



Remediating Heavy Metal Contamination in Choy Sum using some Organic and Biological Amendments

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ABSTRACT

Agricultural land along river basins such as the Bekasi River is highly vulnerable to heavy metal contamination from industrial and domestic activities. Lead (Pb) and Cadmium (Cd) concentrations that exceed the threshold limits have the potential to reduce crop quality and endanger human health. This study aimed to evaluate the effectiveness of single and combined applications of soil ameliorants (rice husk biochar, rice straw compost, and biofertilizers based on *Azotobacter* and *Azospirillum*) in reducing Pb and Cd content in choy sum (*Brassica rapa* var. *parachinensis*). The research was conducted in a greenhouse using contaminated soil from the banks of the Bekasi River, arranged in a completely randomized design consisting of 5 treatments and 4 replications. The results showed that the combined treatment of biochar + biofertilizer was the most effective formulation, reducing heavy metal content in choy sum to Pb at 0.42 mg/kg and Cd at 0.04 mg/kg. While the Cd level was well below the safe threshold of 0.2 mg/kg, the Pb content still exceeded the recommended limit of 0.2 mg/kg. These findings indicate that biochar and biofertilizer can synergistically suppress heavy metal uptake by immobilizing metals and enhancing microbial activity. Although further refinement is required to meet Pb safety standards, this approach shows strong potential as a sustainable remediation strategy to support food safety.

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INTRODUCTION

Rehabilitation of contaminated soil, to protect human health and achieve sustainable development, has become a primary focus for governments and communities (Cheng et al., 2016). Healthy soil is an essential component in supporting sustainable food systems, as it functions as a living ecosystem that supports plants, animals, and humans (Lehmann et al., 2020; Saravanan et al., 2024). Furthermore, irrigation water, as the primary source of agricultural water supply, must also meet quality standards for its intended use. Government Regulation of

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the Republic of Indonesia 22/2021 establishes water quality standards based on its intended use, including for agricultural irrigation. However, data show that the quality of several rivers on Java Island contains parameters exceeding the threshold, including the Bekasi River (West Java Regional Development Planning Agency, 2009; Water Resources Agency, 2017).

The Bekasi River watershed, particularly the tertiary irrigation area of Babelan Subdistrict, Bekasi Regency, is one of the locations showing significant indications of water and soil pollution. Water quality analysis revealed physicochemical parameters such as dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) that exceeded the quality standards for agricultural purposes. This condition directly affects soil and crop quality, especially leafy vegetables such as green spinach, red spinach, and water spinach, which are commonly cultivated in the area. Heavy metal contamination is one of the most hazardous forms of environmental pollution due to its toxicity. Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), and nickel (Ni) are particularly harmful because they do not degrade easily and can accumulate in plant tissues, posing serious health risks to consumers (Kumar et al., 2020; Sharma et al., 2009). Once released into the environment, these metals can contaminate soil and water, enabling their entry into the food chain through plant uptake. Primary producers, such as crops and aquatic plants, readily absorb these metals, which then bioaccumulate and biomagnify through different trophic levels, ultimately reaching humans and other top consumers (Osman et al., 2021). Prolonged consumption of metal-contaminated food can lead to severe health problems, including neurological disorders, kidney damage, and developmental abnormalities (Haghighizadeh et al., 2024), depending on the type and concentration of metals involved. Previous studies have shown that vegetable crops in the Babelan area of Bekasi contain heavy metals exceeding the permissible limits, particularly in water spinach and spinach (Situmorang & Simatupang, 2021). The accumulation of these heavy metals is influenced by irrigation water quality, vehicle emissions, and the characteristics of contaminated soils (Danapriatna et al., 2024; Aier et al., 2024).

