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Effect of biochar type on planting media with different heavy metal containments of Pb, Cd, And Cr on growth, results and quality of padi results (*Oryza Sativa* L.)

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Abstract

Heavy metal pollution in agricultural soils has become a serious issue, especially in paddy fields located in the downstream of Tukad Badung River, Bali. This study aimed to analyze the effect of biochar types on growing media with heavy metal content of Pb, Cd, and Cr on growth, yield, and quality of rice (Oryza sativa L.). The planting medium was taken from heavy metal polluted soil in the region. The biochar used came from rice straw and husk, coconut husk and shell, and fruit and vegetable waste. The research was conducted using a one-factor randomized group design (RAK) with 27 treatment combinations (3 types of heavy metals × 3 types of biochar × 3 replications). The results showed that coir and coconut shell biochar gave the best effect in reducing heavy metal mobility in soil and increasing rice yield, with a 40% reduction in grain heavy metal content. In conclusion, biochar is an effective and environmentally friendly solution to mitigate heavy metal contaminated soil and increase agricultural productivity.

Keywords: Biochar; Heavy metals; Rice; Yield quality; Soil contamination

1. Introduction

Human-induced soil pollution is a serious challenge in modern agriculture, especially in areas close to industrial waste sources. One of the most dangerous types of pollution is the accumulation of heavy metals, such as lead (Pb), cadmium (Cd), and chromium (Cr), which originate from the disposal of textile industry waste, household waste, and excessive use of pesticides and fertilizers. The Tukad Badung River in Denpasar, Bali, is one such case, where the river water used for irrigation has been contaminated with heavy metals [10]. This condition not only reduces soil quality, but also adversely affects crop yields and human health through the food chain.

Rice (Oryza sativa L.), as one of the main commodities in Indonesia, is highly susceptible to heavy metal pollution. Rice has the ability to absorb and accumulate heavy metals from soil to plant tissues, which can reduce productivity and crop quality. As a staple food crop, the impact of this pollution is a critical issue that needs to be addressed immediately. Previous studies have shown that heavy metals such as Pb, Cd, and Cr can inhibit plant growth, reduce photosynthetic efficiency, and increase plant tissue toxicity [6].

The use of biochar has been proposed as a potential solution to address soil pollution. Biochar is solid carbon produced from pyrolysis of biomass under oxygen-limited conditions. Biochar has superior physical and chemical properties, such as high porosity, large surface area, and good cation exchange capacity, so it can adsorb heavy metals and improve soil quality. Research [1] showed that biochar from rice straw can reduce the mobility of Pb and Cr, while [5] reported that rice husk biochar can reduce the concentration of Pb and Cd in soil, thus reducing the accumulation of heavy metals in plants. However, the effectiveness of biochar is highly dependent on the raw materials and pyrolysis method used.

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This study was conducted to answer some fundamental questions related to soil pollution due to heavy metals in agricultural areas. The main focus of this study was to determine whether the level of heavy metal pollution such as lead (Pb), cadmium (Cd), and chromium (Cr) in paddy field soils in the downstream Tukad Badung River has exceeded the allowable threshold. In addition, this study also aims to test the effectiveness of using biochar in reducing the mobility of heavy metals in polluted soil and increasing the growth and yield of rice plants.

This research seeks to determine the type of biochar that is most effective in improving soil quality, increasing plant growth, and increasing crop yields. Thus, this research is expected to provide new insights related to soil pollution mitigation efforts using biochar, especially in rice field soils in the downstream area of the Tukad Badung River that have been contaminated with heavy metals.

The main objectives of this study were to analyze the level of heavy metal contamination in paddy field soils downstream of the Tukad Badung River and evaluate how different types of biochar affect the growth, yield and quality of rice plants. In addition, the study was also designed to determine the interaction between the level of heavy metal contamination and the type of biochar used, as well as its impact on the growth and yield of rice plants.

Thus, the results of this study are expected to provide practical solutions to rehabilitate heavy metal contaminated soils, support the sustainability of the agricultural sector, and provide benefits for the management of paddy fields in Bali and other areas with similar problems.

2. Methodology

The time of this research was carried out in May-October 2024, where the research sampling of irrigation water and plants before treatment was in the rice fields downstream of the Badung river. Making biochar was carried out in the Experimental Garden of the Agroecotechnology Study Program, Faculty of Agriculture, Udayana University. This study used a 1-factor Randomized Group Design (RAK) with 3 levels of biochar types with 3 types of heavy metals with 3 replications.

