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Response of *Tetradesmus obliquus* to acid blue 92 exposure: Pigment modulation, antioxidant metabolism, fatty acid remodeling, and supporting ANN analysis

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ABSTRACT

Textile dyes rank among the most persistent and hazardous organic pollutants found in aquatic ecosystems. In the present study, the green microalgae *Tetradesmus obliquus* was evaluated for its tolerance and ability to biodegrade the azo dye Acid Blue 92 (AB92), with a thorough examination of the physiological and biochemical reactions of the algae. The algal cultures were exposed to increasing concentrations of AB92, and assessments were made on its growth, pigment composition, lipid profile, and some indicators of oxidative stress. Results indicated a concentration-dependent inhibition of growth and photosynthetic pigments. An artificial neural network (ANN) model was also developed in MATLAB ($R^2 = 0.93$) to predict and optimize AB92 removal efficiency based on key environmental and operational parameters. The reduction in carotenoids, phenolic, and flavonoid compounds suggested their consumption in reactive oxygen species scavenging. Fatty acid analysis revealed a shift from polyunsaturated to saturated and monounsaturated species, reflecting adaptive membrane remodeling under stress. GC–MS analysis of the culture medium confirmed AB92 degradation and identified several intermediates, demonstrating the metabolic transformation of the dye. These findings emphasize the potential of *T. obliquus* as an eco-efficient candidate for azo dye remediation and provide new insights into the interplay between stress physiology and biodegradation mechanisms in microalgae.

1. Introduction

Synthetic dyes are extensively used in textile, leather, pharmaceutical and cosmetics industries, and their discharge into aquatic environments poses serious ecological and toxicological concerns [1–3]. Among synthetic dyes, azo dyes represent the largest class and are particularly persistent because of their complex aromatic structures and azo (–N=N–) linkages, which confer resistance to biodegradation and may produce hazardous aromatic amines upon cleavage [4–6]. Acid Blue 92 (AB92) is a representative sulfonated azo dye commonly employed in textile dyeing processes, and its presence in effluents can reduce light penetration, disturb photosynthetic activity in aquatic systems, and induce oxidative stress in aquatic organisms [6]. Conventional physicochemical treatment methods such as coagulation, adsorption, and advanced oxidation frequently involve substantial operational expenses, energy demand, or the generation of secondary pollution, highlighting the necessity for environmentally friendly and economically viable biological alternatives [7,8].

The use of microalgae for bioremediation has emerged as a viable approach for treating wastewater contaminated with dyes [9]. Microalgae not only assimilate nutrients and organic pollutants but can also adsorb, transform, or metabolically degrade dyes while producing valuable biomass for biofuel or bioproduct applications [10]. Their capability to tolerate and adapt to xenobiotic stress relies on dynamic metabolic and physiological responses, including modulation of photosynthetic pigments, antioxidant defense systems, and membrane lipid composition [11,12]. Consequently, investigating these responses provides insight into both detoxification mechanisms and the potential biotechnological value of treated biomass.

Among green microalgae, the family Scenedesmaceae comprises

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