To address these issues, appropriate remediation efforts are needed to reduce the level of heavy metal contamination in the soil and improve the quality of agricultural yields. Soil remediation can be carried out using various approaches, both in-situ and ex-situ, depending on the characteristics of the contaminant and site conditions (Liu et al., 2018). One potential method is ex-situ remediation using a combination of organic materials such as biochar, rice straw compost, and biological fertilizers. Biochar is known to adsorb heavy metals, increase cation exchange capacity, and improve soil structure (Beesley et al., 2010). The use of rice straw compost and biological fertilizers plays a crucial role in increasing soil fertility and nutrient mobilization. Rice straw compost serves as a source of organic and micronutrients, increasing the availability of nitrogen, phosphorus, and potassium, which are essential for plant growth (Mohamed et al., 2019; Raj et al., 2023).

The application of rice straw compost can increase the organic carbon content of the soil, which improves physical structure and air retention (Herdiansyah et al., 2024; Dewi et al., 2022). Meanwhile, biofertilizers provide microorganisms that mobilize nutrients, neutralize pollutants, and increase microbial activity for decomposition and mineralization to maximize the availability of plant nutrients (Patel et al., 2023). The use of a combination of both has been proven effective in reducing greenhouse gas emissions and increasing the efficiency of nutrient use (Shahane et al., 2019; Kumar & Bordoloi, 2024). Based on this, the study aims to: (1) Identify the level of heavy metal contamination in soil and vegetable crops in cultivated land around the river, and (2) Determine the optimal remediation formulation based on biochar, rice straw compost, and biofertilizer in reducing soil contamination.

MATERIAL & METHODS

Research Location and Materials

This study was conducted for nine months, from May 2024 to January 2025, with a structured division of activities. Preparation of the growing media, treatment application, and plant maintenance were carried out under controlled conditions in the Greenhouse of the Faculty of Agriculture, Universitas Islam 45 (UNISMA), Bekasi, while soil and plant sample analyses were conducted at the accredited Agro Chemistry Laboratory, Crop Protection and Horticulture Agency of West Java Province. The growing medium consisted of contaminated soil collected from the banks of the Bekasi River at specific coordinates 6°07'06.8" S & 107°02'23.8" E, at an elevation of 23 m above sea level (Figure 1). The soil was classified as Entisol with specific characteristics previously analyzed (Table 1). A total of 7 kg of soil was placed into each standard-sized polybag for cultivating choy sum (*Brassica rapa* var. *parachinensis*) as the test crop. Choy sum is a widely consumed vegetable commodity, as it is suitable for various types of dishes and as a complement to staple foods (Huang et al., 2021; Zou et al., 2021; Zunaidi et al., 2024).

Three remediation materials were applied: (1) the "SMS Agrobost" biofertilizer containing a microbial consortium of *Azotobacter* sp. (2.1×10^7 CFU/ml) and *Azospirillum* sp. (2.0×10^7 CFU/ml); (2) rice straw compost with a water content of 62%, pH 7.45, and organic C content of 15.24% (Table 2); and (3) rice husk biochar produced by pyrolysis at 400 °C, consisting of 50% cellulose, 25% lignin, and 16.5% ash. The application protocol followed established procedures: biofertilizer was applied at a rate of 1 L diluted in 150–200 L of water and sprayed at 7, 14, 21, and 28 days after planting (DAP) (Ha, 2014; Rashid et al., 2014). Straw compost was added at 14 g/polybag (equivalent to 4 t/ha), and biochar at 7 g/polybag (equivalent to 2 t/ha). When collecting water and soil samples, we wore gloves and boots to prevent contamination and protect the research team from potential exposure to hazardous materials. During the processing of organic and biological amendments, the use of gloves, helmets, and protective eyewear is mandatory. We washed our hands thoroughly with soap and water before and after handling samples, chemicals, or organic materials. All tools and instruments are kept sterile and dry to minimize measurement errors. These practices comply with the operational standards and procedures specified in SNI ISO/IEC 17025:2017 (Ruyadi et al., 2017).



Fig. 1. Water and soil sampling.

Table 1. Soil content and characteristics.

