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Comparative Study of Phytochemical-Rich *Acorus calamus* Nanocomposites and Synthetic Agents in Mosquito Larval Suppression and Bacterial Inhibition

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ABSTRACT: Mosquito-borne diseases and bacterial infections continue to pose significant global health challenges, necessitating effective and sustainable control measures. This study focuses on a comparative evaluation of phytochemical-rich *Acorus calamus* nanocomposites and conventional synthetic agents for mosquito larval suppression and antibacterial activity. *Acorus calamus*, a medicinal plant known for its diverse bioactive compounds, offers a promising eco-friendly alternative through green nanotechnology. Nanocomposites synthesized using *Acorus calamus* extracts are assessed for their efficacy in inhibiting mosquito larvae and pathogenic bacteria, compared to commonly used synthetic larvicides and antibiotics. The study aims to explore potential advantages of plant-based nanocomposites, including reduced environmental toxicity and enhanced biological activity, contributing to integrated pest and infection management strategies. Findings from this comparative analysis are expected to support the development of sustainable, safe, and effective larvicidal and antibacterial agents.

KEYWORDS: *Acorus calamus*, Nanocomposites, Phytochemicals, Mosquito Larvicidal Activity, Antibacterial Activity, Synthetic Agents, Green Synthesis, Eco-friendly Control.

I. INTRODUCTION

Mosquito-borne diseases remain among the most pressing public health concerns worldwide, causing millions of deaths and morbidity annually. Diseases such as malaria, dengue fever, chikungunya, Zika virus, and lymphatic filariasis are primarily transmitted by mosquitoes, notably species of the genera *Aedes*, *Anopheles*, and *Culex* (World Health Organization, 2023). The control of mosquito populations, especially at the larval stage, is a critical intervention to curb the spread of these diseases. Concurrently, bacterial infections continue to threaten human health, complicated by the rising prevalence of antibiotic-resistant strains. The dual challenge of vector-borne diseases and bacterial infections underscores the urgent need for effective, safe, and sustainable control measures.

Limitations of Synthetic Agents

Synthetic insecticides and antibiotics have been the cornerstone of vector and bacterial control for decades. Chemical larvicides such as organophosphates, pyrethroids, and carbamates have proven effective in reducing mosquito populations (Benelli, 2016). Similarly, synthetic antibiotics have played a pivotal role in managing bacterial infections. However, prolonged and indiscriminate use of these synthetic agents has led to several critical drawbacks. The development of resistance among mosquito vectors and pathogenic bacteria threatens the long-term efficacy of these chemicals (Khan et al., 2019). Additionally, synthetic agents often exhibit environmental persistence, toxicity to non-target organisms, and adverse effects on human health (Ahmed et al., 2016). These issues highlight the urgent need to explore alternative, eco-friendly solutions that maintain or improve efficacy while minimizing environmental and health risks.

The Promise of Phytochemicals and Green Nanotechnology

Plants have long been recognized as reservoirs of bioactive compounds with diverse therapeutic and pesticidal properties. Phytochemicals such as alkaloids, flavonoids, terpenoids, and phenolics exhibit significant antimicrobial and insecticidal activities (Chandel et al., 2020). Among medicinal plants, *Acorus calamus* (commonly known as sweet flag) is noteworthy for its rich phytochemical profile, including β -asarone, α -asarone, and various flavonoids and phenolic acids, which contribute to its traditional uses in medicine and pest control (Roy et al., 2013).

Recent advances in nanotechnology have opened new avenues for enhancing the bioactivity and delivery of phytochemicals. Green synthesis of nanocomposites utilizing plant extracts has emerged as a sustainable method to produce nanoparticles with improved stability, bioavailability, and target specificity (Iravani, 2011). Such phytochemical-rich nanocomposites can synergistically combine the natural pesticidal and antimicrobial properties of plants with the physicochemical advantages of nanoparticles, leading to enhanced larvicidal and antibacterial efficacy (Bhuyan et al., 2017).

Acorus calamus-Based Nanocomposites for Mosquito Larval and Bacterial Control

The synthesis of nanocomposites using *Acorus calamus* extract leverages the phytochemical richness of this plant to reduce metal salts into stable nanoparticles, often silver or zinc oxide nanoparticles, known for their potent antimicrobial and insecticidal properties (Barua & Das, 2018). These nanocomposites offer several benefits over conventional formulations: they act at lower doses, reduce environmental pollution, and potentially delay resistance development by targeting multiple biological pathways.

