

Agricultural Waste-Derived Bio-Adsorbents for Sustainable Water and Wastewater Treatment

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Abstract: *The increasing contamination of water resources by heavy metals, dyes, nutrients, pesticides, pharmaceuticals, and other pollutants has created a need for effective, affordable, and environmentally sustainable water-treatment technologies. Agricultural activities and food-processing industries generate substantial quantities of residues, including rice husk, sugarcane bagasse, wheat straw, corn cobs, coconut shells, fruit peels, and spent tea leaves. These materials are often discarded, burned, or used in low-value applications, despite their potential to serve as raw materials for bio-adsorbent production. Agricultural waste-derived bio-adsorbents offer a promising approach to wastewater treatment because their lignocellulosic composition, surface functional groups, and porous structures can support the removal of various dissolved contaminants. This review examines the development, modification, characterization, and environmental applications of agricultural waste-derived bio-adsorbents, considering research available up to 31 December 2022. The major categories of raw biomass adsorbents, chemically modified materials, biochar, and activated carbon are discussed. Important adsorption mechanisms, including ion exchange, surface complexation, electrostatic interactions, pore filling, and precipitation, are described along with the effects of pH, adsorbent dosage, contact time, initial pollutant concentration, temperature, and competing ions. The review also considers regeneration, safe disposal, economic feasibility, and the limitations of scaling laboratory findings to real wastewater systems. Published studies demonstrate that agricultural residues can be converted into useful treatment materials, but their practical application requires standardized testing, evaluation in complex wastewater matrices, and careful assessment of the entire material life cycle. Agricultural waste valorization therefore represents a promising contribution to circular-economy approaches for water and wastewater management..*

Keywords: Agricultural waste, bio-adsorbents, biosorption, wastewater treatment, biochar, activated carbon, heavy metals, dyes, sustainable water treatment, waste valorization.