Seasonal Evaluation of Microalgae-Based Wastewater Treatment for Biomass Valorisation

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Microalgae-based treatment technologies represent a promising alternative to conventional wastewater treatment, offering not only compliance with discharge limits but also alignment with circular economy principles. Wastewater can serve as a nutrient-rich, cost-free medium that supports biomass production with potential for resource recovery.

This study evaluates the feasibility of implementing such systems under the climatic conditions of Northern Italy, with particular focus on the reuse of harvested biomass in agriculture.

Two commonly used cultivation technologies were compared: a 280 L raceway pond (RWP) and a 340 L tubular glass photobioreactor (TGR), both equipped with temperature, pH, and level control systems as well as mixing mechanisms (paddle wheel in the RWP, recirculation pump in the TGR). The systems were fed with screened urban wastewater from a 7000 PE treatment plant selected for its favourable mass-based C:N:P ratio (20:10:1). Although relatively low in nutrients, this influent was chosen to simulate the characteristics of small-scale treatment plants, in line with the new Urban Wastewater Treatment Directive (2024/3019), which mandates treatment starting from 1000 PE.

The reactors operated in semi-continuous mode with daily feeding during daylight hours. Hydraulic retention time was adjusted monthly based on historical irradiance data to ensure light availability remained the main limiting factor for biomass growth. Carbon dioxide was added to maintain optimal pH, and temperature was regulated using a heat pump to enable year-round operation and quantify the associated energy demand.

During winter, the indigenous microalgal consortium was dominated by *Scenedesmus spp.*, achieving high nutrient removal efficiencies in both systems (TN>85%, TP>95%, COD>50%) and satisfactory biomass productivity despite suboptimal environmental conditions. Performance varied significantly across seasons, with biomass yields ranging from 2 to 20 g m^{-2} d^{-1}. Data collection is ongoing for the warmer months to complete the seasonal performance analysis.

Future work will focus on the development and optimization of the process control strategy, starting with flow rate and retention time regulation to enhance biomass productivity and overall process efficiency. The collected biomass will undergo further characterization to assess its potential as a biostimulant for agricultural applications.

Keywords: *microalgae cultivation, wastewater treatment, nutrient recovery, raceway pond, tubular photobioreactor*