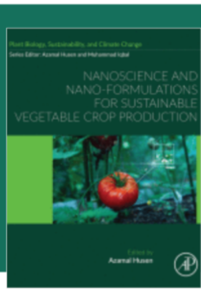

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Nanoscience and Nano-Formulations for Sustainable Vegetable Crop Production

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Key Features

- Highlights novel research in nanomaterials, nanocomposites, and nano-encapsulation, showcasing their roles in improving seed performance, stress tolerance, soil and water management, and postharvest quality
- Explores the integration of nano-sensors and omics approaches to enable precision monitoring and data-driven decision-making
- Includes essential considerations on biosafety, toxicity mitigation, and regulatory compliance, supporting informed and responsible utilization of nanotechnology in

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Nanoscience and Nano-Formulations for Sustainable Vegetable Crop Production

CHAPTER

4 Exposure of nano-formulations to vegetable crops and changes in morpho-physiological, anatomical, and molecular features

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4.1 Introduction

The twenty-first century agricultural sector faces unprecedented challenges, including soil degradation, climate change, pest resistance, and the need to sustainably feed a growing global population. In this context, nanotechnology presents a powerful set of tools to augment crop production and address sustainability concerns (Kah et al., 2013; Wang et al., 2016). Defined as the science of manipulating matter at scales of 1–100 nm, nanotechnology allows for the design of materials that exhibit novel physicochemical properties such as increased reactivity, enhanced solubility, and controlled-release profiles, which can be harnessed to improve plant health and productivity (Joudeh and Linke, 2022).

Vegetable crops, due to their high economic value and nutritional importance, are especially susceptible to environmental fluctuations and require precise management inputs. Traditional agricultural practices often involve excessive application of chemical fertilizers and pesticides, leading to ecological degradation, pest resurgence, and reduced soil fertility (Derosa et al., 2010; Apoorva and Kundlas, 2024). Nano-formulations offer a viable alternative by enabling targeted delivery of nutrients or active compounds, reducing environmental load while improving efficiency (Rico et al., 2011; Easwaran et al., 2024).

Nano-agrochemicals are generally classified into several categories: nano-fertilizers that enhance nutrient uptake and utilization efficiency; nano-pesticides that improve pest control with lower toxicity; nano-coatings that extend the post-harvest shelf life of vegetables; and nano-sensors that facilitate real-time monitoring of plant health and soil conditions (Rastogi et al., 2017). These materials can enter plant

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