Sampling of heavy metal analysis of Pb, Cd, and Cr in soil, roots, stover, seeds and irrigation water of rice plants before being given biochar type treatment was carried out in the downstream area of Tukad Badung River, Denpasar, Bali, which is known to be exposed to industrial waste and household waste. This location was chosen because high levels of heavy metal pollution such as lead (Pb), cadmium (Cd) and chromium (Cr) have affected soil quality in agricultural areas. Soil samples were taken from five different locations using polluted irrigation water. Samples were collected at a depth of 0-20 cm using a sterile soil drill, and all samples were mixed homogeneously to produce a composite sample. The samples were then stored in sterile containers before being further analyzed at the Analytical Laboratory, Udayana University.

For this study, biochar was produced from three main types of raw materials: rice straw and husk, coconut husk and shell, and fruit and vegetable waste. Each feedstock was dried to a low moisture content, then processed using the pyrolysis method at 400-600°C under limited oxygen conditions. The resulting biochar was crushed into particles less than 2 mm in size to ensure uniform distribution when mixed with the growing medium.

The local rice seeds used were sown first in the nursery until they reached 21 days of age. Preparation of planting media for rice plants begins with drying the soil from 5 subak in the downstream of the Badung river that has been composited, then the dried soil is pulverized and sieved. The soil that has been finely then weighed as much as 7 kg and then put into plastic pots. The plastic pots used are 7 kg in size as many as 27 pieces. After that, it was evenly mixed with biochar as much as 52.5 grams per 7 kg of soil in accordance with the recommended use of biochar for rice which is 10-15 tons/ha. After that, a code was given according to the treatment of biochar types with different raw materials. Planting media that are given biochar and given a treatment code are watered with water to field capacity and ready for planting. The planting media was planted with rice seedlings as many as 3 seedlings per plastic pot.

Rice plants are intensively maintained. Maintenance includes fertilization, watering, soil loosening, pest and disease control, and others to ensure optimal rice growth and yield. Fertilization is carried out according to the recommendations for fertilizing rice plants. The recommended fertilizer dose for rice plants based on MOA No. 22 of 2022 is a single fertilizer dose package of Urea, TSP and KCl at a dose of 300 kg Urea/ha, 50 kg TSP/ha, and 50 kg KCL/ha respectively, or a dose package of Phonska Plus 15-15-15 compound fertilizer at a dose of 400 kg/ha and Urea at a dose of 100 kg/ha. Harvesting was done when the rice seeds were physiologically ripe, characterized by yellowing of the rice grain.

Data collected included observations on yield and quality of plant yields, namely grain yield at 12%, number of productive tillers, total grain weight per clump, and leaf chlorophyll content. To evaluate the effect of biochar on heavy metal pollution, Pb, Cd, and Cr contents were analyzed in soil before and after treatment, as well as in plant tissues such as roots, stover, and rice seeds. Analysis of heavy metal content was conducted using an atomic absorption spectrophotometer (AAS) in an accredited laboratory.

The results were analyzed statistically using analysis of variance (ANOVA) in accordance with the design used. If the interaction had a significant effect, it was followed by Duncan at the 5% level, but if the interaction had no significant effect, the effect of a single factor was tested with the BNT test at the 5% level. In addition, data from the test results of heavy metal content of Pb, Cd and Cr in the roots, stems, leaves and seeds of rice plants were compared with the quality standards of heavy metal content.

3. Results and discussion

The analytical results in Table 1 show that the soil in the downstream of Badung River contains significant concentrations of heavy metals, namely Pb at 75.43 mg/kg, Cd at 11.23 mg/kg, and Cr at 5.73 mg/kg. These high concentrations reflect the impact of pollution due to human activities, such as industrial and domestic waste, as well as the use of chemical-based fertilizers containing heavy metals. It was previously reported that domestic waste and inorganic fertilizers are one of the main sources of Cd and Pb in agricultural land, with high bioaccumulation potential in soil if not managed properly [3].

The heavy metal content in rice roots had the highest Cd content, which was 134.47 mg/kg, followed by Cr at 28.94 mg/kg, and Pb at 21.59 mg/kg (Table 1). The high content of Cd can be attributed to its more mobile nature in soil solution compared to Pb, making it easier to be absorbed by plant roots. In contrast, Pb is more likely to accumulate in the soil and is difficult to translocate to plant tissues. The absorption of heavy metals in roots is also influenced by soil pH and cation exchange capacity, which can accelerate the adsorption of certain metals in roots [3].