Parameter	Unit	Value	Status	Test method
Water Content	%	5.77	-	Gravimetric
pH H ₂ O	-	6.2	Slightly Acidic	Electrometric
Exchangeable Acidity	cmol(+)/kg	0.003	-	Titrimetric
Exchangeable Al	cmol(+)/kg	0	-	Titrimetric
Exchangeable H	cmol(+)/kg	0.03	-	Titrimetric
Organic C	%	1.04	Low	Spectrophotometry
Total N	%	0.14	Low	Kjeldahl
C/N Ratio	-	7.4	Low	-
P ₂ O ₅ HCl 25%	mg/100g	117	Very High	Spectrophotometry
K ₂ O HCl 25%	mg/100g	36	Moderate	AAS
Available P (Olsen)	mg/kg	129.5	Very High	Spectrophotometry
Exchangeable Ca	cmol(+)/kg	20.72	-	Percolation & AAS
Exchangeable Mg	cmol(+)/kg	6.84	-	Percolation & AAS
Exchangeable K	cmol(+)/kg	0.34	-	Percolation & AAS
Exchangeable Na	cmol(+)/kg	0.28	-	Percolation & AAS
CEC	cmol(+)/kg	25.81	-	Percolation & Titrimetric
Pb	mg/kg	20.2	-	AAS
Cd	mg/kg	0.7	-	AAS
Sand	%	44	Clay Loam	Pipette
Silt	%	26	Clay Loam	Pipette
Clay	%	30	Clay Loam	Pipette

Table 2. Rice straw content.

Parameter	Value	Test method
Water Content	62	Gravimetric
pH H ₂ O	7.45	Potentiometry
Organic C (%)	15.24	Walkley & Black
Total N (%)	0.7	Kjeldahl
C/N Ratio	21.77	-
P ₂ O ₅ (%)	0.18	HClO ₄ + HNO ₃ Digestion
K ₂ O (%)	0.6	HClO ₄ + HNO ₃ Digestion
CaO (%)	5.5	HClO ₄ + HNO ₃ Digestion
MgO (%)	1.25	HClO ₄ + HNO ₃ Digestion
CEC (cmol kg ⁻¹)	18.98	NH ₄ OAc pH 7.0

Note: Assessment based on criteria from Pusat Penelitian Tanah (2015).

Experimental Design and Data Analysis

We used a completely randomized design with five treatments and four replications (quadruple) (Forrest, 2002). The five treatments tested consisted of: single application of biofertilizer, single application of biochar, single application of straw compost, a combination of straw compost and biofertilizer, and a combination of biochar and biofertilizer. Each experimental unit consisted of a polybag containing 7 kg of contaminated soil with choy sum as indicators. The main variables observed included the content of heavy metals Pb and Cd in the soil and plant tissue. Supporting fertilization was carried out using urea at a dose of 1 g/polybag applied at 10 DAPs, and NPK fertilizer at a dose of 1.4 g/polybag given every 2 weeks (**Figure 2**). Soil chemical analysis for C-Organic parameters was carried out using the Kurmies method using a Spectrophotometry tool (Iskandar et al., 2025), while the content of heavy metals Pb and Cd in the soil and in the choy sum tissue was analyzed using the atomic absorption spectrophotometry (AAS) method according to standard laboratory procedures (Mukhopadhyay, 2018; Danapriatna et al., 2023a).

The data obtained were analyzed using analysis of variance (ANOVA) to identify mean differences among three or more groups by comparing variation between groups with variation

