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Growth and Oxidative Stress of Brittlewort (*Nitella pseudoflabellata*) in Response to Cesium Exposure

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Abstract The present study evaluated the impact of cesium (^{133}Cs) at four concentrations (0, 0.001, 0.01, and 0.1 mg L^{-1}) on growth, concentrations of chlorophyll and carotenoid pigments, and oxidative stress responses in the charophyte, *Nitella pseudoflabellata*, over 30 days. Oxidative stress was quantified by measuring anti-oxidant enzyme activities and H_2O_2 content. When compared with the control, significantly elevated activity levels of the anti-oxidative enzymes ascorbic peroxidase, catalase and guaiacol peroxidase were observed at 0.1 mg L^{-1} (all $p < 0.05$), even though the H_2O_2 level was not significantly elevated. Carotenoid and chlorophyll a and b pigment levels were significantly reduced (all $p < 0.05$) at Cs exposures of 0.01 and 0.1 mg L^{-1}. Photosynthetic efficiency (i.e., F_v/F_m) was significantly reduced ($p < 0.05$) at Cs concentrations $\geq$0.001 mg L^{-1}. Significant reduction ($p < 0.05$) of plant growth (i.e., shoot length) was also observed after 1 week of exposure at Cs concentrations $\geq$0.001 mg L^{-1}. Our results suggested that Cs exposure reduced plant growth and affected plant functioning via activating the defense mechanism against oxidative stress in *Nitella*.

Keywords Oxidative stress · Cesium · Antioxidant enzymes · *Nitella pseudoflabellata*

Aquatic systems are challenged by an array of fluctuations in abiotic stress vectors. In particular, anthropogenic inputs, including heavy metals and other toxic substances, have been prominent in the last few decades and have exceeded the tolerance limits for certain species in aquatic systems (Nagajyoti et al. 2010). Stable Cs (^{133}Cs) is an alkali metal that originates from an aluminosilicate mineral called pollucite (White and Broadley 2000). The major anthropogenic sources of ^{133}Cs are mining of pollucite ores and the production and use of Cs compounds in electronic and energy production (especially coal-burning power plants) (ATSDR 2004). The Cs concentrations found in freshwater and marine ecosystems range from 1×10^{-5} to 12×10^{-3}, and 5×10^{-4} to 2×10^{-3} mg L^{-1}, respectively (Komarov and Bennett 1983), whereas soils have been reported to contain 0–26 mg kg^{-1} ^{133}Cs (Cook et al. 2007). Although the naturally occurring Cs levels are harmless, Cs accumulation over longer time periods can be toxic to plants (Bystrzejewska-Piotrowska et al. 2005; Hampton et al. 2004). Therefore, ^{133}Cs accumulation may pose a risk to aquatic plants in areas with anthropogenic inputs in the long run.

Aquatic flora provide a wide spectrum of ecological functions and play a crucial role in maintaining the integrity of aquatic ecosystems. Their functions include the provisioning of habitats, refuge and food for fish and other invertebrates, primary production, retention of substances, and contributions to biogeochemical cycles (Bennett et al. 2005; Bornette and Puijalon 2011; Folkard 2011; Nepf 2012). Algae are plant-like aquatic organisms containing chlorophyll for photosynthesis, while their bodies are not

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