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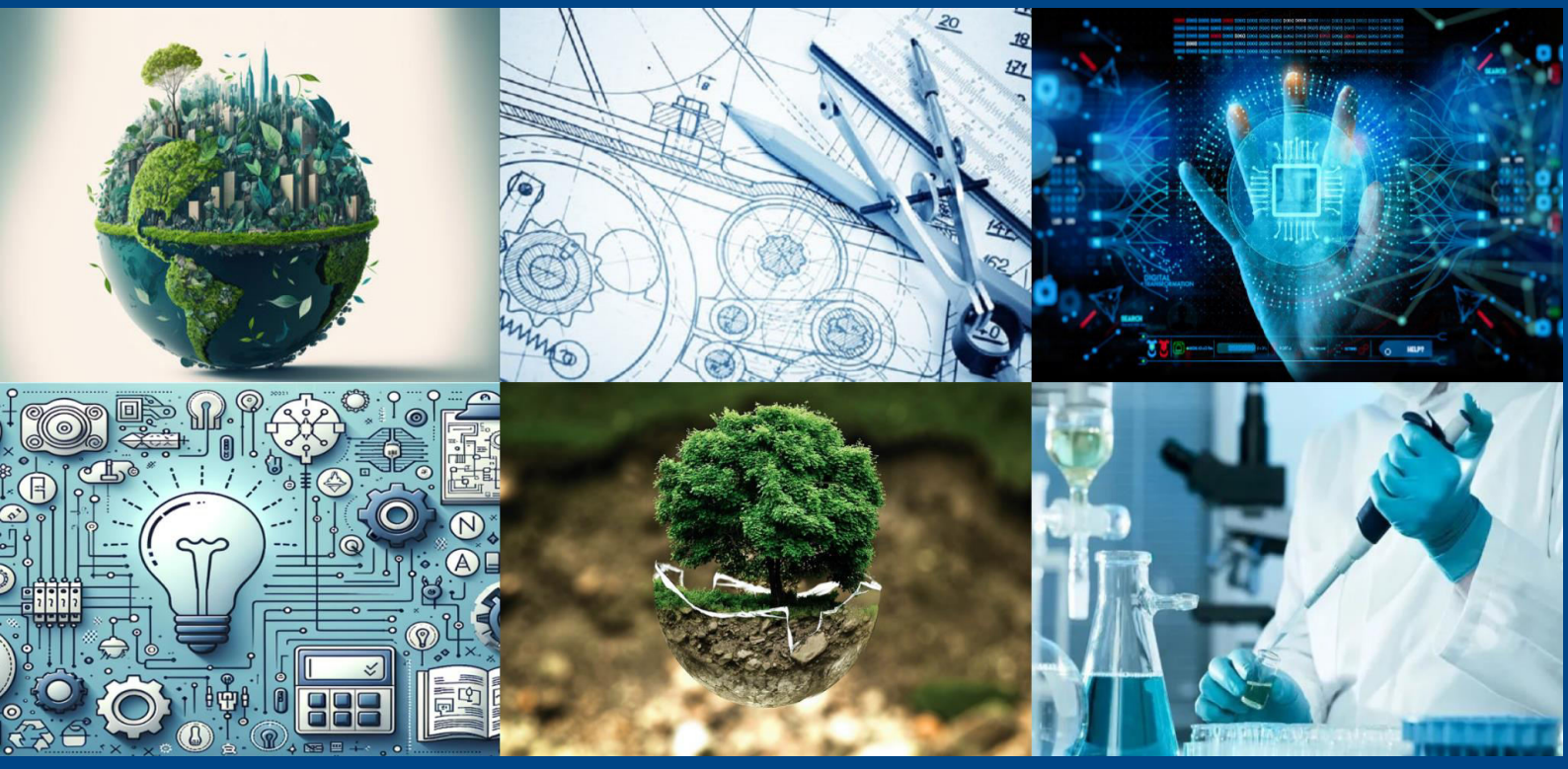

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Green Synthesis of Acorus calamus-Based Nanocomposites for Mosquito Larvicidal and Antibacterial Applications

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ABSTRACT: The increasing threat of vector-borne diseases and the rise in antimicrobial resistance have created an urgent need for sustainable and eco-friendly alternatives to conventional chemical treatments. Green synthesis of nanoparticles using medicinal plant extracts offers a promising solution, combining biological efficacy with environmental safety. Acorus calamus, a traditionally known therapeutic plant, contains bioactive compounds with proven insecticidal and antimicrobial properties. This study proposes the green synthesis of nanocomposites using Acorus calamus extract and explores their potential in mosquito larval control and antibacterial applications. The use of plant-mediated nanomaterials may offer a dual-functional approach—targeting mosquito vectors while also serving as effective agents against bacterial pathogens. The proposed work supports eco-toxicological safety and aligns with current global efforts to develop sustainable biopesticides and antibacterial agents.

