Chapter 8
Bio-Nanocomposites as Functional Materials for the Future: Integrating Green Chemistry and Nanotechnology for Global Sustainability Challenges

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ABSTRACT

Bio-nanocomposites are leading materials that leverage the strengths of nanotechnology with sustainable, bio-based polymers and present a greener option for traditional composites. These are composites that comprise nanoscale fillers in the form of nanoparticles, nanofibers, and nanotubes, and bio-based matrices of starch, cellulose, and proteins. These are stronger in terms of mechanical, thermal, and barrier properties, and their green profile remains unscathed. Bio-nanocomposites present opportunities to answer global sustainability questions such as decreasing dependence on petroleum-based plastics, energy efficiency, and promoting the cir-

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cular economy by combining green chemistry and nanotechnology. This chapter addresses synthesis routes, properties, characterization techniques, performance, and different applications in packaging, automotive, electronics, and agriculture. It also addresses future research directions to design the properties of bio-nanocomposites for large-scale commercialization.

1. INTRODUCTION

1.1 Definition of Bio-Nanocomposites

Bio-nanocomposites are multi-phase materials combining biobased polymers and nanometer-dimensioned fillers or nanoparticles, creating products that have higher mechanical, thermal, and functional properties with their eco-friendliness. Most of these products have a renewable or biodegradable matrix (e.g., cellulose, starch, chitosan, or proteins) reinforced with nanofillers (e.g., carbon nanotubes, nano clays, metal nanoparticles, or graphene) added for enhanced performance traits (Shibata, 2011). The nanoscale size of these fillers improves the matrix properties, providing substantial benefits over conventional composites, such as enhanced strength, flexibility, barrier properties, and lower environmental footprint. Bio-nanocomposites are a promising area in material science, combining the advantages of natural polymers with the special properties of nanomaterials for various applications (Thirugnanasambandan, 2022).

1.2 Historical Background

The development of bio-nanocomposites was spurred by the increasing need for green materials in the latter half of the 20th century due to environmental pressure on non-biodegradable plastics and hazardous industrial practices. Nanotechnology research, early on, was instrumental in revealing the distinct characteristics of nanomaterials, including high surface area, mechanical strength, and reactivity.