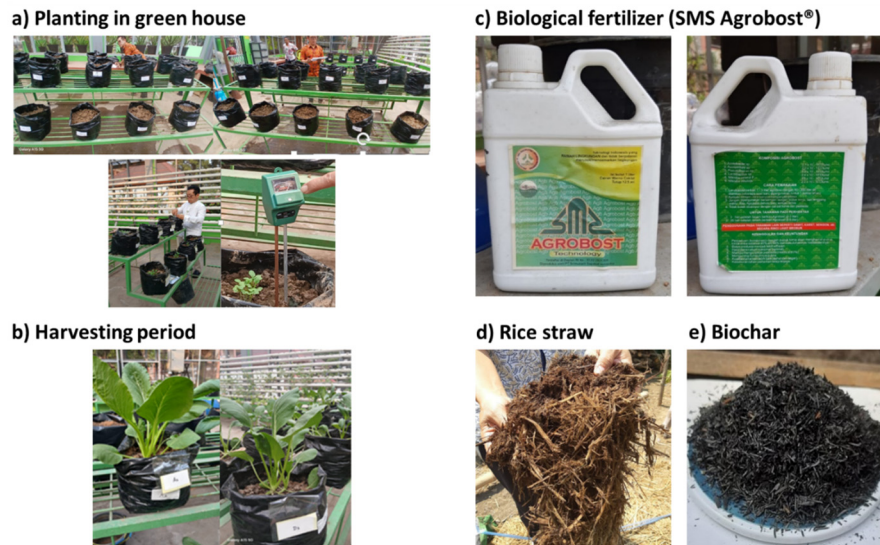


Fig. 2. Experiment planting with research materials (biological fertilizer, biochar, and straw compost).

Table 3. Heavy metals in soils before treatments and planting.

ID	Treatment	Parameter		
		C-Organic (%)	Pb (mg/kg)	Cd (mg/kg)
1	Original soil	1.04	20.2	0.7
2	Biological fertilizer	1.13	20	0.7
3	Biochar	1.34	21.7	0.8
4	Straw compost	1.09	21.8	0.6
5	Straw compost + biological fertilizer	1.4	22.1	0.7
6	Biochar + biological fertilizer	1.3	23.4	0.7

Note: Quality standard for Pb = 15-25 mg/kg and Cd = 0.2 mg/kg.

within groups (Dede et al., 2025). If the ANOVA results indicated significant differences, the test was followed by a least significant difference (LSD) test at the same level to determine specific differences among treatments (Sedgwick, 2014; Agbangba et al., 2024). All statistical tests were conducted at a 95% confidence level. The initial soil analysis showed Pb content of 20.2 mg/kg, Cd 0.7 mg/kg, and organic C 1.04%, which was considered low. The soil texture was dominated by clay loam with a composition of 44% sand, 26% silt, and 30% clay. These initial soil characteristics served as the basis for determining the formulation and dosage of remediation materials used in the experiment.

RESULTS AND DISCUSSION

Heavy Metal Contamination in Soil and Remediation Effectiveness

The initial soil organic matter content in this study was 1.04%, which is considered low (Table 3). After the application of various remediation treatments, most showed varying increases in organic matter levels. The most significant increase was observed in the «Compost + Biofertilizer» treatment (1.40%), followed by «Biochar» (1.34%), and «Biochar + Biofertilizer» (1.30%). This finding is consistent with the research of Kizito et al. (2019), who reported an increase in soil organic matter of up to 232% through the application of nutrient-enriched biochar. The recalcitrant nature of biochar, which inhibits microbial decomposition, plays a key role in increasing soil carbon stability (Kheir et al., 2023), while the combination with biofertilizer provides a labile carbon source that strengthens microbial activity. Initial analysis

results showed that the Pb concentration in all treatments was still within the quality standard range according to Government Regulation 101/2014, which is 15-25 mg/kg (Table 3). However, Cd levels in all treatments (averaging 0.6-0.8 mg/kg) exceeded the established threshold of 0.2 mg/kg. This indicates that agricultural land along the Bekasi River is significantly contaminated with this heavy metal due to domestic and industrial waste runoff.

In the control treatment (without ameliorant), Pb content was recorded at 20.2 mg/kg and Cd at 0.7 mg/kg. The single application of biofertilizer showed no significant changes, with Pb and Cd levels remaining at 20.0 and 0.7 mg/kg, respectively. This was consistent with the findings of Dewi et al. (2024) and Hazra (2022), who stated that the effectiveness of biofertilizers requires time for adaptation and development of microbial populations before they can show a significant impact. Remediation effectiveness also depends significantly on the specific capabilities of the microorganisms and local environmental conditions (Setiawati et al., 2022; Fallo et al., 2023). The biochar and rice straw compost treatments actually showed an increase in Pb concentration to 21.7 and 21.8 mg/kg, respectively, and Cd to 0.8 and 0.6 mg/kg. This condition may be caused by a suboptimal stabilization (aging) process, where the ameliorant material experiences an initial phase of interaction with heavy metals (Chen et al., 2020; Bortoloti & Baron, 2022).

