain per hill which has implications for increasing overall crop yields. Leaf chlorophyll content is an important indicator of plant health and photosynthetic efficiency. The use of biochar can increase leaf chlorophyll content because biochar increases nutrient availability. Overall, the use of biochar, especially biochar Bc, showed a significant influence on grain yield with a water content of 12%, number of productive tillers, total weight of grain per hill, and leaf chlorophyll content. This shows the potential of biochar as an effective soil amendment to increase agricultural productivity and crop quality.

Table 2 Average value of grain yield 12% water content, number of productive tillers, total weight of grain per hill, and leaf chlorophyll content

Treatment	Variable			
	Grain yield moisture content 12%	**Number of productive offspring**	**Total weight of grain per hill (g)**	**Chlorophyll content of leaves**
Types of biochar				
B_r	54.82 a	29.00 a	64.86 a	32.69 a
B_c	60.58 a	30.33 a	70.05 a	31.04 b
B_l	58.80 a	28.67 a	68.53 a	32.14 a
BNT 5%	9.43	3.47	9.20	1.08

Analysis data on heavy metal content in roots is presented in Table 3. The results show that the roots of rice plants accumulated heavy metals with Pb which was only detected in the Br (4.2 mg/kg) and Bl (5.4 mg/kg) biochar treatments, whereas Cu was detected in all types of treatment, the highest was in the Bc treatment (22.7 mg/kg), while the heavy metal Hg was not detected in all treatments.

The Cu levels in all biochar treatments indicate that the Br, Bc, and Bl biochar treatments allow more Cu to be absorbed into plants. This difference could be caused by the higher availability of Cu in the soil or due to the influence of biochar which is less effective in binding Cu compared to other heavy metals. The undetectable availability of the heavy metal Hg in all biochar treatments could be caused by several factors, such as the ability of biochar to bind Hg effectively or the insufficient sensitivity of the tool to detect Hg in very small concentrations.

Table 3 Analysis of heavy metals Pb, Cu, and Hg in the roots of rice plants after being treated with heavy metal and biochar injections

No.	Kode Sampel	Unit	Result			Average
			(Pb)	**(Cu)**	**(Hg)**	
	Br	mg/kg	4.2	8.9	nd	4.3
	Bc	mg/kg	nd	22.7	nd	7.5
	Bl	mg/kg	5.4	10.7	nd	5.3

Description: Analysis was carried out in the Analytical Lab, Udayana University

Data on the analysis of heavy metal content in rice plant stover are presented in Table 4. It is shown in the table that the concentration of the heavy metal Pb was only detected in the treatment with Br biochar (2.9 mg/kg). Concentrations of the heavy metal Cu were detected in almost all treatments with the highest value in Br biochar (49.9 mg/kg). Meanwhile, the heavy metal Hg was not detected in all treatments given. The highest average concentration was shown in the Br biochar treatment (17.5 mg/kg). The Br biochar treatment showed higher Pb accumulation than other biochar treatments with the highest Cu accumulation. This indicates that the biochar in this sample may be less effective in inhibiting Cu translocation from roots to other plant parts. Meanwhile, in the Bl sample the Cu content was very low, which indicates that Bl biochar is more effective in retaining Cu in the soil or reducing its availability to plants.

The levels of the heavy metal Hg in rice stover indicate that the Hg concentration in the soil may be very low or the biochar is successful in retaining and adsorbing Hg so effectively that it is not available to plants. The analysis results showed that biochar treatment had a significant influence on the accumulation of heavy metals in rice plant stover. However, their effectiveness varies depending on the type of heavy metal. The biochar treatment showed its effectiveness in inhibiting the accumulation of the heavy metal Hg, while the heavy metal Cu in some biochar treatments was still quite high.

Table 4 Analysis of heavy metals Pb, Cu, and Hg in rice plant stover after being treated with heavy metal and biochar injections

No	Sample Code	Unit	Result			Average
			(Pb)	(Cu)	(Hg)	
	Br	mg/kg	2.6	49.9	nd	17.5
	Bc	mg/kg	nd	10.6	nd	3.5
	Bl	mg/kg	nd	0.6	nd	0.2

Description: Analysis was carried out in the Analytical Lab, Udayana University

Table 5 Analysis of heavy metals Pb, Cu, and Hg in rice seeds after being treated with heavy metal and biochar injections

No	Sample Code	Unit	Result			Average
			(Pb)	(Cu)	(Hg)	
	Br	mg/kg	nd	7.4	nd	2.4
	Bc	mg/kg	nd	18.5	nd	6.1
	Bl	mg/kg	nd	61.4	nd	21.0

Description: Analysis was carried out in the Analytical Lab, Udayana University

Data analysis of heavy metal content in rice seeds is presented in Table 5. It is shown in the table that the concentrations of heavy metals Pb and Hg were not detected in all types of biochar treatment. Concentrations of the heavy metal Cu were detected in all biochar treatments, with the highest concentration value being in the Bl treatment (61.4 mg/ha) and the lowest average concentration being in the Br treatment (7.4 mg/ha).

Analysis data showing the absence of Pb in seeds indicates that biochar is more effective in reducing Pb availability, both through adsorption in the soil and by inhibiting its translocation from roots and stover to seeds. These results indicate that Pb has low mobility in the rice plant system. Bl biochar treatment showed the highest Cu accumulation in seeds. This shows that Bl biochar treatment is less effective in inhibiting Cu translocation to seeds. In contrast, the Br treatment had the lowest Cu content which may indicate a better effect of biochar in reducing Cu availability.

