GSC Biological and Pharmaceutical Sciences
eISSN: 2581-3250 CODEN (USA): GBPSC2
Cross Ref DOI: 10.30574/gscbps
Journal homepage: https://gsconlinepress.com/journals/gscbps/

(Research Article)

Check for updates

Effect of Biochar Type on Planting Media Contaminated with Heavy Metals Pb, Cd, and Cu on Growth and Yield of Rice (*Oryza sativa* L.) as well as Bioaccumulation Factor and Translocation Factor

Oktavia Deni Ella Damanik, I Nyoman Rai * and Ni Nyoman Ari Mayadewi

Department of Agroecotechnology, Faculty of Agriculture, Udayana University, Indonesia.

GSC Biological and Pharmaceutical Sciences, 2025, 30(03), 083-093

Publication history: Received on 12 January 2025; revised on 01 March 2025; accepted on 03 March 2025

Article DOI: https://doi.org/10.30574/gscbps.2025.30.3.0072

Abstract

Most people around the world, especially Indonesia, use rice (*Oryza sativa* L.) as a staple food. Rice plants from agricultural land downstream of the Badung River are suspected to have indications of heavy metal contamination due to pollution of the Badung River which is used as irrigation in Subak Kerdung agricultural land. This study aims to evaluate the effect of various types of biochar on planting media polluted with heavy metals on growth, yield, Bioaccumulation Factor (BAF), and Translocation Factor (TF) in rice plants. This study used a 3-level Randomized Group Design (RAK) of biochar types (rice straw and husk, fruit and vegetable waste, and lignohumic from wood waste) with 9 replications. The results showed that rice plants obtained from Subak Kerdung agricultural land showed that rice plants detected heavy metal content of Pb, Cd and Cu exceeded the maximum limit of heavy metals allowed in plants according to WHO (World Health Organization). Biochar is able to significantly reduce heavy metal levels in the growing media. Lignohumic-based biochar proved to give better results in increasing rice yield. Cu metal consistently had the highest accumulation ability (BAF) and translocation (TF) across biochar treatments and tended to be more easily absorbed and translocated by plants. In contrast, Pb metal showed the lowest bioaccumulation and translocation values, indicating that it is relatively difficult to be accumulated by plants, and its distribution from roots to shoots is very limited.

Keywords: Rice; Heavy metals; Biochar; BAF; TF

1. Introduction

Contaminants that are increasingly found in soil, especially in agricultural land, are heavy metals. Many risks arise from heavy metal contamination, such as soil pollution and food safety and quality [3,16]. Heavy metal contaminants that contaminate the soil will then contaminate all plants that grow on the contaminated soil and will accumulate these metals in the roots, stems, leaves and fruit [1]. Most people around the world, especially Indonesia, use rice (*Oryza sativa* L.) as a staple food. Optimal rice production is essential for national food security. In particular, to determine the ability of plants to transfer heavy metals, translocation and bioaccumulation values in plants can be calculated. The results of bioaccumulation (BAF) and translocation (TF) analysis of heavy metals showed variations in the accumulation efficiency and distribution of heavy metals in plants.

Based on the results of previous research, the results of the analysis of rice plant samples obtained from Subak Kerdung farmland showed that rice plants detected heavy metal content of Pb with an average value of 5.488 mg/kg; Cu 42.605 mg/kg; Cd 0.088 mg/kg [13]. The content of heavy metals detected in rice plants cultivated in Subak Kerdung farmland exceeds the maximum limit of heavy metals allowed in plants [15].

* Corresponding author: I Nyoman Rai

One of the soil improver products is biochar. Biochar, which is made from agricultural biomass as raw material, is a cheap and effective activated carbon in absorbing heavy metal contaminants in soil and plants [11]. In previous studies, it was stated that raw materials and pyrolysis conditions (temperature, time, etc.) can affect stability and nutrient content [5]. Biochar obtained from different raw materials shows very different physical and chemical properties [10]. Based on this statement, the selection of biomass types as biochar raw materials currently needs to be a concern. Because each biomass has a different chemical compound content that certainly needs consideration of the selection of the conversion process and processing technology so that an optimal product will be produced according to its designation. Therefore, this study was conducted to evaluate the effect of biochar type on heavy metal contaminated growing media on growth, yield, and bioaccumulation and translocation of heavy metals in rice plant organs. The results of this study are expected to provide ecological and practical solutions to increase the productivity of rice plants in heavy metal contaminated land.