The adsorption capacity of biochar is strongly influenced by the characteristics of the raw materials and the incubation time (Ambaye et al., 2020; Alsamadany et al., 2022). Yuan et al. (2023) explained that during the initial phase, heavy metal uptake occurs rapidly, but the absorption rate slows down as metal diffusion into the pores of biochar increases. The combination of biochar and compost with biofertilizers resulted in an increase in Pb content to 22.1 mg/kg (compost + biofertilizer) and 23.4 mg/kg (biochar + biofertilizer). In comparison, Cd remained stable at 0.7 mg/kg. This phenomenon can be attributed to the complex interactions between organic matter, microbes, and heavy metals (Srivastav et al., 2024). Organic compounds such as biochar and compost can reduce heavy metal availability through chelation processes involving carboxyl and hydroxyl functional groups, which act as binding sites for heavy metals (Irfan et al., 2021; Wang et al., 2023; Qin et al., 2022).

Although the initial results did not show a significant reduction in Pb and Cd levels, the use of combined remediation materials demonstrated long-term potential. Biological remediation processes generally require considerable time to produce tangible effects, as reflected in the ANOVA results, which indicated significant differences among treatments in heavy metal content of choy sum (Table 4). These findings suggest that the treatments applied were able to influence heavy metal dynamics within the soil-plant system (Sabir et al., 2020). Heavy metals such as Pb and Cd are hazardous contaminants that can accumulate in plant tissues and pose risks to human health through the food chain (Alloway, 2013). Several studies have demonstrated the effectiveness of biochar in adsorbing heavy metals and reducing their availability to plants through mechanisms such as increasing soil pH and binding metal ions (Ahmad et al., 2012). These results provide a promising foundation for developing more effective remediation strategies to address heavy metal contamination in agricultural land.

Lead Contamination

The application of all three ameliorants has been shown to affect heavy metal concentrations, particularly Pb, in plant tissues through changes in soil chemistry and increased biological activity. However, when compared with previous research findings, the results in Table 5 and Figure 2a show an anomaly: the single treatment «Straw Compost» actually produced the highest Pb levels (0.58 mg/kg). This value is likely due to several factors, such as the dose applied or the specific characteristics of the compost used. Nevertheless, the overall positive impact of organic amendments on reducing Pb remains significant. For example, research by Danapriatna et al. (2023b) showed that food crops treated with straw compost experienced a 30-40% reduction in Pb concentration compared to untreated controls, highlighting the importance

Table 4. ANOVA for contamination of Pb and Cd in the plants.

Contaminant	Parameter	SS	df	MS	F	p
Pb (mg/kg)	Between groups	0.08	4.00	0.02	6682	0.00
	Within groups	0.04	15.00	0.00		
	Total	0.12	19.00	-		
Cd (mg/kg)	Between groups	0.01	4.00	0.00	10336	0.00
	Within groups	0.00	15.00	0.00		
	Total	0.01	19.00	-		

Note: SS = sum of squares; df = degree of freedom; MS = mean square; F = F-statistic; p = probability value.

Table 5. Heavy metal content in the plant after different treatments.

Treatment	Heavy metal contents	
	Pb (mg/kg)	Cd (mg/kg)
Biological fertilizer	0.424 a	0.050 a
Biochar	0.427 a	0.057 ab
Straw compost	0.582 b	0.075 bc
Straw compost + biological fertilizer	0.480 a	0.090 c
Biochar + biological fertilizer	0.420 a	0.042 a
LSD	0.080	0.018
Quality standard for food	0.200	0.200

