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Integrated Cyanobacteria–Zeolite Bioprocess for Nutrient Reclamation and Microbial Control

Adriana Hegedűs [1,*], Răzvan Vinţan [1,2], Maria Nicoară [1,3], Bogdan Drugă [1]

[1] Institute of Biological Research Cluj, National Institute of Research and Development for Biological Sciences, Cluj-Napoca, Cluj County, Romania
[2] Faculty of Biology and Geology, "Babeş-Bolyai" University
[3] Doctoral School of Integrative Biology, Faculty of Biology and Geology, "Babeş-Bolyai" University, Cluj-Napoca, Romania
* Correspondence: adriana.hegedűs@icbcluj.ro;

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Abstract: The nitrogen-fixing cyanobacterium *Trichormus variabilis* offers a biotechnological alternative to synthetic fertilizers and a sustainable approach to wastewater remediation. This study evaluates a three-layer culturing system combining *T. variabilis* strain AICB 1382 with natural zeolites for municipal wastewater treatment. Over 14 days, system performance was assessed in terms of nutrient recovery, biomass yield, and microbial community dynamics. Results showed efficient nitrate, ammonium, and phosphate removal. Biomass production was enhanced in zeolite-enriched cultures, where zeolites served dual functions: acting as nutrient adsorbers for gradual release and providing structural support for cyanobacterial biofilm formation. This enabled vertical stratification and the establishment of distinct microbial populations. The presence of *T. variabilis* strongly influenced prokaryotic communities, lowering overall diversity but promoting the decline of multidrug-resistant bacteria. In contrast, zeolite treatments maintained higher bacterial richness, particularly in the lower culture layers. Eukaryotic assemblages were shaped more by wastewater properties than by culturing conditions, though zeolites promoted diatom and green algal growth, which was suppressed when *T. variabilis* dominated. Overall, this stratified bio-cultivation platform demonstrates high efficiency for nutrient reclamation, biomass generation, and microbial risk reduction. The system's design supports potential scale-up into a semi-continuous, self-sustaining biotechnology capable of facilitating biomass harvesting while ensuring environmental safety for agricultural reuse or safe discharge into urban rivers.

Keywords: Trichormus variabilis; Zeolite-Assisted Treatment; Nutrient Removal; Microbial Community Dynamics; Sustainable Wastewater Biotechnology