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NANOSCIENCE AND NANO-FORMULATIONS FOR SUSTAINABLE VEGETABLE CROP PRODUCTION

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CHAPTER

3 Fullerene and carbon nanotubes for vegetable seed priming, germination, and seedling development

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3.1 Introduction

Seed germination represents a pivotal stage in the plant life cycle, directly affecting crop yield, uniformity, and resilience to environmental stressors. For vegetable crops, namely tomato, lettuce, cucumber, and spinach, achieving uniform germination and vigorous seedling development is essential to ensure marketable quality and consistent harvesting. Traditional seed priming methods, viz., hydropriming, osmopriming, and hormonal priming, have proven effective in enhancing germination; however, their benefits appear to have reached a plateau (Farooq et al., 2019; Waqas et al., 2019). This limitation has driven the exploration of innovative technologies like nanotechnology, which presents new opportunities to address enduring agricultural challenges. Among the various nanomaterials (NMs) under investigation, carbon-based nano-particles (NPs), particularly fullerenes and carbon nanotubes (CNTs), have shown promising effects on seed performance. Their capability to penetrate seed coats, interact with intracellular structures, and regulate gene expression positions them as powerful tools in modern seed priming strategies (Husen and Siddiqi, 2014a; Husen, 2020; Fonseca et al., 2024; Chaachouay et al., 2025). Nanotechnology involves the manipulation of materials at the atomic or molecular level, typically within the 1–100 nm range. In plant science, its applications include nano-fertilizers, nano-pesticides, growth stimulants, and seed coatings (Husen, 2022, 2023). Owing to their high surface-area-to-volume ratio, increased reactivity, and ability to cross biological membranes, NPss are particularly effective in interacting with plant systems (Husen and Siddiqi, 2014b). Fullerene (C_{60}), referred to as "buckyballs," is a

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