Heavy metals in stems and leaves shown in Table 1 were lower than in roots. Cd was detected with an average concentration of 1.73 mg/kg, while Cr amounted to 15.44 mg/kg, while Pb was not detected because it has low mobility properties.

While the content of heavy metals in rice seeds has very low levels of heavy metals. Cd was detected with an average concentration of 0.11 mg/kg, Cr was 0.61 mg/kg, and Pb was not detected (Table 1). Plant mechanisms that prevent heavy metal transport to seeds are important protective measures for food safety. However, the presence of Cd, although small, remains a concern due to its properties that can accumulate in the food chain and potentially endanger human health in long-term consumption [8].

Irrigation water used for irrigating rice fields showed Pb content of 0.21 mg/kg, Cd of 0.02 mg/kg, and Cr of 0.04 mg/kg. Although the concentration is lower than that of soil, irrigation water remains a potential pathway for heavy metal transfer to soil and plants. This is in line with reports that irrigation with heavy metal contaminated water can increase the accumulation of heavy metals in agricultural ecosystems in the long term [8].

Table 1 Results of Heavy Metal Analysis of Pb, Cd, and Cr in Soil, Roots, Stover, Seeds, and Irrigation Water of Rice Plants Before Treatment

No.	**Types of heavy metals**	**Unit**	**Results**			
			Sample 1	**Sample 2**	**Sample 3**	**Average**
Soil						
	Pb	mg/kg	73.48	80.15	72.58	75.43
	Cd	mg/kg	11.13	11.51	11.05	11.23
	Cr	mg/kg	5.53	5.94	5.71	5.73
Rice roots						
	Pb	mg/kg	35.38	18.31	11.08	21.59
	Cd	mg/kg	156.71	135.85	110.80	134.47

	Cr	mg/kg	36.67	31.40	18.77	28.94
Rice stem + leaf						
	Pb	mg/kg	ttd	ttd	Ttd	-
	Cd	mg/kg	1.72	1.18	2.30	1.73
	Cr	mg/kg	13.38	15.71	17.23	15.44
Rice seeds						
	Pb	mg/kg	ttd	ttd	ttd	-
	Cd	mg/kg	0.11	ttd	Ttd	0.11
	Cr	mg/kg	ttd	0.99	0.82	0.61
Irrigation water						
	Pb	mg/L	0.18	0.14	0.31	0.21
	Cd	mg/L	0.02	0.01	0.03	0.02
	Cr	mg/L	0.03	0.03	0.06	0.04

Description: Spectrometric analysis method, carried out at the Unud Integrated Lab; Room conditions during analysis: temperature 20 ± 2 0C, humidity 60 ± 10%; ttd = not detected, test detection limit for Pb = 0.0170 mg/kg, Cd = 0.0010 mg/kg, Cu = 0.0070 mg/kg, Cr = 0.0019 mg/kg, and Hg = 0.0019 mg/kg.

The utilization of biochar as an organic material resulting from agriculture that can be utilized optimally so that it has a long-term influence in dealing with environmental pollution, especially heavy metals. The utilization of biochar as a solution to adsorb heavy metals has a significant effect, this can be shown in Table 2 in affecting the growth, yield and quality of rice yields.

Table 2 Grain analysis results of 12% moisture content, number of productive tillers, total grain weight per clump, and leaf chlorophyll content after the treatment of biochar type and type of planting media

Treatment	**Variables**			
	Grain analysis results of 12% moisture content (ton/Ha)	**Number of productive tillers**	**Total grain weight per clump (g)**	**Leaf Chlorophyll Content (SPAD)**
Types of biochar				
B_r	54.82 b	29.00 a	64.86 a	32.69 a
B_c	60.58 a	30.33 a	70.05 a	31.04 b
B_w	55.75 b	30.78 a	65.01 a	31.64 ab
BNT 5%	4.59	2.77	5.19	1.20

Biochar type Bc produced the highest grain yield of 12% water content (60.58 g), significantly different from biochar types Br (54.82 g) and Bw (55.75 g). These results indicate that biochar type Bc has a better ability to support rice productivity, this is due to its properties that can increase nutrient availability and improve soil physical and chemical properties. This biochar may have a higher cation exchange capacity (CEC), thus increasing the efficiency of nutrient uptake by plants.

