Biochar derived from the invasive aquatic plant *Myriophyllum spicatum*: Characterization via SEM–EDX and application in lead removal

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Abstract The accumulation of lead (Pb) in aquatic environments remains a significant environmental challenge due to its toxicity and persistence. Meanwhile, invasive aquatic plants, such as *Myriophyllum spicatum*, cause ecological and economic issues due to their rapid growth and extensive biomass production. Converting this problematic biomass into biochar presents an opportunity to address both issues simultaneously. This study investigates biochar derived from M. spicatum via pyrolysis at 600°C, characterized using SEM–EDX, for its effectiveness in removing lead from aqueous solutions. Pyrolysis decreased carbon content through the conversion of organic carbon into volatile products, while the non-volatile calcium content increased more than fourfold. Pb(II) adsorption capacities improved significantly, from 73.9 mg/g in raw biomass to 92.4 mg/g in biochar, indicating an enhancement of over 20% in lead removal efficiency. These findings demonstrate the potential of biochar from invasive aquatic plants as a sustainable and effective solution for remediating lead-contaminated water, thus supporting the principles of the circular economy and contributing to ecosystem restoration.

Keywords: biochar, *Myriophyllum spicatum*, SEM–EDX, lead, removal

1. Introduction

Cleaning up environments impacted by heavy metals, particularly lead (Pb), is still a significant challenge because of its toxicity and resilience (Yan et al., 2025). A promising adsorbent for heavy metal removal is biochar, a low-density, carbon-rich charred material produced by pyrolyzing biomass that is sustainable (Wu et al., 2019).

Aquatic plants that are invasive in nature exhibit behaviors and characteristics such as quick reproduction, resistance to surrounding predators, and environmental adaptation (Palai et al., 2024). Therefore, invasive aquatic plants have been posing an increasing threat to global ecosystems and economies. The global economy lost almost US$32 billion because of aquatic and semi-aquatic invasive plants between 1975 and 2020 whose submerged plants accounted for over a quarter, or $8.4 billion (Macêdo et al., 2024). Due to their widespread distribution, invasive aquatic plants provide excellent resources for the production of biochar (Palai et al., 2024).

Rapid growth and the formation of dense surface mats by *Myriophyllum spicatum* can have negative effects on the ecology, such as displacing native plants, reducing the amount of sunlight accessible to other primary producers, and slowing water circulation (Schultz and Dibble, 2012).

This study's main objective is to use scanning electron microscopy and energy dispersive X-ray analysis (SEM-EDX) to characterize biochar made from invasive aquatic plant *M. spicatum* that was produced at pyrolysis temperature 600° C. Additionally, the biochar will be tested for its ability to remove lead (Pb(II)) from aqueous solution.

2. Materials and methods

2.1. Preparation of materials, characterization and lead removal

Using a underwater harvester, the public company "Ada Ciganlija" harvested the fresh aquatic weed from Sava Lake (Belgrade, Serbia) which was used for this study. First *M. spicatum* was prepared by the same procedure explained in (Milojković et al., 2019) and after that, its biochar was prepared in a horizontal tube furnace at the UK Biochar Research Centre, as described in (Milojković et al., 2024). SEM-EDS analysis was performed using a JEOL JSM-7001F field-emission scanning electron microscope coupled with an Oxford Instruments Xplore 15 energy dispersive X-ray spectrometer. Materials 0.1 g (*M. spicatum* and its biochar) were placed in contact with the 1 mM $Pb(NO_3)_2$ solutions (50 mL) in 100 mL glass erlenmeyers. The flasks were stirred at 220 rpm for 1h in a Heidolph Unimax 1010 orbital shaker.

3. Results and Discussion

SEM image of *M. spicatum* biochar show that surface of the biochar appears to have more developed pores and curves due to the emission of low-mass gaseous species during pyrolysis that may interact with the solid residue (biochar) (Michalak et al., 2019). EDX showed that carbon content decreases since pyrolysis transforms most carbon into volatile gases and liquid and calcium content in *M. spicatum* biochar increases more than 4 times because calcium is a non-volatile therefore it is concentrated as the organic substance breaks down. *M. spicatum* had a Pb(II) sorption capacity of 73.9 mg/g, while its biochar had a capacity of 92.4 mg/g, which is more than 20%.

4. Conclusion

In summary, biochar derived from the invasive aquatic plant *Myriophyllum spicatum* presents a promising, cost-effective, and environmentally sustainable method for addressing water contamination. Through SEM–EDX analysis, the increased calcium content observed in biochar was linked to improved adsorption properties, resulting in significant enhancement in lead removal efficiency. Future research should explore optimization of pyrolysis conditions, evaluate large-scale application feasibility, investigate economic and lifecycle sustainability, and assess biochar's adsorption kinetics, long-term stability, and regeneration capacity. Ultimately, utilizing invasive aquatic plant biomass for biochar production exemplifies circular economy principles, transforming environmental challenges into opportunities for ecological restoration and pollution remediation.

Acknowledgements: This work was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (grant number 451-03-136/2025-03/200023)

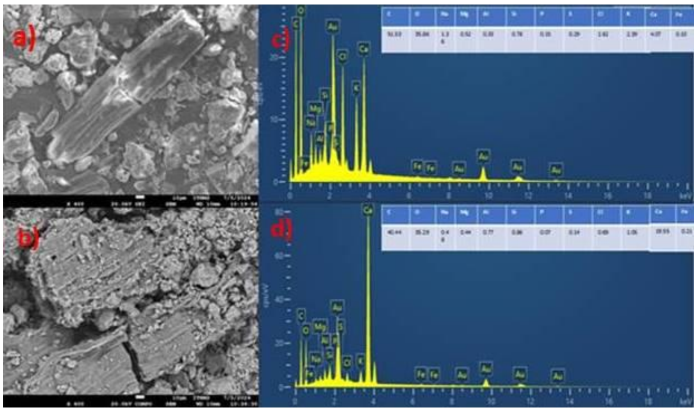

Figure 1. SEM images of *M. spicatum* a) and its biochar b) EDX spectra of *M. spicatum* c) and its biochar d)

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