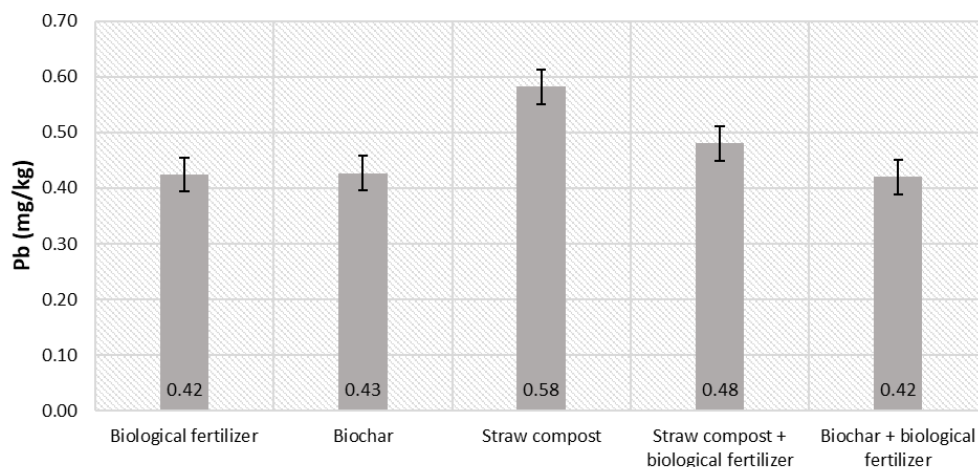
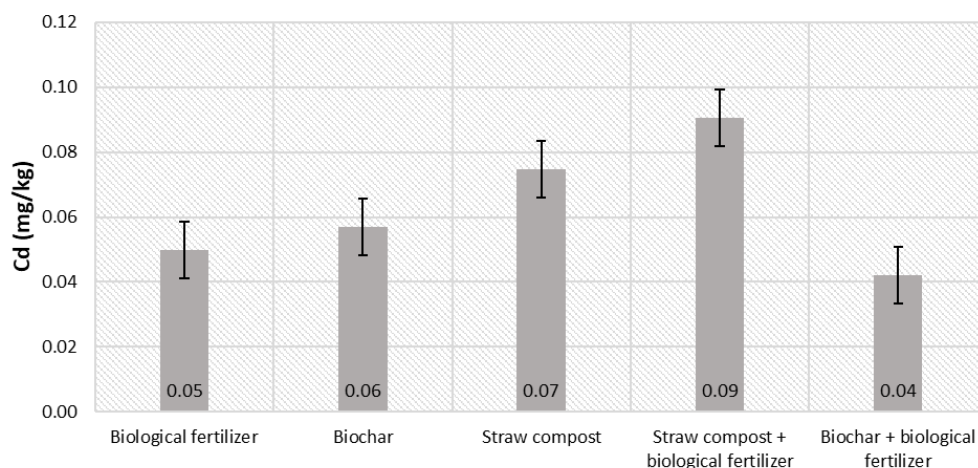
Note: The same letters in one column indicate no significant difference.

of synergistic effects in increasing remediation effectiveness. Organic amendments such as straw compost play a role in reducing the availability and uptake of heavy metals by plants. The composting process can raise soil pH and total phosphorus content, thereby reducing heavy metal availability (Zeng et al., 2025). A significant reduction in Pb levels in plants fed with organic matter is associated with improvements in soil biochemical parameters (Lin et al., 2019). Furthermore, the addition of organic amendments can increase the activity of soil microbes that play a role in immobilizing metal ions, effectively suppressing Pb concentrations in plant tissues (Liu et al., 2023).

The combination of biochar and biofertilizer with straw compost is more optimal in suppressing Pb accumulation in plants. Biochar, known for its high adsorption capacity, can immobilize heavy metals in the soil and limit their uptake by plants (Tong et al., 2023). This is evident in research data, where the treatments «Biochar + Biofertilizer» (0.42 mg/kg) and «Straw Compost + Biofertilizer» (0.48 mg/kg) produced lower Pb levels than the single treatment «Straw Compost» (0.58 mg/kg). In the context of food safety, comparing Pb concentrations with established threshold values is crucial for risk assessment. The maximum limit for Pb in food plant tissue is generally set at 0.2 mg/kg or lower according to health standards (Thu & Loan, 2024). Therefore, although the «Straw Compost» treatment showed the highest value, further evaluation is still needed regarding its compliance with safe limits. Overall, the results of this study, particularly for the combination treatment, indicate that appropriate organic amendment practices can maintain Pb accumulation below threshold levels. This emphasizes the importance of organic farming practices in supporting food security while increasing crop productivity (Rantung et al., 2024).

