Sustainable Agriculture with KGM-HPMC-Based Biochar Hydrogels: Enhancing Soil, Water and Nutrient Use

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Abstract:

Chile is one of the countries most severely impacted by climate change, facing extreme droughts, persistent water scarcity, and significant declines in agricultural productivity. The excessive use of chemical fertilizers has further contributed to soil degradation and environmental pollution. In response, this study presents the development of eco-friendly nanocomposite hydrogels based on konjac glucomannan (KGM) and hydroxypropyl methylcellulose (HPMC), incorporating biochar derived from grape and olive residues. These hybrid systems combine the biocompatibility, biodegradability, and water-retaining capabilities of biopolymers with the functional advantages of metal oxide nanoparticles, offering innovative solutions for modern agriculture and environmental remediation. Additionally, using agroindustrial residues contributes to waste valorization and supports circular economy principles.These hydrogels aim to improve soil quality, enhance water retention, and enable controlled nutrient delivery for sustainable agriculture.The hydrogels were synthesized via chemical crosslinking and reinforced with metal oxide nanoparticles (FeO, ZnO, MgO) and an NPK fertilizer complex. Comprehensive physicochemical characterization was conducted using FTIR, SEM-EDS, TEM, XRD, TGA-DSC, and BET analysis. Swelling behavior and nutrient release were evaluated under different pH conditions.

Results revealed that the nanocomposite hydrogels formed stable, porous polymer networks with enhanced thermal stability and mechanical strength. High water retention capacity and sustained nutrient release confirmed their suitability as multifunctional soil conditioners. The integration of biochar and nanoparticles was validated structurally and contributed to improved functional performance. In conclusion, these biodegradable and non-toxic hydrogels represent a promising technology for climate-resilient and circular agriculture, particularly in drought-affected regions like central Chile. Their scalable design and use of agroindustrial waste align with sustainable development and environmental protection goals.

Keywords:

Nanotechnology, Biopolymer-based Hydrogels, Sustainable Agriculture, Controlled Release.