Total grain weight per clump also showed a similar pattern, where biochar type Bc gave the highest yield (70.05 g), significantly different from other types of biochar. This suggests that Bc type biochar not only supports greater grain yield, but also has a direct influence on panicle filling and the efficiency of resource conversion into productive biomass.

The highest leaf chlorophyll content was found in biochar type Br (32.69), significantly different from biochar Bc (31.04), but not significantly different from biochar Bw (31.64). Higher chlorophyll content reflects better photosynthetic efficiency, which can contribute to plant vegetative growth. However, the high chlorophyll content in Br biochar was not directly reflected in grain yield, suggesting that this type of biochar supports physiological growth rather than direct crop yield.

Biochar has an important role in improving soil properties and supporting plant growth. Biochar types, such as BC, show advantages in supporting rice yield and quality, through increased nutrient utilization efficiency and improved root environment quality. Thus, the selection of the appropriate type of biochar is an important step in efforts to increase the productivity and quality of rice yields.

The results of heavy metal analysis of Pb, Cd, and Cr in the roots of rice plants after biochar treatment and heavy metal injection showed significant differences based on the type of biochar used. Table 3 shows that rice roots treated with biochar from rice straw and husk (Br) had the highest accumulation of heavy metals with an average of 1.83 mg/kg. In contrast, biochar from coconut husk and shell (Bc) showed the lowest accumulation of heavy metals with an average of 0.33 mg/kg, while biochar from fruit and vegetable waste (Bw) was in the middle position with an average of 0.55 mg/kg. This variation suggests that the type of biochar feedstock plays an important role in determining the effectiveness of biochar in stabilizing heavy metals in the soil environment.

Biochar from rice straw and husk (Br) showed the highest accumulation of heavy metals in the roots of rice plants. This may be due to the characteristics of these biochars which have a lower adsorption capacity for heavy metals compared to other types of biochars. Rice husk generally has a high carbon content, but its porosity and surface area may not be optimal enough to adsorb heavy metals maximally. In addition, rice straw can be high in silica, which may affect the interaction between biochar and heavy metals. The high accumulation of heavy metals in these plants indicates that biochar from rice straw and husk may be less effective to stabilize heavy metals in polluted soil. Research by [11] also supports this finding, where rice husk biochar is known to have heavy metal sorption capacity that depends on the management of its physical and chemical structure.

Biochar from coconut husk and shell (Bc) has the lowest average accumulation of heavy metals, which is 0.33 mg/kg. This indicates that this type of biochar is very effective in stabilizing heavy metals in the soil. Biochar from coconut husk and shell generally has a large surface area and high porosity, which allows for more efficient adsorption of heavy metals. In addition, the activated carbon content in this biochar can increase the cation exchange capacity, thereby reducing the mobility of heavy metals in the soil. Previous research by [12] showed that biochar with these physical and chemical properties can significantly reduce heavy metal uptake by plants. These findings confirm that coir and coconut shell biochar has great potential as a remediation agent for heavy metal contaminated soil.

Biochar from fruit and vegetable waste (Bw) showed moderate performance with an average heavy metal accumulation of 0.55 mg/kg. This performance can be explained by the composition of biochar derived from organic waste with varying carbon content. Fruit and vegetable waste usually produces biochar with lower porosity and surface area than biochar from coconut shell, but higher than biochar from rice husk. In addition, the content of certain minerals in these biochars may affect their ability to adsorb heavy metals. Research by [12] also indicated that biochar from mixed organic materials has a performance that depends on the pyrolysis process and the quality of the feedstock. With a performance that falls between Br and Bc, biochar from fruit and vegetable waste can be considered a good alternative, although not as effective as biochar from coconut husk and shell.

This difference in heavy metal accumulation in rice plants can be explained by the different physical and chemical properties of biochar. Biochar from rice husk and coconut shell has greater surface area and porosity than biochar from fruit and vegetable waste. These properties allow biochar to more effectively adsorb heavy metals from the soil solution and prevent them from being absorbed by plants. In addition, the mineral and ash content in biochar can affect soil pH, which in turn affects the availability of heavy metals in the soil.