KEYWORDS: Acorus calamus, green synthesis, nanocomposites, mosquito larvicidal activity, antibacterial applications, eco-friendly nanoparticles.

I. INTRODUCTION

1.1. Background

The escalating prevalence of vector-borne diseases and the surge in antimicrobial resistance have underscored the pressing need for innovative, sustainable, and eco-friendly alternatives to conventional chemical treatments. Traditional synthetic pesticides and antibiotics, while effective, often lead to environmental contamination, non-target species toxicity, and the development of resistant strains. Consequently, the scientific community has been exploring green nanotechnology as a promising avenue to address these challenges.

Green synthesis of nanoparticles leverages biological entities, such as plant extracts, to produce nanomaterials in an environmentally benign manner. This approach not only reduces the reliance on hazardous chemicals but also enhances the biocompatibility and functionality of the synthesized nanoparticles. Among various medicinal plants, Acorus calamus (commonly known as sweet flag) has garnered attention due to its rich phytochemical profile and documented therapeutic properties.

1.2. Significance of Acorus calamus

Acorus calamus is a perennial herbaceous plant traditionally used in Ayurvedic and Chinese medicine. Its rhizomes and leaves are rich in bioactive compounds, including phenylpropanoids, monoterpenes, sesquiterpenes, and flavonoids. These phytochemicals exhibit a range of biological activities, such as antimicrobial, insecticidal, antioxidant, and anti-inflammatory effects.

The plant's insecticidal properties have been particularly noteworthy. Studies have demonstrated the efficacy of Acorus calamus extracts against various mosquito species, including *Aedes aegypti* and *Culex quinquefasciatus*, which are vectors for diseases like dengue, Zika, and filariasis. The larvicidal activity is attributed to the presence of compounds like β-asarone and other volatile oils that disrupt the normal development of mosquito larvae.

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Furthermore, the antimicrobial potential of Acorus calamus has been validated against a spectrum of bacterial pathogens. The plant's extracts have shown inhibitory effects on both Gram-positive and Gram-negative bacteria, making it a candidate for developing alternative antibacterial agents.

1.3. Green Synthesis of Nanoparticles

Nanotechnology has revolutionized various sectors, including medicine, agriculture, and environmental science. The unique physicochemical properties of nanoparticles, such as high surface area-to-volume ratio and quantum effects, enable novel applications. However, conventional methods of nanoparticle synthesis often involve toxic chemicals and high energy inputs.

Green synthesis offers a sustainable alternative by utilizing biological systems for nanoparticle production. Plant-mediated synthesis is particularly advantageous due to the abundance of phytochemicals that can act as reducing and capping agents. These biomolecules facilitate the reduction of metal ions to nanoparticles and stabilize them, preventing aggregation.

The process typically involves mixing a plant extract with a metal salt solution under ambient conditions. The phytochemicals in the extract reduce the metal ions to their respective nanoparticles, which can then be harvested and characterized. This method is not only eco-friendly but also cost-effective and scalable.

1.4. Acorus calamus-Mediated Nanoparticle Synthesis

The use of Acorus calamus in green nanoparticle synthesis is a burgeoning area of research. The plant's rich phytochemical content makes it an ideal candidate for producing various metal nanoparticles, including silver, gold, and iron oxide. These nanoparticles inherit the biological properties of the plant, enhancing their efficacy in applications like antimicrobial and larvicidal activities.

For instance, iron oxide and manganese oxide nanoparticles synthesized using Acorus calamus extracts have demonstrated significant larvicidal activity against mosquito larvae. The polyphenolic compounds in the plant are responsible for the bio-reduction and stabilization of these nanoparticles.

Similarly, silver nanoparticles produced using Acorus calamus have shown potent antibacterial effects against multiple bacterial strains. The synergistic action of the plant's phytochemicals and the inherent properties of silver nanoparticles contribute to their enhanced antimicrobial activity.

1.5. Mosquito Larvicidal Applications

Mosquito-borne diseases remain a significant public health concern globally. The development of resistance to conventional insecticides necessitates alternative control strategies. Nanoparticles synthesized via green methods offer a promising solution due to their unique mechanisms of action.

Nanoparticles can penetrate the exoskeleton of mosquito larvae, leading to cellular damage and death. Their small size allows for better dispersion in aquatic habitats, ensuring effective larvicidal activity. When combined with bioactive plant extracts like Acorus calamus, the efficacy of these nanoparticles is further amplified.

Studies have reported that crude hexane leaf extracts of Acorus calamus exhibit higher mortality percentages against *Aedes aegypti* and *Culex quinquefasciatus* larvae. Incorporating these extracts into nanoparticle synthesis could enhance their larvicidal properties, providing an eco-friendly alternative to chemical larvicides.