2. Material and methods

2.1. Place and Time of Research

The research was conducted at the Experimental Garden of the Faculty of Agriculture, Udayana University, Pegok, Denpasar. Then further studied in the Agronomy and Horticulture Lab of Udayana University from May to October 2024. This study used Randomized Group Design (RAK) 3 levels of biochar types with 9 replications. The treatment was the type of biochar (B), which consisted of Br: Biochar of rice straw and husk, Bw: Fruit and vegetable waste biochar, Bl: Lignohumic biochar from wood waste.

2.2. Manufacture of biochar

Biochar from different raw materials for straw husk biochar (Br) and vegetable fruit biochar (Bw) were made according to Wedayani's method [11], while Lignohumic biochar is biochar that is already available on the market and obtained from Russia under the trade name Lignohumate. Biochar Br and Bw are made by cutting/shredding small pieces of raw material and then dried by drying in the sun until completely dry. After that, biochar is made by pyrolyzing at 400°C. The pyrolysis process is carried out manually using the pyrolysis method in stages. The charcoal produced from the pyrolysis process is then pulverized by pounding using lumping or using a *blender* according to the condition of the raw material. The smooth charcoal is then activated using $CaCl_2$ solution so that it becomes biochar. Biochar that is ready is then analyzed using the *Scanning Electron Microscope (SEM)* test to determine its physico-chemical characteristics, as well as proximate tests (water content, ash content, volatile content and carbon content in biochar). SEM tests were carried out on each type of biochar using a voltage of 5.0 kV, an average working distance of 10.5 mm, a current probe of 30 and varying magnification at MERO Foundation. Proximate tests were conducted using ASTM D7582 MVA at the Engineering Laboratory, Faculty of Engineering, Udayana University.

2.3. Seed sowing

Rice seeds before sowing are soaked for 48 hours in a 500 ml water solution that has been mixed with 3 cloves of onion and *monosodium glutamate* (MSG). The soaked seeds were then drained and tended for 2 days. After maturing, the seeds were sown in a nursery box for 21 days.

2.4. Media preparation

Preparation of planting media for rice plants begins with drying the soil from 5 subak in the downstream Badung river that has been composited, then the dried soil is mashed 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.

2.5. Maintenance

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 is done when the rice seeds are physiologically ripe, characterized by yellowing of the rice grain.

3. Observation Variable

3.1. Results of Analysis of Heavy Metal Content of Pb, Cu and Cd in Soil, Irrigation Water and Rice Plant Organs from Subak in the Lower Badung River

Phase I of the research involved surveying and sampling soil, irrigation water and rice plants in Subak-subak that utilize the downstream Badung River water as a source of irrigation. The samples were then analyzed to detect the metal content of lead (Pb), cadmium (Cd) and copper (Cu). The testing of heavy metal content was conducted at the Analytical Laboratory of Udayana University.

3.2. Results of Analysis of Heavy Metal Content of Pb, Cd and Cu in Soil and Plant Organs after Biochar Treatment and Heavy Metal Injection

Measurement of heavy metal content in soil, roots, stover and seeds after biochar treatment aims to evaluate the accumulation and distribution of heavy metals and the effectiveness of biochar in reducing pollution during the study.

3.3. Results of the Effect of Biochar Treatment and Heavy Metal Injection on Growth and Yield of Rice

3.3.1. Plant height

Plant height was observed every 2 weeks until maximum height. The first observation was 2 weeks after the seedlings were planted (MSBD).

3.3.2. Total grain weight per clump (g)

Total grain weight per clump is the total weight of grain produced by one clump of rice plants, including filled grain (which contains seeds) and empty grain (which does not contain seeds). This parameter is used to measure the productivity of rice plants in a clump as an indicator of yield.

3.3.3. Grain yield at 12% moisture content (g)

Yield of 12% moisture content grain per pot is measured after drying 12% moisture content grain or can be converted from harvested dry grain yield using the formula.