Table 3 Results of Heavy Metal Analysis of Pb, Cd, and Cr in the Roots of Rice Plants After Biochar Treatment and Heavy Metal Injection

No.	Sample Code	Methods	Unit	Results			Average
				Pb	Cd	Cr	
1.	Br	Spektrometri	mg/kg	4.21	0.42	0.84	1.83
2.	Bc	Spektrometri	mg/kg	0.00	0.01	0.97	0.33
3.	Bw	Spektrometri	mg/kg	0.17	0.09	1.37	0.55

Description: Analysis conducted at Analytical Lab, Udayana University

The results of this study have important implications in the management of heavy metal-contaminated soils. The use of biochar from certain raw materials, such as coconut husks and shells, can be an effective solution to reduce heavy metal accumulation in food crops. However, further research is needed to understand the specific mechanisms involved in the interaction between biochar, heavy metals and rice plants. In addition, the long-term effects of biochar application on soil quality and crop yields also need to be explored.

Table 4 and Table 5 show the results of the analysis of heavy metal content of Pb, Cd, and Cr in rice plant stover and seeds after treatment with biochar from various raw materials. These results provide an overview of the ability of biochar to adsorb heavy metals and prevent their accumulation in rice plants, which is an important indicator in mitigating soil pollution and food safety.

The analysis showed that biochar from rice straw and husk (Br) had the highest accumulation of heavy metals in the stover with an average of 1.39 mg/kg. Meanwhile, in rice seeds, the average accumulation of heavy metals was recorded at 0.44 mg/kg. The high accumulation of heavy metals in the stover compared to seeds indicates that most of the heavy metals are trapped in plant tissues that are not directly involved in seed formation. The characteristics of Br biochar, such as less than optimal porosity and high silica content, might affect its effectiveness in stabilizing heavy metals in soil. Research by [11] supports these results by mentioning that rice husk biochar has varying heavy metal sorption capacity depending on the pyrolysis process and physicochemical properties.

In addition, the higher distribution of heavy metals such as Pb in the stover suggests that this biochar may not be effective enough in preventing heavy metal translocation from soil to plant tissues. In the context of food safety, these results emphasize the importance of selecting biochar types that are more effective in reducing heavy metal accumulation in consumable plant parts.

Biochar from coconut husk and shell (Bc) showed the best results in suppressing heavy metal accumulation, both in the stover (average 0.63 mg/kg) and seeds (average 0.24 mg/kg). This effectiveness can be explained by the physical and chemical properties of Bc biochar, such as high surface area and activated carbon content that can increase cation exchange capacity. [12] stated that biochar with such characteristics can significantly stabilize heavy metals by reducing their mobility in the soil. The absence of heavy metals Pb and Cd in the results of the analysis of stover and seeds indicates that biochar Bc is able to bind these two types of heavy metals very well, thus preventing their accumulation in plant tissues. These results are relevant to research by [4], who found that coconut-based biochar has a high ability to stabilize heavy metals thanks to its pore structure and mineral content that supports heavy metal sorption.

Biochar from fruit and vegetable waste (Bw) showed moderate performance in suppressing heavy metal accumulation. In the stover, the average accumulation of heavy metals was 0.41 mg/kg, while in the seeds it was only 0.15 mg/kg. This performance indicates that Bw biochar has a better ability to absorb heavy metals than Br, but still below Bc. Organic wastes such as fruits and vegetables produce biochar with high carbon content, but the pore structure and surface area may not be as optimal as biochar from coconut shells. The absence of Pb and Cd in the stover and seeds suggests that this biochar is able to reduce the translocation of both heavy metals, although its effectiveness against Cr is still lower than Bc. Research by [7] indicated that biochar from mixed organic waste can perform well depending on the raw materials and pyrolysis process, which is in line with the results of this study.

The results in Table 4 and Table 5 show that the type of biochar affects the accumulation of heavy metals in rice plant tissues. Biochar from coconut husk and shell proved to be the most effective in reducing heavy metal accumulation in rice plant stover and seeds, making it the best choice for remediation of polluted soil. Research by [12] and [4] supports this finding by mentioning that coconut-based biochar has a high capacity in stabilizing heavy metals through unique physical and chemical mechanisms.

In contrast, biochar from rice straw and husk showed less than optimal performance, which may be due to their less favorable physical and chemical properties. This underscores the importance of biochar feedstock selection based on the specific needs of environmental remediation. Further research is needed to explore the interaction mechanism between biochar, heavy metals and plants and to optimize the biochar production process to make it more effective.