The heavy metal Cu which accumulates in the stover and seeds of rice plants shows that the plants have been exposed to and absorb the heavy metal Cu better than other heavy metals. This could be caused by the nature of the heavy metal Cu which is easily absorbed by plant roots. [2] stated that the heavy metal Cu absorbed by plants can disrupt plant growth, usually causing symptoms of leaf chlorosis, damage to the chloroplast structure, and electron transport in photosynthesis can also be disrupted. [4] stated that the heavy metal Cu content in roots can affect chlorophyll levels in leaves.

Biochar, rice husk and straw (Br) has the highest BAF value (0.74), indicating the efficiency of accumulation of the heavy metal Pb from soil to plants. A TF value of 0.61 indicates that Pb is quite capable of moving from the roots to the rice grains or shoots. The BAF value for the heavy metal Cu tends to be high (1.42) and has a very high TF value (6.47) which indicates that Cu is more likely to be localized to rice grains or shoots. Meanwhile, Hg metal was not detected so there was no accumulation. Biochar Br shows good ability to absorb the heavy metals Pb, Cu and Hg, but the translocation of heavy metals to plant parts that can be consumed makes it less safe for food quality.

In coconut shell and fiber biochar (Bc) the TF values for the heavy metals Pb and Cu indicate that heavy metals are not absorbed by plants. However, the BAF value for the heavy metal Cu shows an accumulation of 1.12. Meanwhile, lignohumic biochar (Bl) has a BAF value of 0.62, which indicates quite good absorption of the heavy metal Pb, but the TF value indicates no translocation to rice grains or shoots. The heavy metal Cu bioaccumulated as much as 1.55 but the TF value showed no translocation in rice seeds. The heavy metal content Hg was not detected in plant organs, this is most likely the heavy metal being absorbed by biochar or stabilized in the soil due to biochar [3]. The adsorption of heavy metals can be done through a physical adsorption process where biochar with a high surface area and porous structure allows heavy metals to enter the pores and survive physically. As for other adsorption with cation exchange capacity, when the negatively charged biochar surface attracts positively charged heavy metal ions such as Pb^{2+} and Cu^{2+} [3].

Table 6 BAF and TF Values of Heavy Metals Pb, Cu, and Hg in Rice Plants Planted with Different Types of Biochar Treatment

Types of Heavy Metals	**Concentration in Soil (mg/g)**	**Concentration in Plants (mg/g)**	**Concentration in Roots (mg/g)**	**Concentration in shoots (mg/g)**	**Nilai BAF**	**Nilai TF**
Biochar Straw and Rice Husk (Br)						
Pb	9.20	6.80	4.21	2.58	0.74	0.61
Cu	46.39	66.31	8.87	0.42	1.43	6.47
Hg	0.29	0	0	0	0	0
Biochar Fiber and Coconut Shell (Bc)						
Pb	9.89	0	0	0	0	0
Cu	46.20	51.92	22.74	0	1.12	0
Hg	0.24	0	0	0	0	0
Lignohumic (Bl)						
Pb	8.75	5.39	5.39	0	0,616	0
Cu	46.45	72.44	10.74	0	156	0,00
Hg	0.25	0	0	0	0	0

Planting media with Br biochar can support plant growth and good grain yields, however Br biochar poses a risk in terms of food safety because Br biochar is able to translocate heavy metals to parts of the rice plant, especially the rice grains that are consumed. Planting media treated with Bc biochar is more effective in stabilizing heavy metals so that they do not accumulate in plant parts, so that Bc biochar can improve the quality of rice yields. Meanwhile, planting media treated with Bl biochar is more effective in stabilizing heavy metals in the soil in the long term. The rice yields produced are not as much as other biochars, but the results are quite good without any risk of heavy metal contamination.

4. Conclusion

Based on the results of this research it can be concluded as follows:

- Rice husk and straw biochar (Br) has the ability to absorb heavy metals and Cu well (BAF), but tends to translocate heavy metals in rice grains (TF). So it is less safe for the quality of rice yields. Biochar from coconut shells and coconut fiber (Bc) is more effective in stabilizing heavy metals in the soil (low BAF and TF) so that food quality is safer. Lignohumic biochar (Bl) has the ability to stabilize heavy metals in the long term due to the low translocation of heavy metals to plant parts (low TF), so Bl is more suitable for rehabilitating contaminated soil.
- Biochar has high effectiveness in restraining the mobility of the heavy metals Pb and Hg which showed that they were not detected in all treatments. This reflects the potential of biochar to reduce health risks associated with Pb and Hg contamination in food.
- Biochar Bl (lignohumic) is more effective in stabilizing heavy metals in the soil, but is less ideal for preventing Cu accumulation in seeds, so it is more suitable for long-term soil rehabilitation rather than short-term food production.
- Ms media combined with Br biochar provides the best plant growth, but has the risk of heavy metals accumulating in the rice grains. Meanwhile, the combination of Ms media with biochar Bc and Bl provides higher food safety due to low accumulation of heavy metals in plant parts, especially rice grains.

Compliance with ethical standards

Acknowledgment

The author would like to thank Udayana University, Denpasar, Bali, for funding and support this research.

Disclosure of conflict of interest

There are no impact interests that need to be disclosed

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