Investigation of bamboo-derived adsorbents for water treatment: Challenges in water hardness removal caused by calcium and magnesium ions

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Bamboo is a renewable, low-cost biomass that has gained attention as a sustainable adsorbent for water purification. This study explored the potential of bamboo-derived adsorbents for removing calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, the main contributors to water hardness. Raw bamboo leaves and stems, chemically modified using NaOH, HNO_3, and EDTA, as well as bamboo-derived biochar, were investigated. Biochar was prepared by pyrolyzing bamboo stems at 500, 600, and 700°C for 1 hour and bamboo leaves at 250, 300, 350, and 400°C for 30 minutes to enhance porosity and surface reactivity. Characterization of adsorbents was carried out using SEM, FTIR, XRD, XRF, and methylene blue surface area analysis. SEM showed a porous surface favorable for methylene blue adsorption, while FTIR confirmed C-H, Si-O groups involved in binding. XRD indicated a low-crystallinity amorphous structure typical of lignocellulosic biomass. The Surface area of the adsorbent was 9.30 m^2/g. Batch adsorption with AAS analysis showed raw bamboo had low or negative removal, with XRF confirming desorption of native Ca and Mg ions. To improve performance, chemical modifications and biochar production were tested; however, among modifications, NaOH (0.1 M) achieved the highest removals, with 25.61% for Ca^{2+} using bamboo stem and 34.53% for Mg^{2+} using bamboo leaves. HNO_3, dual acid–alkali treatments, and EDTA modification provided only marginal improvements (≤13.49% for Ca^{2+} and ≤3.50% for Mg^{2+}), while some conditions resulted in desorption. Comparative testing of other natural biosorbents including rice husk, coconut coir, banana peel, *Panicum maximum*, tea waste, *Eichhornia crassipes*, and areca nut husk also showed poor performance. These findings highlight limitations of untreated or modified biomass for hardness ion removal, stressing the need for advanced activation to improve functional groups, porosity, and ion exchange. Bamboo has potential as a sustainable adsorbent, but current forms are ineffective, needing chemical activation and process optimization.

Keywords: *Bamboo, Water hardness, Adsorption, Biochar, Modification*