Table 4 Results of Heavy Metal Analysis of Pb, Cd, and Cr in Rice Plant Stover After Biochar Treatment and Heavy Metal Injection

No	Sample Code	Method	Unit	Results			Average
				Pb	Cd	Cr	
1.	Br	Spektrometri	mg/kg	2.58	0.34	1.39	1.39
2.	Bc	Spektrometri	mg/kg	0.00	0.00	0.63	0.63
3.	Bw	Spektrometri	mg/kg	0.00	0.00	0.41	0.41

Description: Analysis was conducted at Analytical Lab, Udayana University

Table 5 Results of Heavy Metal Analysis of Pb, Cd, and Cr in Rice Plant Seeds After Biochar Treatment and Heavy Metal Injection

No	Sample Code	Method	Unit	Results			Average
				Pb	Cd	Cr	
1.	Br	Spektrometri	mg/kg	0.00	0,07	0,44	0,44
2.	Bc	Spektrometri	mg/kg	0.00	0.00	0,24	0,24
3.	Bw	Spektrometri	mg/kg	0.00	0.00	0,15	0,15

Description: Analysis was conducted at Analytical Lab, Udayana University

Heavy metal concentrations in soil, plants, roots, and shoots, as well as Bioaccumulation Factor (BAF) and Translocation Factor (TF) values produced by the three types of biochar (rice straw and husk, coconut husk and shell, and fruit and vegetable waste) provide an in-depth picture of the effectiveness of biochar in managing heavy metal contamination in soil and plants.

The calculation of bioaccumulation factor (BAF) and translocation factor (TF) shown in Table 6 revealed differences in the effectiveness of biochar types towards stabilization of heavy metals Pb, Cd, and Cr in rice plants. This detailed analysis discusses the capabilities of each biochar, supported by relevant research references.

In the treatment with Br biochar, the highest BAF value was recorded for Cd metal (2.72), followed by Pb (0.74) and Cr (0.54). This indicates that Cd metal is more easily accumulated in plant tissues, while Cr metal tends to have higher mobility, as indicated by the TF value of 2.18. The high TF value for Cr indicates that this metal is more easily translocated from the roots to the shoots.

The characteristics of biochar from rice straw and husk, such as relatively low carbon content and less than optimal pore structure, may limit the binding capacity of heavy metals. Research by [9] states that agricultural waste-based biochar often has a heavy metal sorption capacity that depends on the degree of pyrolysis and ash content. Thus, the effectiveness of Br biochar can still be improved through modification of the production process, such as increasing the pyrolysis temperature.

Biochar from coconut husk and shell showed the highest effectiveness in suppressing heavy metal accumulation and translocation. The BAF values for Pb and Cd were 0.00, indicating that these biochars successfully reduced the bioavailability of these metals significantly. Even for Cr, the BAF value of only 0.36 indicates excellent sorption capacity.

This effectiveness is supported by the physical and chemical properties of Bc biochar, such as large surface area and high active carbon content. In a study by [13], coconut-based biochar was reported to have high adsorption power towards heavy metals due to the presence of active functional groups that increase the affinity towards metal ions. The low TF values (below 1 for all metals) also indicate the biochar's ability to suppress metal mobility from the roots to the shoots.

In the fruit and vegetable waste biochar, the BAF values for Cd (0.28) and Cr (0.40) indicated moderate accumulation capacity. Meanwhile, the TF value for Cr (0.41) was lower than that of Br, indicating that Bw biochar was more effective in inhibiting the translocation of these metals. However, the BAF and TF values for Pb metal were very low (0.02 and 0.00), indicating the good ability of this biochar in suppressing Pb mobility.

Biochar from fruit and vegetable waste tends to have high carbon content, but its pore structure and stability may be lower than biochar from hard materials. This is consistent with the findings of [2], which states that biochar from organic waste is more effective for certain heavy metals depending on its chemical structure and manufacturing process.

The results of this study confirmed that coir and coconut shell biochar had the highest effectiveness in reducing heavy metal bioavailability and translocation. Research by [13] and [2] supports these findings, highlighting the superiority of coconut-based biochar in stabilizing heavy metals. In contrast, biochar from rice straw and husk showed less than optimal results, while fruit and vegetable waste biochar gave moderate results.

This study highlights the importance of biochar type selection based on physical and chemical properties and specific remediation needs. Further modifications to the biochar production process could improve the efficiency of heavy metal stabilization and provide a sustainable solution to soil pollution problems.

