

Original Research

Biochar Based on *Boehmeria nivea* from Arsenic-Contaminated Soil and the Effect on Soil

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Received: 10 January 2024

Accepted: 23 March 2024

Abstract

The utilization of remediating plants is an important factor that restricts phytoremediation. Ramie has good adsorption capacity for various heavy metals and is widely used in plant remediation. To achieve the multi-purpose development of heavy metal-contaminated ramie, research has been conducted on the preparation of biochar for using it as a raw material, and the feasibility of returning the prepared biochar to the soil has been explored. The results indicate that 300 °C is the appropriate pyrolysis temperature for preparing ramie biochar. Under these conditions, the biochar yield is $42.90 \pm 2.29\%$, significantly higher than other pyrolysis temperatures, and the arsenic concentration is also lower. Removing arsenic from ramie biochar is crucial for biochar to return to the soil, and $85.62 \pm 1.36\%$ of arsenic can be removed through three rounds of 300 mM sodium hydroxide extraction. Adding modified biochar to heavy metal-contaminated soil can increase soil pH and organic matter content but does not significantly increase soil arsenic content. However, adding modified biochar did not significantly alter soil microbial community structure. A feasible plan for preparing reusable biochar using contaminated ramie was proposed in this study. The research results can directly serve the remediation of soil arsenic pollution using ramie and have reference significance for other plants to carry out heavy metal remediation.

Keywords: ramie, phytoremediation, soil microorganism, pyrolysis temperature, biochar

Introduction

Heavy metal pollution is an important environmental issue worldwide. It threatens the survival and health of individual organisms and poses a significant threat to the ecosystem and human health through the food chain [1]. Until now, the heavy metals that pollute soil mainly included cadmium (Cd), chromium (Cr), mercury (Hg), lead (Pb), arsenic (As), copper (Cu), zinc (Zn), nickel (Ni), etc. [2]. Many studies have been conducted on the toxicology and remediation of heavy metal pollution [3, 4].

As is the 53rd most prevalent element in the Earth's crust and is considered one of the most carcinogenic and toxic "heavy metals," specifically As (III) [5, 6]. Studies have shown that over 50 countries are affected by As contamination and that As pollution is worsening [6]. To alleviate the toxicity of As pollution, various remediation strategies have been studied, among which bioremediation is considered a promising and environmentally-friendly option for the on-site reduction or stabilization of pollutants and for managing As contamination [6, 7]. Currently, the construction of a network between biological organisms

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a speed of 30 r/min. After centrifugation and filtration, As content was determined using an atomic fluorescence spectrophotometer. During the above experimental process, ramie powder was used as a control to measure all the indicators. All chemical substances and standard materials used in the experiments were purchased from the National Standard Material Resource Sharing Platform (<http://www.gbwppt.cn/>).

Modification of Biochar Based on As Removal

Considering that the experimental ramie comes from mining areas and the biochar contains heavy metals, we selected biochar with the highest As content for the As removal experiments to modify the biochar. Based on previous reports, sodium oxalate [23] and sodium hydroxide [24] were selected for BC modification. Biochar (2 g) was weighed and placed in a 50 mL centrifuge tube. Then, different concentrations of sodium oxalate (25, 50, and 75 mM/L) or sodium hydroxide (100, 200, and 300 mM/L) solution were added at a solid-liquid ratio of 1:10 for the extraction experiments. The mixture was flipped, shaken for 12 h (70 rpm), and centrifuged for 10 minutes (8000 r/min). Subsequently, the biochar was separated from the extraction agent and dried at 60 °C for 72 h. These steps were repeated thrice to remove As from the biochar, and the nutrient and heavy metal contents of the biochar were measured after each removal. Three replicates were used for each experiment, and pure water was used as the control.

Effects on Soil Properties and Microbial Communities

The modified biochar with the highest As removal efficiency was used to explore its impact on soil. Heavy metal-contaminated soil was also obtained from Xikuangshan (E 111.49914°, N 27.769811°). Different proportions of biochar (0.5%, 1%, and 2%) were added to the heavy metal-contaminated soil, and no biochar was added as a control (CK). The experimental groups with different proportions of biochar were denoted as R_{0.5}, R₁, and R₂. Soil and biochar were mixed evenly after adding biochar, soil pH, soil redox potential (soil Eh), soil organic matter, and As content every seven days. The methods used to measure soil pH and As content were the same as those used to measure biochar. Soil Eh was measured in triplicate using an Eh meter according to the method reported by Honma et al. [25]. The soil organic matter (SOM) was measured using the potassium dichromate external heating method [4, 26].

Soil samples were collected on the 28th day to determine the composition of the soil microbial communities, including bacteria and fungi. Four soil samples were taken from the edge of the basin and one soil sample from the center; the five samples were mixed. DNA was extracted from 1.0 g of each soil sample using a DNA Extraction Kit (D5625-01) (Omega Bio-Tek, Norcross, GA, USA), according to the manufacturer's

instructions [27]. The integrity and quality of the extracted DNA were assessed by agarose gel electrophoresis and a NanoDrop spectrophotometer (ND-1000, Thermo Fisher Scientific, Waltham, MA, USA). The primers used for bacterial DNA were 338F and 806R, targeting the V3-V4 region. The primers used for amplifying fungal DNA were ITS1F and ITS2F, which targeted the ITS region. Equal amounts of PCR amplicons were sequenced using an Illumina MiSeq platform at Majorbio Biotechnology Co., Ltd. (Shanghai, China).

Data Analysis

All experiments were repeated at least thrice. Differences between experimental treatments were compared using one-way analysis of variance, and 0.05 was set as a p value. Statistical analysis was conducted using R 4.3.1, and drawings were performed using Origin 2024.

Results and Analysis

Biochar Yield, Elemental Content, and Leaching Toxicity

As the pyrolysis temperature increased, the ramie biochar yield decreased continuously (Table 1). When the pyrolysis temperature is 300 °C, the yield of ramie biochar is 42.90 ± 2.29%. When the pyrolysis temperature reaches 600 °C and 700 °C, the yield of ramie biochar is 28.00 ± 0.36% and 27.01 ± 0.26%, respectively, but the difference is insignificant (p > 0.05). The prepared ramie biochar is alkaline, and the pH of the biochar prepared under the pyrolysis temperature condition of 300 °C is significantly lower than that of other pyrolysis temperatures (Table 1).

As the raw material of ramie is heavy-metal-contaminated soil, the heavy metal content of ramie biochar is relatively high (Fig. 1). As the pyrolysis temperature increased, the As concentration in the biochar increased (Fig. 1A). The As concentration was 6.4 ± 0.46 mg·kg⁻¹ in ramie raw materials, whereas the As concentration in biochar was 43.97 ± 1.51 mg·kg⁻¹ when the pyrolysis temperature reaches 700 °C. When the pyrolysis temperature is below 500 °C, there is no significant difference in Cd concentration between ramie biochar and ramie raw materials (p > 0.05, Fig. 1B). However, when the pyrolysis temperature is 600 °C and 700 °C, the Cd concentration in biochar is 0.12 ± 0.03 mg·kg⁻¹ and 0.11 ±

Table 1. Differences in biochar yield and pH at different temperatures.

Biochar	Yield (%)	pH
ZBC300	42.90 ± 2.29 a	9.42 ± 0.46 b
ZBC400	33.48 ± 0.80 b	10.36 ± 0.12 a
ZBC500	29.97 ± 0.96 c	10.28 ± 0.14 a
ZBC600	28.00 ± 0.36 d	10.10 ± 0.04 a
ZBC700	27.01 ± 0.26 d	10.34 ± 0.06 ± a

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