3.4. Bioaccumulation factor (BAF)

Bioaccumulation factor of rice plants to heavy metals Pb, Cd, and Cu. Can be calculated by the formula

$$\mathrm{BAF} = \frac{\text{Kandungan Logam Berat Tanaman}}{\text{Kandungan Logam Berat Tanah}}$$

3.5. Translocation factor (TF)

Translocation factor of rice plants to heavy metals Pb, Cd, and Cu. Can be calculated by the formula

$$\mathrm{TF} = \frac{\text{Kandungan Logam Berat batang atau biji}}{\text{Kandungan Logam Akar}}$$

4. Results and discussion

4.1. Results of Heavy Metal Content Analysis of Pb, Cu and Cd in Soil, Irrigation Water and Rice Plant Organs from Subak in the Lower Badung River

The test results of heavy metal content of Pb, Cu and Cd in soil showed the highest levels of heavy metals in the soil were Pb with an average of 75.428 mg/kg while the lowest levels were found in Cd with an average of 11.231 mg/kg. In the roots of rice plants, the heavy metal with the highest concentration was Cd with an average of 134.466 mg/kg while the lowest level was Pb with an average of 21.591 mg/kg. Meanwhile, in rice stover, the highest metal content was found in Cu with an average of 5.453 mg/kg, while the lowest metal was Cd with an average of 1.734 mg/kg. For rice seeds, the highest heavy metal content was also Cu with an average of 1.955 mg/kg, while Cd had the lowest level with an average of 0.109 mg/kg. In irrigation water, the dominant heavy metal is Pb with an average of 0.208 mg/kg, while the lowest level is Cd with an average of 0.019 mg/kg. The complete test results are shown in Table 1 below.

Table 1 Levels of Heavy Metals Pb, Cu and Cd in Soil, Irrigation Water and Rice Plant Organs Before the Study

No.	Type of heavy metal	Unit	Results			
			Sample 1	Sample 2	Sample 3	Average
Soil sample						
1	Pb	mg/kg	73.476	80.150	72.583	75.428
2	Cd	mg/kg	11.132	11.511	11.050	11.231
3	Cu	mg/kg	63.506	70.662	61.109	65.092
Rice root sample						
1	Pb	mg/kg	35.383	18.311	11.080	21.591
2	Cd	mg/kg	156.712	135.854	110.801	134.466
3	Cu	mg/kg	34.595	31.108	22.759	29.487
Rice stem and leaves sample						
1	Pb	mg/kg	ND	ND	ND	-
2	Cd	mg/kg	1.724	1.182	2.296	1.734
3	Cu	mg/kg	5.155	4.874	6.329	5.453
Rice seed sample						
1	Pb	mg/kg	ND	ND	ND	-
2	Cd	mg/kg	0.109	ND	ND	0.109
3	Cu	mg/kg	2.215	1.724	1.926	1.955
Irrigation water sample						
1	Pb	mg/kg	0.182	0.135	0.308	0.208
2	Cd	mg/kg	0.017	0.014	0.027	0.019
3	Cu	mg/kg	0.119	0.100	0.272	0.164

Description: Spectrometric analysis method, carried out in the Integrated lab. Room conditions at the time of analysis: temperature 20 ± 2 0C, humidity 60 ± 10%. ND = not detected, test detection limit for Pb = 0.0170 mg/kg, Cd = 0.0010 mg/kg, Cu = 0.0070 mg/kg

4.2. Results of Analysis of Heavy Metal Content of Pb, Cd and Cu in Soil and Plant Organs after Biochar Treatment and Heavy Metal Injection

4.2.1. Heavy metal content of Pb, Cd and Cu in soil after biochar treatment

The results of the analysis of total heavy metal content in rice-planting soil showed that the highest heavy metal content was Cu, followed by Pb, and the lowest was Cd in all types of biochar. The highest average Cu content was found in lignohumic, which amounted to 46.454 mg/kg, followed by biochar straw and rice husk with an average of 46.391 mg/kg, while the lowest Cu content was found in fruit and vegetable waste biochar with an average of 45.494 mg/kg. For Pb content, rice straw and husk biochar has the highest value with an average of 9.199 mg/kg, compared to lignohumic which has an average of 8.756 mg/kg, while the lowest Pb content is found in fruit and vegetable waste biochar with an average of 8.608 mg/kg. The Cd content showed that lignohumic had the highest content with an average of 0.368 mg/kg, followed by fruit and vegetable waste biochar with an average of 0.321 mg/kg, and the lowest Cd content was found in straw and rice husk biochar with an average of 0.309 mg/kg.