Table 6 Calculation Results of Bioaccumulation Factor and Translocation Factor of Heavy Metals Pb, Cd, and Cr in Rice Plants After Biochar Treatment and Heavy Metal Injection

Type of Heavy Metal	Concentration in soil (mg/g)	Concentration in Plants (mg/g)	Concentration at the Root (mg/g)	Concentration at the shoot (mg/g)	Value BAF	Value TF
Biochar Rice straw and husk (Br)						
Pb	9.20	6.80	4.21	2.59	0.74	0.61
Cd	0.31	0.84	0.42	0.42	2.72	0.98
Cr	4.98	2.67	0.84	1.83	0.54	2.18
Biochar coconut husk and shell (Bc)						
Pb	9.88	0.00	0.00	0.00	0.00	0.00
Cd	0.39	0.01	0.01	0.00	0.02	0.00
Cr	5.16	1.84	0.97	0.87	0.36	0.90
Biochar Fruit and Vegetable Waste (Bw)						
Pb	8.61	0.17	0.17	0.00	0.02	0.00
Cd	0.32	0.09	0.09	0.00	0.28	0.00
Cr	4.86	1.94	1.37	0.56	0.40	0.41

4. Conclusion

This study provides a comprehensive overview of the effectiveness of biochar in reducing heavy metal pollution (Pb, Cd, and Cr) in soil and rice plants, and its impact on plant growth and yield. Based on the results of the study, it was found that the type of biochar used had a significant effect on heavy metal accumulation in plant tissues, plant productivity, and crop safety.

Biochar from coconut husk and shell (Bc) proved to be the most effective type of biochar in suppressing heavy metal accumulation in plant tissues. This is indicated by very low Bioaccumulation Factor (BAF) and Translocation Factor (TF) values for Pb and Cd metals, and moderate BAF and TF values for Cr metals. The ability of Bc biochar in reducing heavy metal mobility can be attributed to its physical and chemical properties, such as large surface area, high activated carbon content, and superior cation exchange capacity. In addition, Bc biochar also contributed significantly to the increase in rice yield, with the highest grain yield of 60.58 tons/ha. This effectiveness makes Bc biochar a top choice in mitigating heavy metal-contaminated soil while increasing agricultural productivity.

In contrast, biochar from rice straw and husk (Br) showed less than optimal performance. The high BAF value for Cd metal indicates that this type of biochar tends to be less effective in suppressing heavy metal accumulation in plant tissues. In addition, the high TF value for Cr metal indicated that Br biochar was not effective enough in preventing heavy metal translocation from roots to shoots. The characteristics of Br biochar, such as suboptimal pore structure and high silica content, are thought to be limiting factors in its ability to adsorb heavy metals efficiently. Nevertheless, Br biochar can still be used as an alternative with potential that can still be improved through modification of the production process, such as increasing the pyrolysis temperature.

Biochar from fruit and vegetable waste (Bw) showed moderate performance, with better ability to suppress heavy metal accumulation than Br, but still below Bc. The BAF values for Pb and Cd metals were quite low, indicating the effectiveness of Bw biochar in suppressing the mobility of these metals in the soil. However, the TF value for Cr metal which was higher than Bc indicated that this biochar still had limitations in preventing heavy metal translocation to upper plant tissues. The lower pore structure and chemical stability of Bw biochar compared to Bc may be one of the reasons for this limitation. Nevertheless, Bw biochar can still be considered as a viable alternative, especially for soils with less heavy metal contamination.

The results also showed that the heavy metal content in rice seeds was very low, especially for Pb and Cd, with undetectable values in some treatments. This phenomenon indicates the existence of a natural mechanism in rice plants that prevents the transport of heavy metals to seeds, thus providing food safety assurance. The presence of biochar as a soil ameliorant further strengthens this mechanism by reducing the bioavailability of heavy metals in the soil.

In conclusion, this study confirms that biochar has great potential as an environmentally friendly solution to address soil pollution due to heavy metals and improve agricultural yields. Biochar from coconut husk and shell (BC) is recommended as the top choice due to its high effectiveness in stabilizing heavy metals and supporting crop productivity. However, this study also revealed that the effectiveness of biochar is highly dependent on the raw materials and production methods. Therefore, modifications to the biochar production process, such as pyrolysis temperature adjustment and pore structure optimization, need to be carried out to improve its performance. Further research is also needed to evaluate the long-term effects of biochar application on soil quality and agricultural yields, and to ensure its sustainable use in mitigating soil pollution and supporting food security.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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