

Water treatment by adsorption using sage-based adsorbents: removal of pollutants and phytotoxicity.

Abstract

Water pollution remains one of the most pressing environmental challenges, threatening ecosystems, food security, and human health. Industrial effluents, agricultural runoff, and domestic wastewater often introduce dyes, nitrates, phosphates, and pathogenic microorganisms into aquatic systems. Conventional water treatment approaches can be costly or energy-intensive, or produce secondary waste, emphasizing the urgent need for sustainable, eco-friendly alternatives. In this context, plant-based adsorbents have gained increasing attention due to their low cost, availability, and biodegradability. This study explores the adsorption potential of sage-derived bioadsorbents in removing various classes of pollutants. Three materials were prepared and evaluated: untreated sage powder (S), pyrolyzed sage charcoal at 300 °C (C), and activated charcoal (AC), obtained through phosphoric acid activation followed by pyrolysis at 450 °C. The materials were tested against methylene blue dye, nitrate, and phosphate solutions, as well as bacterial suspensions containing *Escherichia coli*, total coliforms, and *Streptococcus D*. The results demonstrated that AC exhibited the highest efficiency in phosphate (0.122 mg/g, 49%) and nitrate removal (1.72 mg/g), as well as superior bacterial reduction, highlighting its multifunctional performance. Interestingly, untreated sage powder showed the greatest affinity for dye removal, achieving a methylene blue adsorption capacity of 4.34 mg/g, which suggests that different pollutants may interact preferentially with specific bioadsorbents. Phytotoxicity tests using *Eruca vesicaria* revealed low toxicity for AC in liquid conditions, and both S and AC supported plant growth when incorporated into soil-like media, indicating safe agricultural reuse. Overall, these findings underscore the potential of sage-derived materials, particularly activated charcoal, as versatile, low-toxicity bioadsorbents for sustainable and integrated water purification systems.