Table 2 Total Heavy Metal Content of Pb, Cd and Cu in Soil After Rice Cultivation Research

No.	Type of heavy metal	Unit	Total heavy metals			
			Sample 1	Sample 2	Sample 3	Average
Biochar of Straw and Rice Husk						
1	Pb	mg/kg	8.930	8.751	9.918	9.199
2	Cd	mg/kg	0.324	0.322	0.282	0.309
3	Cu	mg/kg	47.483	45.338	46.354	46.391
Biochar of Fruit and Vegetable Waste						
1	Pb	mg/kg	9.140	8.267	8.419	8.608
2	Cd	mg/kg	0.216	0.328	0.421	0.321
3	Cu	mg/kg	45.376	45.059	46.048	45.494
Lignohumic Biochar						
1	Pb	mg/kg	9.097	8.214	8.958	8.756
2	Cd	mg/kg	0.363	0.359	0.384	0.368
3	Cu	mg/kg	45.735	47.397	46.230	46.454

Description: Analyses were conducted at the Soil Science Lab, Faculty of Soil Science, Moscow State University, Russia.

4.3. Heavy metal content of Pb, Cd and Cu in rice plant organs after biochar treatment and heavy metal injection

4.3.1. Rice Root

Sample Bl had the highest Pb content of 5.395 mg/kg, followed by Br with 4.211 mg/kg. The lowest Pb content was found in Bw, which was 0.173 mg/kg. The highest Cd content was found in Bl, which was 0.546 and the lowest was found in Bw, which was 0.090 mg/kg. The highest Cu content was found in Bw, which was 11.755 mg/kg, followed by Bl (10.738 mg/kg) and the lowest Cu content was found in Br (8.872 mg/kg). The content of heavy metals Pb, Cd and Cu in rice roots after the study can be seen in Table 4 below.

Table 3 Content of Heavy Metals Pb, Cd and Cu in Rice Roots after the Study

Metal	Br	Bw	Bl
Pb	4.211	0.173	5.395
Cd	0.424	0.090	0.546
Cu	8.872	11.755	10.738

4.3.2. Rice Stover

Table 4 Heavy Metal Content of Pb, Cd and Cu in Rice Stover After the Study

Metal	Br	Bw	Bl
Pb	2.586	0.000	0.000
Cd	0.340	0.000	0.000
Cu	49.994	65.772	0.214

Sample Br has the highest Pb content, which is 2.586 mg/kg, while the Pb content in samples Bw and Bl was not detected (0 mg/kg). Sample Br has the highest Cd content, which is 0.34 mg/kg, while the Cd content in samples Bw and Bl was not detected (0 mg/kg). Sample Bw had the highest Cu content, at 65.772 mg/kg, followed by Br (49.994 mg/kg), while the lowest Cu content was found in Bl (0.214 mg/kg).

4.3.3. Rice Seeds

No Pb content was detected in all biochar treatments at the Br, Bw and Bl levels. Cd content was detected only in the Br sample, with a value of 0.078 mg/kg, while no Cd content was detected in the Bw and Bl samples (0.00 mg/kg). The highest Cu content was found in the Bl sample, at 61.487 mg/kg, followed by Br (7.452 mg/kg). The lowest Cu content was found in Bw, which was 5.322 mg/kg.

Table 5 Heavy Metal Content of Pb, Cd and Cu in Rice Seeds After the Study

Metal	Br	Bw	Bl
Pb	0.00	0.00	0.00
Cd	0.078	0.000	0.000
Cu	7.452	5.322	61.487

4.4. Results of the Effect of Biochar Treatment and Heavy Metal Injection on Rice Growth and Yield

4.4.1. Plant height

Plant height in the treatment of biochar types, showed no significant difference between the levels of Br, Bw, and Bl. The highest plant height value was found in the Bl treatment at 91.96 cm, followed by Br at 88.41 cm, while the lowest plant height was found in the Bw treatment at 84.89 cm.

4.4.2. Total grain weight per clump (g)

The total weight of grain per clump in the biochar type treatment was not significantly different with the highest value in Bl (68.53 g), followed by Bw (65.01 g), and the lowest in Br (64.85 g).

4.4.3. Grain yield at 12% moisture content (g)

Grain yield with 12% moisture content in biochar type treatment was not significantly different, with the highest value in Bl (58.80 g), followed by Bw (55.76 g), and the lowest in Br (54.82 g).

Table 6 Effect of Biochar Types in Planting Media with Different Heavy Metal Content of Pb, Cd and Cu on Plant Height, Total Grain Weight Per Clump, 12% Water Content Grain Yield in Rice (*Oryza sativa* L.)

