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Engineering a Fungi–Biochar–UiO-66 Hybrid Platform for Simultaneous Removal of Legacy and Emerging Aquatic Contaminants

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The simultaneous occurrence of toxic heavy metals and nanoplastics in aquatic environments presents a complex challenge for conventional water treatment technologies. Here, we report the development of a sustainable biochar–UiO-66 nanocomposite incorporating biologically synthesized iron oxide nanoparticles for the efficient and concurrent removal of chromium (Cr) ions and nanoplastics from water. Iron oxide nanoparticles were produced via a green fungal synthesis using *Aspergillus iranicus* and immobilized onto sugarcane husk–derived biochar. The iron-loaded biochar was subsequently integrated with the zirconium-based metal–organic framework UiO-66, yielding a chemically stable and hierarchically porous composite material. Material characterization confirmed the successful formation of the UiO-66 framework and uniform dispersion of nanoscale iron oxide (approximately 25–55 nm) within the biochar matrix, resulting in enhanced surface functionality and accessible adsorption sites. Batch adsorption experiments demonstrated that the biochar–UiO-66 composite exhibited significantly improved performance compared to iron nanoparticles alone. Under near-neutral pH and moderate temperature conditions, the composite achieved adsorption capacities exceeding 240 mg g^{-1} for Cr ions and 200 mg g^{-1} for nanoplastics. Adsorption equilibrium data were best described by the Langmuir isotherm model, indicating predominantly monolayer adsorption, with estimated maximum capacities approaching 470 mg g^{-1} for Cr and 290 mg g^{-1} for nanoplastics. Process optimization using Response Surface Methodology combined with Artificial Neural Network modelling identified optimal operational parameters, which were experimentally validated, achieving removal efficiencies greater than 97% for both contaminants. The applicability of the composite was further demonstrated using chromium-impacted groundwater, where rapid and simultaneous removal of Cr and nanoplastics was observed. This study highlights a fungi-assisted biochar–MOF strategy as an eco-friendly and scalable approach for addressing co-existing legacy and emerging water contaminants.