DOI: https://doi.org/10.57233/ihcfs.001

ISBN: 978-978-68-07775

BOOK OF PROCEEDINGS

IHCFS – 2025 WEBSITE: fos.fugusau.edu.ng

1ST INTERNATIONAL HYBRID CONFERENCE OF FACULTY OF SCIENCE

(A PUBLICATION OF FACULTY OF SCIENCE, FEDERAL UNIVERSITY GUSAU, NIGERIA)

GREEN NANO BIOTECHNOLOGY FOR SUSTAINABLE INDUSTRIAL GROWTH: THE EMERGING ROLE OF INSECT-DERIVED NANOPARTICLES

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ABSTRACT

The integration of nanotechnology with biological sciences has created new opportunities in sustainable industrial development. Green nanobiotechnology leverages biological systems to produce nanoparticles in ways that are environmentally safe and economically viable. Among these systems, insects have emerged as a promising, underexplored resource. This paper examines the role of insect-derived nanoparticles within green nanobiotechnology, exploring their synthesis mechanisms, functional properties, and applications across agriculture, healthcare, and energy sectors. It further emphasizes how incorporating insect-based nanomaterials can drive sustainable economic growth while supporting circular economy strategies and safeguarding the environment.

Keywords: Eco-friendly-Nanomaterials, Green -Nanobiotechnology, Insect-derived Nanoparticles, Sustainable industry

1.0 INTRODUCTION

Industrial advancement has historically been achieved at the expense of environmental integrity. Modern economies must therefore innovate to achieve growth that is ecologically balanced and socially beneficial (Huston et al., 2021). Nanotechnology is a transformative field, but conventional methods of nanoparticle synthesis often rely on toxic chemicals, energy-intensive processes, and costly reagents (Khan *et al.,* 2022). Green nanobiotechnology offers a paradigm shift by employing plants, microbes, and increasingly, insects, as biological platforms for nanoparticle production under mild, eco-friendly conditions (Saxena *et al.,* 2025).

Insects, abundant and diverse, possess biochemical compounds—proteins, lipids, enzymes, and chitin-derived polymers—that make them ideal for nanoparticle synthesis. Insect-derived nanoparticles combine biocompatibility, structural versatility, and functional tunability, presenting opportunities for sustainable solutions across multiple industries (Mei *et al.,* 2024).

2.0 AIM

The aim of this paper is to explore the potential of insect-derived nanoparticles in green nanobiotechnology and to evaluate their contributions to sustainable industrial development.

3.0 OBJECTIVES

To investigate the biological mechanisms and insect-derived compounds involved in the green synthesis of nanoparticles.

To characterize the structural and functional properties of nanoparticles produced using insect-based systems.

To evaluate the potential applications of insect-derived nanoparticles in agriculture, healthcare, and energy for sustainable industrial development.

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3.1 Insect-Derived Nanoparticles: Mechanisms and Materials

Lipid-mediated reduction: Insect oils contain fatty acids and antioxidants capable of reducing metal salts into nanoparticles without external harsh reagents (Alfutaimani *et al.,* 2024).

Protein stabilization: Enzymes and peptides in insect tissues act as natural capping agents, stabilizing nanoparticles and influencing size and morphology (Suvarnaet *et al.,* 2018).

Chitin and chitosan-based scaffolds: Exoskeleton-derived polysaccharides provide biodegradable frameworks for nanoparticle formation and controlled release systems (Lateef *et al.,* 2016; Flieger *et al.,* 2021).

3.2 Characterization and types of Nanoparticles Produced Using Insect-Based Systems

Nanoparticles synthesized through insect-based systems represent an emerging frontier in green nanobiotechnology due to their biocompatibility, eco-friendly production pathways, and diverse functional potentials (Ajaykumar *et al.,* 2023). To fully understand their usefulness and application potential, it is essential to characterize both their structural and functional properties using reliable analytical approaches. Structural characterization focuses on identifying the physical and chemical attributes of the nanoparticles (Wadhwa *et al.,* 2022). Techniques such as scanning electron microscopy (SEM) or transmission electron microscopy (TEM) are used to reveal particle morphology, shape, and size. Dynamic light scattering (DLS) provides information on the hydrodynamic size distribution and colloidal stability, while X-ray diffraction (XRD) helps determine the crystalline pattern of the biosynthesized nanoparticles. Fourier-transform infrared spectroscopy (FTIR) further confirms the presence of functional groups responsible for nanoparticle formation, stabilization, or bioactivity. Together, these techniques offer a comprehensive understanding of the particles external form, structural arrangement, and surface chemistry (Mourdikoudis *et al.,* 2018; Alfryyan *et al.,* 2022)