Treatment	Plant Height (cm)	Total Grain Weight per Clump (g)	Grain Yield at 12% Moisture Content (g)
Biochar Type			
BC	88.41 a	64.85 a	54.82 a
Bw	84.89 a	65.01 a	55.76 a
Bl	91.96 a	68.53 a	58.80 a
BNT 5%	7.79	10.49	8.56

Description: Numbers followed by the same letter in the same treatment and column the same indicates not significantly different in the least significant difference test (BNT) at the 5% level.

4.5. Bioaccumulation and Translocation Factors of Rice Plants in Transferring Heavy Metals

The highest bioaccumulation value was found for heavy metal Cd with a BAF value of 12.301, indicating the ability to accumulate Cd in plants is higher than Pb and Cu. In contrast, the lowest BAF value was found for Pb with a value of 0.286, indicating relatively low accumulation of Pb in plants. For translocation values, Cu metal showed the highest value of 0.251, indicating the relative ability of plants to distribute Cu from roots to shoots. In contrast, the lowest TF value was found for Cd metal with a value of 0.014, indicating very limited distribution of Cd from roots to shoots. Pb metal had a TF value of 0.000, indicating no distribution of Pb from roots to shoots. The bioaccumulation (BAF) and translocation (TF) values of rice plants are shown in Table 7 below.

Table 7 BAF and TF Values of Heavy Metals Pb, Cd and Cu in Rice Plants Sampled from Farmers' Rice Fields

Type of Heavy Metal	Concentration on the Ground	Concentration at the Root	Concentration in Shoots	Concentration in Plants	BAF Value	TF Value
Pb	75.428	21.591	0.000	21.591	0.286	0.000
Cd	11.231	134.466	1.843	138.152	12.301	0.014
Cu	65.092	29.487	7.408	44.303	0.681	0.251

The results of bioaccumulation (BAF) and translocation (TF) analysis of heavy metals showed that the ability of plants to accumulate and distribute heavy metals varied depending on the type of biochar used and the type of heavy metal analyzed. In plants treated with rice straw and rice husk biochar, the highest bioaccumulation value was found in Cu metal with a BAF value of 1.430, while the lowest value was found in Pb metal with a value of 0.739. For the highest translocation value, Cu metal also showed the highest TF value of 6.475, while the lowest was Pb metal with a TF value of 0.614. In plants treated with fruit and vegetable waste biochar, the highest bioaccumulation value was found in Cu metal with a BAF of 1.821, while the lowest value was found in Pb metal with a BAF of 0.020. The highest translocation value was also found in Cu metal with TF value of 6.048, while Pb and Cd metal had the lowest TF value, each of 0.000. In plants treated with lignohumic biochar, the highest bioaccumulation value was again found in Cu metal with a BAF of 1.559, while the lowest value was Pb metal with a BAF of 0.616. For translocation value, Cu metal showed the highest TF value of 5.746, while Pb and Cd had the lowest TF value of 0.000. The bioaccumulation (BAF) and translocation (TF) values in rice plants grown with different biochar treatments are shown in Table 8 below.

Table 8 BAF and TF values of heavy metals Pb, Cd and Cu in Rice Plants Planted with Different Biochar Treatments

Type of Heavy Metal	Concentration in Soil	Concentration at the Root	Concentration in Shoots	Concentration in Plants	BAF Value	TF Value
Biochar of Straw and Rice Husk						
Pb	9.20	4.211	2.59	6.797	0.739	0.614
Cd	0.31	0.424	0.418	0.842	2.725	0.986
Cu	46.39	8.872	57.446	66.318	1.430	6.475
Biochar of Fruit and Vegetable Waste						
Pb	8.61	0.173	0.00	0.173	0.020	0.000
Cd	0.32	0.090	0.00	0.090	0.280	0.000
Cu	45.49	11.755	71.094	82.849	1.821	6.048
Lignohumic Biochar						
Pb	8.76	5.395	0.00	5.395	0.616	0.000
Cd	0.37	0.546	0.00	0.546	1.484	0.000
Cu	46.45	10.738	61.701	72.439	1.559	5.746

5. Discussion

Based on the test results on irrigation water samples, the content of heavy metals Pb, Cd, and Cu were 0.208 mg/kg, 0.019 mg/kg, and 0.164 mg/kg, respectively. The heavy metal content detected in this irrigation water exceeds the threshold set in Bali Governor Regulation No. 16/2016 on Environmental Quality Standards and Environmental Damage Standard Criteria. The regulation provides guidelines for water quality standards by class, which are described in more detail in Table 9 below.

