

Heavy Metal Effects on Photosynthesis in *Scenedesmus Quadricauda*: Silver and Copper Comparison via OJIP Fluorescence

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Abstract

Heavy metal contamination critically threatens aquatic ecosystems. Microalgae serve as sensitive sentinel organisms, yet conventional growth and survival metrics only reflect ultimate outcomes rather than early cellular damage. This study investigated Ag^+ and Cu^{2+} toxicity to the photosynthetic apparatus of *Scenedesmus quadricauda* using the OJIP chlorophyll fluorescence test. Algal cultures were exposed to AgNO_3 (1–20 μM) and CuSO_4 (10–80 μM) for 2 and 18 hours. Results showed that both metals affected photosynthesis in a concentration- and time-dependent manner, but their toxicity profiles differed markedly. Silver induced rapid, pronounced alterations, with most damage occurring within 2 hours; extending exposure to 18 hours yielded minimal additional toxicity. This acute effect reflects Ag^+ binding to thiol groups, competitive substitution in plastocyanin disrupting electron transport, and oxidative stress induction. Conversely, copper exerted gradual, cumulative toxicity, with severe consequences emerging only after prolonged exposure. This delayed effect stems from Cu^{2+} redox cycling via Fenton-like reactions, generating hydroxyl radicals that cause primary cellular damage. Excess Cu also predisposes PSII to photoinhibition by inducing iron deficiency, reducing chlorophyll content and compromising photosynthetic integrity. For both ions, effects intensified with increasing concentration. These divergent kinetics carry important implications: silver's rapid action suggests acute contamination causes immediate, largely irreversible damage to primary producers, whereas copper's cumulative nature implies chronic low-level exposure leads to progressive ecosystem degradation through sustained photosynthetic impairment. The findings underscore the need for species-specific, time-resolved biomonitoring that integrates biophysical fluorescence parameters with traditional ecotoxicological endpoints, supporting mechanistic understanding of heavy metal–photosystem interactions and informing early-warning systems and evidence-based regulatory thresholds for freshwater ecosystems.

Keywords

Heavy Metals, *Scenedesmus Quadricauda*, Photosynthesis, Ojip Test, Chlorophyll Fluorescence