Chapter 7
Bio-Based Nanocomposites in Sustainable Agriculture:
Bridging Materials Science and Food Security

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ABSTRACT

This chapter explores the integration of bio-based nanocomposites in agricultural systems to address challenges of climate change, resource depletion, and food security. Focusing on the synthesis and characterization of nanocomposites from renewable resources, the work examines green approaches and regenerability aspects crucial for sustainable implementation. Applications including soil conditioning, controlled release fertilizers, crop protection, and water management are analyzed

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through practical case studies demonstrating enhanced agricultural productivity with minimal environmental impact. A comprehensive sustainability assessment evaluates these materials throughout their lifecycle, considering biodegradability, compostability, and economic feasibility. The chapter identifies emerging trends such as multi-functional nanocomposites and integration with precision agriculture technologies, while addressing regulatory considerations essential for responsible development and adoption in sustainable food production systems.

INTRODUCTION

Agriculture faces immense pressures from rapid population growth, climate change, and environmental deterioration, straining the global food supply (Irewale et al., 2024). The world population is projected to reach 9.7 billion by 2050, necessitating a 70% increase in food production to meet the growing demand (FAO, 2017). However, this increase must be achieved sustainably, without further degrading the environment or depleting finite resources. Conventional agricultural practices often rely on synthetic materials and chemicals that can degrade soil health and ecological balance. For example, the excessive use of chemical fertilizers has led to nutrient runoff, eutrophication of water bodies, and greenhouse gas emissions (Savci, 2012). Similarly, the widespread application of synthetic pesticides has raised concerns about their impacts on non-target organisms, biodiversity, and human health (Nicolopoulou-Stamati et al., 2016).

Bio-based nanocomposites, made from renewable resources, offer a promising sustainable alternative by combining the benefits of nanoscale properties with biodegradability and regenerability (Vishnuvarthanan, 2024). These materials enable the development of innovative solutions to enhance agricultural productivity while minimizing environmental impact. Nanocomposites are hybrid materials that incorporate nanoscale fillers, such as nanoparticles, nanofibers, or nanosheets, into a matrix material (Mohanty et al., 2018). The nanoscale dimensions of the fillers impart unique properties, such as high surface area, enhanced mechanical strength, and improved thermal and barrier properties (Dasari et al., 2009). When combined with biopolymers derived from renewable resources, such as starch, cellulose, chitosan, or lignin, bio-based nanocomposites exhibit additional advantages of biodegradability, biocompatibility, and reduced environmental impact (Khalil et al., 2014).

The potential applications of bio-based nanocomposites in agriculture are diverse and far-reaching. They can be used for soil conditioning, improving soil structure, water retention, and nutrient availability. Controlled release fertilizers based on nanocomposites can enhance nutrient use efficiency and reduce environmental losses (Channab et al., 2024). Nanocomposite coatings and films can provide barrier

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