Table 9 Water Quality Standard Based on Class

No.	Parameters	Unit	Class		
			I	II	III
1	Lead (Pb)	mg/L	0.03	0.03	0.03
2	Cadmium (Cd)	mg/L	0.01	0.01	0.01
3	Copper (Cu)	mg/L	0.02	0.02	0.02

Source: Bali Governor Regulation No. 16 of 2016 concerning Environmental Quality Standards and Environmental Damage Standard Criteria

The results of the analysis of soil samples from agricultural land detected concentrations of heavy metals Pb, Cd, and Cu of 75.428 mg/kg, 11.231 mg/kg, and 65.092 mg/kg, respectively. This data indicates the accumulation of heavy metals from the Badung River, which is used as irrigation water in the surrounding agricultural land. The Badung River has long been contaminated with textile and screen printing industry waste [9,11]. The natural heavy metal content in soil within the average non-population range is shown in Table 10 below.

Table 10 Soil Natural Heavy Metal Content Within Average Non-Population Range

Metal	Content (Average) (μg/g)	Non Population Range (μg/g)
Cu	20	2-300
Pb	10	2-200
Cd	0.06	0.05-0.7

Source: Alloway (1995)

Types of biochar from rice straw and husk, lignohumic (wood waste), and fruit-vegetable waste have a significant role in reducing heavy metal concentrations in soil. The test results of heavy metal content of Pb, Cu and Cd in soil samples showed Pb with an average of 75.428 mg/kg, Cd with an average of 11.231 mg/kg and Cu with an average of 65.092 mg/kg. The results of the analysis of total heavy metal content in biochar-treated soil showed that the lowest Pb heavy metal content was found in fruit and vegetable waste biochar with an average of 8.608 mg/kg. The lowest Cd content was found in biochar straw and rice husk with an average of 0.309 mg/kg. The lowest Cu content was found in fruit and vegetable waste biochar with an average of 45.494 mg/kg. The decreased heavy metal content in soil that has been given biochar treatment proves that biochar can remediate soil polluted with heavy metals Pb, Cd and Cu [4].

The results of the analysis of plant samples showed that heavy metals in the soil were transferred to the plants. In rice plants, Pb heavy metal content was detected in the roots with an average of 21.591 mg/kg, while the stover and seeds were not detected. The calculation of the average value of Pb heavy metal content accumulated in rice plants amounted to 7.197 mg/kg. The average value of Pb heavy metal content detected in rice plants exceeds the maximum limit of Pb heavy metal content allowed in plants which is 2 mg/kg [15].

The highest Cd heavy metal content accumulated in the roots with an average of 134.466 mg/kg, while in the stover and seeds were detected at 1.734 mg/kg and 0.109 mg/kg, respectively. The results of the calculation of the average value of heavy metal content of Pb accumulated in rice plants amounted to 45.436 mg/kg. The average value of Cd heavy metal content detected in rice plants exceeds the maximum limit of Cd heavy metal content allowed in plants which is 0.02 mg/kg [15].

The results of the next analysis showed that rice plants detected heavy metal Cu content, the highest content was also found in the roots with an average of 29.487 mg/kg, followed by the stalks at 5.453 mg/kg and seeds at 1.955 mg/kg. so that the average value of accumulated heavy metal Cu content in rice plants was obtained at 12.298 mg/kg. Cu heavy metal content detected in rice plants exceeds the maximum limit of Cu heavy metal content allowed in plants which is 10 mg/kg [15].

Heavy metal contaminants that pollute the soil will then contaminate all plants that grow on the polluted soil and will accumulate these metals in the roots, stems, leaves and fruit (Agustina, 2014). If heavy metals accumulate in plants that function as accumulators and are consumed by living things, it can indirectly be fatal to the health of living things [18].

High heavy metal content in the soil indicates the potential for accumulation in plant parts as evidenced by the Bioacumulation Factor (BAF) and Translocation Factor (TF) values for heavy metals Pb, Cd and Cu. Bioaccumulation factor values were obtained based on the ratio between contaminant concentrations in rice plant organs including roots, stems and leaves to the growing medium containing heavy metals. The bioaccumulation factor value ranges from 0 - 1 indicating that the plant is able to accumulate contaminants in its organs [2]. The translocation factor value is determined based on the ratio between the concentration of contaminants in the upper part of the plant including the stalks and seeds to the concentration of contaminants in the roots of the plant. A translocation factor of more than 1 indicates that the plant is able to translocate the absorbed contaminants to the upper organs of the plant (Branzini and Zubillaga, 2013). The process of absorbing pollutants by plants from the soil through the roots which are then stored in the crown of the plant is referred to as the phytoextraction mechanism [14].