Functional characterization assesses how these nanoparticles behave and interact within biological or environmental systems. Techniques such as UV–Visible spectroscopy help evaluate optical properties and stability, while biological assays such as antimicrobial, antioxidant, cytotoxicity, or catalytic tests are employed to determine activity profiles. These functional evaluations provide insight into how the insect-derived nanoparticles can be applied in areas such as biomedicine, environmental remediation, agriculture, and material science (Lin *et al.,* 2014; Zhang *et al.,* 2016; Jakinala *et al.,* 2021).

Generally, characterizing the structural and functional properties of nanoparticles produced using insect-based systems is a crucial step in validating their quality, understanding their mechanisms of formation, and determining their suitability for practical applications. This comprehensive evaluation strengthens the scientific basis for the use of insects as sustainable nano-factories within green nanobiotechnology science (Lin *et al.,* 2014; Zhang *et al.,* 2016; Jakinala *et al.,* 2021).

3.2.1 Types of Nanoparticles

Metallic nanoparticles (e.g., gold, silver, zinc oxide) with antimicrobial and catalytic properties (Gahlawat and Choudhury, 2019).

Polymeric nanoparticles for drug delivery and agricultural bioformulations (Begines et al., 2020).

Hybrid composites integrating insect-derived chitosan with other biopolymers for advanced material applications (Jakinala *et al.,* 2021).

3.3 Applications in Some Sectors

Agriculture

Nano-fertilizers improving nutrient efficiency and reducing chemical runoff (Rodríguez-Seijo *et al.,*2025).

Bio-nanopesticides offering precision pest control with minimal ecological disruption (Rodríguez-Seijo *et al.,*2025).

Soil remediation using chitosan-based nanoparticles to improve soil structure and microbial balance (Gomes *et al.,* 2022).

Healthcare

Antimicrobial agents effective against multidrug-resistant pathogens.

Wound healing materials promoting tissue regeneration and reducing infection risk.

Drug and vaccine delivery systems utilizing biocompatible insect-derived carriers for targeted therapeutic release (Khalifah *et al.,* 2025).

Energy and Environment

Bio-catalysts enhancing biofuel production efficiency.

Nanostructured materials for improved solar cells and energy storage systems.

Waste valorization where insect farming on organic waste streams generates both protein/feed and nanoparticle precursors, supporting circular economy initiatives (Katre *et al.,* 2024).

Economic and Sustainability Impact

Harnessing insects for nanoparticle synthesis creates opportunities for localized production, reducing dependency on imported raw materials and chemicals. It promotes small and medium enterprises (SMEs), rural development, and job creation. The dual-purpose nature of insect farming—providing both nutritional and industrial products—maximizes resource use efficiency and aligns with sustainable development goals (SDGs) related to industry, innovation, and responsible consumption (Mittal *et al.,* 2020; Sundararajan *et al.,* 2023).

5.0 CHALLENGES AND FUTURE PERSPECTIVES

Challenges include standardizing synthesis protocols, ensuring regulatory safety, and addressing consumer perception of insect-based technologies. Future research should focus on; Optimizing insect strains for higher nanoparticle yield. - Developing scalable bioprocessing systems. - Establishing regulatory frameworks and green certification pathways.

6.0 CONCLUSION

Insect-derived nanoparticles represent a vital next step in the evolution of green nanobiotechnology. Their integration into agriculture, healthcare, and energy industries offers a pathway to sustainable industrial growth while addressing global environmental challenges. As innovation advances, insects will likely transition from being alternative resources to core components of future bio-based economies.

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