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Assessing ecotoxicity, removal efficiency, and molecular response of freshwater microalgae to bisphenol AP

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ABSTRACT

Bisphenol AP (BPAP), an analog of BPA and endocrine disrupter, is increasingly being detected in water, signaling its rise as an environmental contaminant similar to BPA, which is known for its health implications. This study investigated the ecotoxicity of BPAP in four freshwater microalgae (*Chlorella sorokiniana, Chlamydomonas mexicana, Scenedesmus obliquus,* and *Chlorella vulgaris*), along with their removal potential and biotransformation. This was followed by *de novo* transcriptomic analysis to elucidate the molecular response after BPAP exposure. The toxicity (120 h-EC_{50}) of BPAP for microalgal species ranged from 1.509 mg L^{-1} to 6.509 mg L^{-1}. *C. mexicana* exhibited the highest removal efficiency of 86.5 % after 12 days, followed by *C. vulgaris* (86.0 %), *S. obliquus* (78.9 %), and *C. Sorokiniana* (56.5 %) at 1 mg L^{-1}. Eight biotransformed BPAP products were analyzed, and their toxicity was predicted to be lower than that of BPAP using the Ecological Structure Activity Relationships software. Transcriptomic analysis of *C. mexicana* revealed the differential expression of 4611 genes in processes related to metabolism, cellular activities, and stress responses. Genes encoding methyltransferases, glycosyltransferases, and various oxidoreductases, including electron-transferring flavoprotein dehydrogenase and glutaredoxin, were significantly upregulated in algal cells exposed to BPAP, suggesting the potential of *C. mexicana* for BPAP detoxification via glycosylation and transmethylation. These results offer novel insights into the ecotoxicity, removal potential, and biotransformation of BPAP in freshwater microalgae, with transcriptomic analysis, elucidating the molecular mechanisms of BPAP detoxification for effective environmental remediation.

1. Introduction

The widespread industrial application of bisphenols, primarily as plasticizers in products like plastics, thermal papers, and pharmaceuticals and personal care products, has led to considerable pollution and increased health concerns [1]. Due to substantial scientific evidence highlighting the toxicity of bisphenol A (BPA), its use has been restricted in several countries, particularly in food-contact materials [2]. Consequently, industries have been transitioning to “BPA-free” alternatives, with bisphenol AP (BPAP) emerging as a substitute in advanced electronics and the specialized coating industry, with exposure levels reaching 1155 μg p^{-1} d^{-1} [3]. However, the safety of BPAP has not been well established. BPAP can disrupt blood glucose homeostasis and exhibit weak estrogenicity and strong anti-estrogenicity (IC_{50} = 2.35 μM), which could impair sexual development in immature female mice [4]. Furthermore, BPAP’s additional phenyl group attached to the

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Abbreviations: BPAP, Bisphenol AP; BPA, Bisphenol A; LC_{50}/EC_{50}, acute toxicity value; ECOSAR, Ecological Structure Activity Relationships program; HPLC, High–performance Liquid Chromatography; UHPLC/Q-TOF-MS, Ultra High-Performance Liquid Chromatography-Quadrupole Time-of-Flight Mass Spectrometry.

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