In sample plants from farmers' paddy fields, the highest bioaccumulation value was found in heavy metal Cd with a BAF value of 12.301, indicating the ability of Cd accumulation in plants is higher than Pb and Cu. In contrast, the lowest BAF value was found for Pb with a value of 0.286, indicating relatively low accumulation of Pb in plants. For translocation values, Cu metal showed the highest value of 0.251, indicating the relative ability of plants to distribute Cu from roots to shoots. In contrast, the lowest TF value was found for Cd metal with a value of 0.014, indicating very limited distribution of Cd from roots to shoots. Pb metal had a TF value of 0.000, indicating the absence of Pb distribution from roots to shoots.

Plants with biochar treatment of rice straw and husk had the highest BAF value for Cd metal (2.725), while for Cu metal was 1.430, and Pb was 0.739. Fruit and vegetable waste biochar treatment produced the highest BAF value for Cu metal (1.821), followed by Cd (0.280) and Pb (0.020). In the lighnohumic treatment, the highest BAF value was also found for Cu metal (1.559), followed by Cd (1.484) and Pb (0.616). In the straw and rice husk biochar treatment, Cu metal showed the highest TF value (6.475), followed by Cd (0.986) and Pb (0.614). For the fruit and vegetable waste biochar treatment, Cu metal also had the highest TF value (6.048), while Cd and Pb were not translocated to the upper part of the plant (TF = 0.000). In the lighnohumic treatment, Cu metal showed the highest TF value (5.746), while Pb and Cd showed no translocation to the top of the plant (TF = 0.000).

Cu metal consistently had the highest accumulation (BAF) and translocation (TF) abilities across biochar treatments and soil conditions, indicating that Cu tends to be more readily absorbed and translocated by plants than Pb and Cd metals. In contrast, Pb metal showed the lowest bioaccumulation and translocation values, indicating that this metal is relatively difficult to accumulate by plants, and its distribution from roots to shoots is very limited. The ability of plants to absorb metals or contaminants through the roots but no metal dispersal to the crown is called phytostabilization [14]

Heavy metals that contaminate agricultural land have the potential to damage the stability of soil ecosystems [17]. Lead adversely affects the morphology, growth and photosynthesis process of plants [11]. Cd toxicity in plants manifests as chlorosis and growth inhibition. Higher toxicity slows plant growth, resulting in plant necrosis [6]. Plants are poisoned in the presence of excessive cadmium levels. Cd prevents carbon fixation and decreases chlorophyll concentration and photosynthetic activity, thus negatively affecting plants [8]. Copper (Cu) is toxic to all plants at solution concentrations above 0.1 ppm [12]. The impact is clearly visible in the decrease of growth parameters, such as plant height, number of productive tillers, and root length. Treatment with lignohumic biochar (Bl) showed better results for variables such as plant height, total grain weight per clump and grain weight at 12% water content. The results of this study are in line with research (Satriawan and Handyanto, 2015) that the provision of biochar on the soil is also able to increase growth and nutrient uptake in plants.

The use of biochar as a soil improver not only reduces heavy metal pollution but also supports sustainable agriculture. By reducing heavy metal content in rice, biochar helps create a safer and healthier food system. In addition, the use of biomass waste as biochar feedstock supports the concept of *zero waste*, utilizing previously underutilized agricultural waste. Ecologically, biochar application can reduce the risk of environmental pollution due to leaching of heavy metals into groundwater, as reported by [7]. Improved soil quality through biochar also contributes to climate change mitigation through carbon sequestration.

6. Conclusions and Suggestions

Based on the results of this study, it can be concluded as follows.

- The land in the lower reaches of the Badung River has been contaminated with heavy metals Pb, Cd and Cu at concentrations exceeding the permissible threshold, negatively affecting soil fertility and the quality of agricultural produce.

- Biochar from rice straw and husk, lignohumic (wood waste), and fruit-vegetable waste have a significant role in reducing heavy metal concentrations in soil.
- Lignohumic-based biochar is proven to give better results in increasing rice yield.

