

EFFECTS OF TiO₂, Cu, AND CuO NANOPARTICLES ON BIOMASS ACCUMULATION AND BIOCHEMICAL COMPOSITION IN THE MICROALGA *PORPHYRIDIUM PURPUREUM*

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Background: Metal and metal oxide nanoparticles can modulate microalgal metabolism. However, their effects strongly depend on chemical nature, applied concentration, and species specificity. *Porphyridium purpureum* is a red microalga of high biotechnological interest due to its rich content of phycobiliproteins, exopolysaccharides, and fatty acids.

Aim of the study: To evaluate the effects of TiO₂, Cu, and CuO nanoparticles on biomass accumulation and the biochemical profile of *Porphyridium purpureum*.

Materials and methods: TiO₂ (20 nm), CuNPs (25 nm), and CuO (50 nm) nanoparticles (Sigma-Aldrich, Merck KGaA, Germany; size confirmed by TEM) were applied to *Porphyridium purpureum* cultures at 0.1-30 mg/L. At the end of cultivation, biomass, proteins, carbohydrates, lipids, phycobiliproteins, photosynthetic pigments (chlorophyll a, b, carotenoids), and malondialdehyde (MDA) were determined.

Results: TiO₂ nanoparticles induced moderate effects on biomass, causing reductions of 6.8-17% compared to the control at all tested concentrations (0.1-30 mg/L). Protein content generally remained at control levels or showed slight increases (up to +8.6% at 0.1 mg/L), except at 30 mg/L, where a decrease of approximately 2% was observed. Carbohydrates remained stable at low concentrations and increased significantly at 30 mg/L (+31.3%). Lipids decreased moderately (11.6-9.4%), while phycobiliproteins fluctuated around control values. MDA levels did not show significant changes, indicating low oxidative stress induced by TiO₂. Cu nanoparticles exerted the most pronounced effects, causing consistent reductions in biomass across all tested concentrations (1.097-1.223 g/L). Protein content remained stable or slightly increased at low concentrations, whereas phycobiliproteins decreased dramatically at 10 mg/L (-49.9%), indicating high sensitivity of accessory pigments to copper ions. MDA levels increased significantly at 10 mg/L (+72%), confirming the onset of intense oxidative stress. CuO nanoparticles induced milder effects than metallic Cu. Biomass ranged from 1.177 to 1.374 g/L, with a tendency to increase at higher concentrations (30 mg/L: 1.374 g/L). Protein content ranged from 85.7% to 108.9% of the control, with no clear concentration-dependent trend. Carbohydrates decreased at all tested concentrations (10.1-12.6% vs. 16.04% in the control), while lipids increased progressively, reaching 14.4% at 30 mg/L (compared to 13% in the control). MDA levels showed a significant, concentration-dependent increase, from +13% at 0.1 mg/L to +155% at 20 mg/L, indicating the strongest cumulative oxidative stress among all tested nanoparticles.

Conclusions: The obtained data demonstrate that the chemical nature of nanoparticles determines the response pattern of the red microalga *Porphyridium purpureum*. Cu nanoparticles exhibit acute toxicity, CuO induces a dominant pro-oxidative effect, while TiO₂ shows the highest level of biological compatibility.

Keywords: *Porphyridium purpureum*; nanoparticles; TiO₂, Cu, CuO; oxidative stress; biochemical composition.

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