Cadmium Contamination

We found that the biochar + biofertilizer treatment produced the lowest Cd content (0.04 mg/kg), followed by single biofertilizer (0.05 mg/kg) and single biochar (0.06 mg/kg). In contrast, the straw compost + biofertilizer treatment recorded the highest Cd accumulation (0.09 mg/kg) (Table 5 & Figure 3b). This variation indicates that the effectiveness of Cd reduction is highly dependent on the combination of ameliorants used. Biochar has long been recognized for its

a) Pb content after treatments**b) Cd content after treatments****Fig. 3.** Heavy metal contents after different treatments.

potential to improve soil properties while suppressing heavy metal uptake. The application of biochar has been shown to significantly decrease Pb accumulation in *Brassica* species (Maceiras et al., 2024). Although studies related to Cd in choy sum remain limited, broader evidence suggests that biochar not only functions as a heavy metal adsorbent but also improves soil physical and chemical conditions that support plant growth, thereby potentially reducing Cd translocation into plant tissues (Jeyasundar et al., 2021; Kniuipytè et al., 2023).

Biofertilizers also play a crucial role in reducing heavy metal levels while promoting plant growth. Organic fertilizer application to *Brassica rapa* increases nutrient uptake while reducing toxic metal levels (Zhang et al., 2023). Organic treatments can reduce Cd in leafy vegetables, highlighting the importance of nutrient management in contaminated soils (Cámara-Martos et al., 2021). Meanwhile, straw compost provided additional benefits by increasing nutrient availability and reducing metal bioavailability. Composting can suppress heavy metal uptake in various vegetables, contributing to plant resilience to metal stress (Anne et al., 2023). The combination of biochar and compost even works synergistically: the porous structure and surface area of biochar effectively bind Cd ions, while the organic matter from the compost improves soil biochemical properties. The use of organic ameliorants can reduce Cd accumulation in *Brassica rapa* compared to the use of chemical fertilizers alone, which often exceeds food

safety thresholds for heavy metals (Hamdan et al., 2022; Qu et al., 2025).

ANOVA analysis showed significant differences ($p < 0.05$) in Pb accumulation in choy sum among treatments. The «Rice Straw Compost» treatment exhibited the highest Pb concentration, whereas the «Biochar + Biofertilizer» combination produced the best results. The mechanisms of Pb reduction can be explained through several scenarios. First, an increase in soil pH due to organic matter decomposition decreases Pb availability (Gholizadeh & Hu, 2021). Second, ion competition at root absorption sites; and third, immobilization through complexation with organic compounds (Ali et al., 2017; Lacalle et al., 2018). In addition, biofertilizers contribute by transforming metals into more degradable forms through microbial activity (Gascó et al., 2019; Qian et al., 2024). The «Biochar + Biofertilizer» treatment demonstrated the most substantial potential as a remediation formulation for heavy metal-contaminated soils. However, the timing of application and optimal dosage require further investigation, given the initial responses showing fluctuations in soil metal concentrations across treatments (Ayub et al., 2021; Ali et al., 2022; Oh et al., 2023).

CONCLUSION

The combined application of soil amendments, particularly the «Biochar + Biofertilizer» formulation, demonstrated the highest effectiveness in rehabilitating heavy metal-contaminated soils and reducing Pb and Cd accumulation in *Brassica rapa* (choy sum). Although fluctuations in metal concentrations were observed in the early stages due to stabilization processes, this combined treatment successfully decreased metal bioavailability through synergistic mechanisms: increased soil pH, metal immobilization by biochar, and microbial activity from the biofertilizer. This success was reflected in the lower Pb and Cd concentrations in plants, although Cd accumulation under certain treatments still warrants special attention. These findings provide an essential contribution to the development of sustainable remediation strategies based on organic and biological materials to support food security and environmental sustainability. However, further studies on optimal dosages, application timing, interactions of ameliorants with specific soil characteristics, and large-scale field trials are still needed to validate the effectiveness and economic feasibility of this approach before it can be widely implemented.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript.

In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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