6.1. Suggestions

Based on the results of this study, the use of biochar needs to be socialized to farmers as an alternative environmentally friendly technology in managing polluted soil and increasing crop yields. Further research is needed to examine the effect of biochar on other crops besides rice, as well as to evaluate the economic efficiency of its application on a wider scale

Compliance with ethical standards

Acknowledgments

Thank you to Udayana University through the Institute for Research and Community Service (LPPM) for providing funding this research through Inspire Schema and facilitating this research

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Agustina, Titin. "Heavy metal contamination of food and its impact on health." TEKNOBUGA: Journal of Fashion and Boga Technology 1.1 (2014) [Indonesian].

[2] Branzini, A., Zubillaga, M.S. 2013. Phytostabilization as Soil Remediation Strategy. Soil Biology vol. 35. Springer.Heidelberg. pp. 177-198. https://doi.org/10.1007/978-3- 642-35564-6_10.

[3] Christophoridis, Christophoros. "Concentration, fractionation, and ecological risk assessment of heavy metals and phosphorus in surface sediments from lakes in N. Greece." Environmental Geochemistry and Health 42.9 (2020): 2747-2769.

[4] Ippolito, James A., David A. Laird, and Warren J. Busscher. "Environmental benefits of biochar." Journal of environmental quality 41.4 (2012): 967-972.

[5] Oguntunde, Philip G. "Effects of charcoal production on maize yield, chemical properties and texture of soil." Biology and Fertility of soils 39 (2004): 295-299.

[6] Pramanick P, Chakraborty A, Raychaudhuri SS (2022) Partial alleviation of zinc induced oxidative stress by polyamines in Plantago ovata Forsk. Plant Cell Tissue Organ Culture (PCTOC) 1-11.

[7] Salam A.K. (2022). The Potential Roles of Biochar in Restoring Heavy Metal Polluted Tropical Soils and Plant Growt.

[8] Sperdouli, Ilektra. "Excess zinc supply reduces cadmium uptake and mitigates cadmium toxicity effects on chloroplast structure, oxidative stress, and photosystem II photochemical efficiency in Salvia sclarea plants." Toxics 10.1 (2022): 36.

[9] Suwandewi, I.N.M., Ratnawati, I.G.A.A., Darmayasa, I.B.G. 2015. Test of Radioactive Element Content and Escherichia Coli Polluting Bacteria in Industrial Waste in the Badung River Downstream Area, Pemogan Village. Physics Bulletin, 16(1): 7-14 [Indonesian].

[10] Wang, Jie. "Analysis of the long-term effectiveness of biochar immobilization remediation on heavy metal contaminated soil and the potential environmental factors weakening the remediation effect: a review." Ecotoxicology and Environmental Safety 207 (2021): 111261.

[11] Wedayani, Ni Made. "Utilization of banana waste biochar to reduce heavy metal contamination in soil and maize plants." Journal of Degraded and Mining Lands Management 11.2 (2024): 5475-5483.

[12] Widaningrum, Miskiyah, and Suismono. (2007). The Dangers of Heavy Metal Contamination in Vegetables and Alternative Prevention of Contamination. Bulletin of Agricultural Postharvest Technology [Indonesian].

[13] Widyasari, Ni Luh. "Study of controlling the content of Pb, Cu, Cd, and Cr in soils using hyperaccumulator plants." Journal of Degraded & Mining Lands Management 11.2 (2024).

[14] Wong, S.C., Li, X.D., Zhang, G., Qi, S.H., Min, Y.S. 2002. Heavy Metals in Agricultural Soils of the Pearl River Delta, South China. Journal of Environmental Pollution, 119 (1):33-44. https://doi.org/10.1016/S0269-7491(01)00325-6.

[15] World Health Organization (WHO). 1996. Permissible limits of heavy metals in soil and plants. Geneva, Switzerland.

[16] Zaheer, Ihsan Elahi. "Combined application of zinc and iron-lysine and its effects on morpho-physiological traits, antioxidant capacity and chromium uptake in rapeseed (Brassica napus L.)." PLoS One 17.1 (2022): e0262140.

[17] Zhang, Rui. "Current Situation of Agricultural Soil Pollution in Jiangsu Province: A Meta-Analysis." Land 12.2 (2023): 455.

[18] Zhang, Rui. "Health risk assessment of heavy metals in agricultural soils and identification of main influencing factors in a typical industrial park in northwest China." Chemosphere 252 (2020): 126591.