1.6. Antibacterial Applications

The rise of antibiotic-resistant bacteria poses a significant challenge to healthcare systems worldwide. There is an urgent need for novel antibacterial agents that can circumvent resistance mechanisms. Green-synthesized nanoparticles, particularly those mediated by medicinal plants, have emerged as potential candidates.

Silver nanoparticles, for example, are known for their broad-spectrum antibacterial activity. When synthesized using Acorus calamus extracts, these nanoparticles exhibit enhanced efficacy due to the combined antimicrobial properties of silver and the plant's phytochemicals. The nanoparticles can disrupt bacterial cell walls, generate reactive oxygen species, and interfere with DNA replication, leading to bacterial cell death.

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Research indicates that such green-synthesized nanoparticles are effective against various bacterial strains, including *Escherichia coli*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*. Their biocompatibility and reduced toxicity make them suitable for applications in wound healing, coatings for medical devices, and water purification systems.

1.7. Advantages of Green Nanotechnology

The integration of green chemistry principles into nanotechnology offers multiple benefits:

- Environmental Sustainability: Eliminates the use of hazardous chemicals, reducing environmental pollution.
- Cost-Effectiveness: Utilizes readily available plant materials, lowering production costs.
- Biocompatibility: Produces nanoparticles that are less toxic and more compatible with biological systems.
- Scalability: Simplified synthesis processes allow for large-scale production.
- Multifunctionality: Combines the inherent properties of nanoparticles with the bioactivity of plant extracts, enhancing efficacy.

1.8. Challenges and Future Perspectives

Despite the promising potential of green-synthesized nanoparticles, several challenges need to be addressed:

- Standardization: Variability in plant extract composition can affect nanoparticle synthesis and efficacy.
- Mechanistic Understanding: Further research is needed to elucidate the exact mechanisms of action of these nanoparticles.
- Regulatory Frameworks: Establishing guidelines for the safe use and disposal of nanoparticles is crucial.
- Toxicological Assessments: Comprehensive studies are required to assess the long-term effects of nanoparticles on human health and the environment.

Future research should focus on optimizing synthesis protocols, exploring the full spectrum of biological activities, and developing formulations for practical applications. Collaborations between interdisciplinary fields can accelerate the translation of laboratory findings into real-world solutions.

II. DISCUSSION

The green synthesis of nanocomposites using Acorus calamus extract offers a promising and environmentally sustainable approach for developing effective mosquito larvicidal and antibacterial agents. The phytochemicals present in Acorus calamus, such as phenylpropanoids and flavonoids, act as natural reducing and stabilizing agents, facilitating the formation of nanoparticles with enhanced bioactivity. This synergy between the plant's bioactive compounds and the physicochemical properties of nanoparticles leads to improved efficacy compared to conventional chemical agents.

Mosquito larval control through green-synthesized nanocomposites addresses the growing issue of insecticide resistance and environmental toxicity associated with synthetic larvicides. The nanocomposites demonstrate potent larvicidal effects by disrupting larval physiology and cellular functions, ultimately leading to mortality. Additionally, their small size and high surface area improve dispersion and bioavailability in aquatic habitats, ensuring effective contact with mosquito larvae.

From an antibacterial perspective, Acorus calamus-based nanocomposites exhibit significant inhibitory effects on both Gram-positive and Gram-negative bacteria. The dual action of metallic nanoparticles and plant-derived phytochemicals enhances bacterial membrane disruption, generation of reactive oxygen species, and interference with intracellular components, thus preventing bacterial growth and proliferation. This is especially valuable in the context of increasing antibiotic resistance, providing a novel alternative to conventional antibiotics.

Moreover, the green synthesis method ensures eco-friendly production, reducing hazardous chemical waste and toxicity. However, challenges remain regarding the standardization of synthesis protocols and the need for thorough toxicological evaluations to confirm the safety of these nanomaterials in practical applications. Overall, Acorus calamus-mediated nanocomposites hold great potential as dual-function agents in integrated vector management and antimicrobial therapy, aligning with global sustainability goals.

III. CONCLUSION

The green synthesis of nanocomposites using Acorus calamus extract presents a sustainable and eco-friendly strategy for developing potent mosquito larvicidal and antibacterial agents. The inherent bioactive compounds of Acorus calamus synergize with the unique properties of nanoparticles, resulting in enhanced biological efficacy against mosquito larvae and pathogenic bacteria. This dual-functional approach addresses critical challenges in vector control and antimicrobial resistance, offering a safer alternative to conventional chemical pesticides and antibiotics. While promising, further research is necessary to optimize synthesis methods, ensure consistent quality, and assess long-term safety and environmental impacts. Ultimately, Acorus calamus-based nanocomposites have significant potential to contribute to integrated pest management and antimicrobial applications, supporting public health and environmental sustainability.

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