Green Synthesis of Multifunctional Biopolymer-Based Hydrogels for Sustainable Environmental and Biomedical Applications

BasharXXX[1]*, XYZ Kumar[2], ABC Ahmad[1]

Affiliations:

[1]Department of Chemistry, Islamic University of Science and Technology (IUST), Awantipora, Jammu & Kashmir, India

[2]Department of Materials Science, XYZ University, India

Corresponding Author:

Email: xxxxxx@iust.ac.in

Abstract

Hydrogels are three-dimensional polymeric networks capable of absorbing and retaining large quantities of water while maintaining their structural integrity. The growing demand for environmentally friendly and multifunctional materials has stimulated the development of hydrogels synthesized from renewable biopolymers using green chemistry principles. In this study, a biodegradable hydrogel was synthesized using modified pectin and carboxymethyl chitosan through a non-toxic crosslinking strategy under mild reaction conditions. The synthesized hydrogel exhibited rapid gelation, high swelling capacity, excellent mechanical stability, and enhanced water retention properties.

The structural and physicochemical characteristics of the hydrogel were investigated using Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), Thermogravimetric Analysis (TGA), and rheological studies. The hydrogel demonstrated a highly porous interconnected network with a swelling ratio exceeding 1500% in distilled water and maintained structural stability over multiple swelling–deswelling cycles. Furthermore, the material showed promising adsorption efficiency for model organic dyes and sustained release behavior for model therapeutic compounds, indicating its multifunctional nature. The developed hydrogel offers a sustainable platform for applications in controlled drug delivery, wastewater treatment, wound dressing, and atmospheric water harvesting. The use of naturally derived polymers significantly reduces environmental impact while improving biodegradability and biocompatibility. This work highlights the potential of green synthesis strategies in developing next-generation functional materials that support circular economy principles and contribute to sustainable technological development. Such innovations align with the objectives of **VIKSIT J&K 2047** by promoting eco-friendly materials, resource conservation, and advanced manufacturing technologies.

Keywords:

Biopolymer Hydrogels; Green Synthesis; Pectin; Carboxymethyl Chitosan; Sustainable Materials; Drug Delivery; Environmental Remediation

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