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Tripartite Synergy in a Baffled Duckweed Reactor for 2-Chloro-4-Nitroaniline Remediation: Metabolic Pathways, Microbial Dynamics, and Biochar Valorization

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This study presents a novel, integrated treatment approach for petrochemical wastewater laden with 2-chloro-4-nitroaniline (2-Cl-4-NA) and heavy metals using a baffled duckweed reactor (BDR). Unlike traditional systems, this BDR leverages a unique tripartite synergy between *Lemna gibba*, a specialized symbiotic bacterial community, and in-situ photocatalytic oxidation. At an optimized hydraulic retention time (HRT) of 12 days, the system achieved a superior 2-Cl-4-NA removal efficiency of 84.3%. For the first time, the metabolic pathway in this integrated system was mapped, identifying 4-amino-3-chlorophenol and 2-amino-3-chloro-5-hydroxyphenol as key intermediates. The mechanical novelty lies in the dual-role of *L. gibba*: it facilitates (H₂O₂)-mediated photocatalytic degradation and provides essential oxygen to the rhizosphere, stimulating the production of bacterial monooxygenase and dioxygenase enzymes for ring cleavage. Concurrently, the bacteria break down the toxic parent compound into metabolites that the duckweed subsequently assimilates as a carbon source. High-throughput sequencing confirmed a specialized microbial consortium, dominated by Proteobacteria and Bacteroidetes, with functional genera such as *Dechloromonas* and *Thioclava* driving the degradation. These findings establish the BDR as a highly efficient, sustainable, and multi-pathway bioremediation technology for complex industrial pollutants. The harvested biomass was used for biochar productivity for further application (0.77 g biochar/gbiomass).

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References

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