Climate-Resilient Microalgae-Based CO_2 Capture Systems for Sustainable Urban Environments

Y. Garrido, J. Quesada-Medina, J.D. Sánchez, A. Sánchez-Zurano, E. Iniesta-López, M.A. Sánchez Muñoz, A. Hernández-Fernández, I. Alfaro Abarca, A. Pérez de los Ríos, and F.J. Hernández-Fernández

Department of Chemical Engineering, Faculty of Chemistry, University of Murcia (UMU), Campus de Espinardo, E-30100 Murcia, Spain

Abstract

Microalgae-based carbon capture has emerged as a sustainable alternative for mitigating atmospheric CO_2 emissions while simultaneously generating valuable biomass. However, the long-term performance of outdoor photobioreactors strongly depends on environmental conditions, particularly seasonal temperature fluctuations. This work evaluates the resilience of a native *Scenedesmus* sp. strain cultivated in a 50 L bubble-column photobioreactor designed for future integration into urban infrastructure for passive atmospheric CO_2 capture.
The photobioreactor was operated under controlled climatic conditions simulating representative spring, extreme summer, and winter environments. Temperature, light intensity, and photoperiod were reproduced using a climatic chamber, while algal growth was monitored through optical density, cell counting, dry biomass, elemental carbon analysis, and physicochemical parameters throughout long-term operation. The system was designed to operate with minimal maintenance, without pH adjustment or medium replacement, reproducing realistic outdoor operating conditions. Results demonstrated continuous cultivation for more than 60 days under spring conditions and approximately 75 days under extreme summer temperatures despite an initial thermal shock. Biomass concentrations reached 1.04 and 0.68 g L^{-1} under spring and summer conditions, respectively, confirming the high thermal tolerance of the native strain. In contrast, temperatures below 10 °C resulted in culture failure, indicating the need for a low-energy heating strategy during winter operation.
The proposed semi-autonomous system demonstrates the feasibility of integrating native microalgae into urban CO_2 capture devices capable of operating under Mediterranean climatic conditions. These findings contribute to the development of climate-resilient nature-based solutions that combine carbon capture, biomass production, and sustainable urban infrastructure, supporting future low-carbon cities and circular economy strategies.

Keywords: carbon capture; climate resilience; microalgae; photobioreactor; sustainable cities