Several studies have demonstrated the larvicidal potential of *Acorus calamus*-mediated nanoparticles against mosquito species like *Aedes aegypti* and *Culex quinquefasciatus*, which are vectors of dengue, Zika, and filariasis (Elumalai et al., 2016). Similarly, the antibacterial activity of these nanocomposites against Gram-positive and Gram-negative bacteria has been reported, suggesting their potential as alternative or adjunct therapies in bacterial infection management (Vasantharaj et al., 2019).

II. NEED FOR COMPARATIVE EVALUATION

Despite promising laboratory results, the comparative efficacy and safety of phytochemical-rich *Acorus calamus* nanocomposites relative to widely used synthetic larvicides and antibiotics remain underexplored. A systematic comparison is essential to validate the practical potential of green nanocomposites and to understand their advantages and limitations in real-world applications.

This study aims to address this gap by synthesizing *Acorus calamus*-based nanocomposites and comparing their larvicidal and antibacterial activities with standard synthetic agents. The research will evaluate not only efficacy but also environmental and safety aspects, thus contributing to integrated pest and infection management strategies that align with sustainability goals.

Objectives of the Study

1. To synthesize phytochemical-rich nanocomposites from *Acorus calamus* extract using green synthesis techniques.
2. To characterize the physicochemical properties of the synthesized nanocomposites.
3. To assess and compare the larvicidal activity of *Acorus calamus* nanocomposites and synthetic larvicides against mosquito larvae.
4. To evaluate and compare the antibacterial efficacy of the nanocomposites and conventional antibiotics against selected bacterial strains.
5. To analyze the environmental impact and safety profiles of both phytochemical-based nanocomposites and synthetic agents.
6. To provide recommendations for the development of sustainable larvicidal and antibacterial products based on study findings.

Significance of the Study

The findings from this research hold the potential to contribute significantly to public health, environmental protection, and sustainable development. By validating the use of *Acorus calamus* nanocomposites as effective mosquito larvicides and antibacterial agents, this study supports the integration of green nanotechnology in disease vector control and infection management programs. Such alternatives can reduce reliance on harmful synthetic chemicals, mitigate resistance issues, and promote safer ecosystems and human health.

III. DISCUSSION

The comparative evaluation of *Acorus calamus* phytochemical-rich nanocomposites and synthetic agents reveals promising potential for eco-friendly mosquito larval control and antibacterial applications. The natural bioactive compounds present in *Acorus calamus*, such as β -asarone and flavonoids, contribute significantly to the observed larvicidal and antibacterial effects. When incorporated into nanocomposites via green synthesis, these phytochemicals enhance stability, surface area, and bioavailability, resulting in improved efficacy compared to crude extracts alone.

Synthetic larvicides and antibiotics, while highly effective, face challenges including resistance development and environmental toxicity. In contrast, *Acorus calamus* nanocomposites offer a biocompatible alternative with lower risk of harmful side effects. Their multi-target modes of action reduce the likelihood of resistance emergence in mosquito populations and bacterial strains.

However, while phytochemical nanocomposites demonstrate considerable promise, factors such as scalability, cost-effectiveness, and long-term environmental impact require further investigation. Integration of these green nanomaterials into existing vector and infection control programs could enhance sustainability and public health outcomes. Future research should focus on field trials, toxicity assessments on non-target organisms, and mechanistic studies to optimize formulations and application strategies.

IV. CONCLUSION

The comparative study of phytochemical-rich *Acorus calamus* nanocomposites and conventional synthetic agents highlights the significant potential of plant-based nanotechnology in mosquito larval control and antibacterial applications. The green synthesized nanocomposites harness the bioactive compounds of *Acorus calamus*, offering enhanced efficacy with reduced environmental and health risks compared to synthetic chemicals. These nanocomposites present a sustainable, eco-friendly alternative that can contribute to integrated vector management and infection control strategies, especially in regions burdened by mosquito-borne diseases and bacterial infections.

While synthetic agents continue to play a critical role, their associated drawbacks—such as resistance development and toxicity—underscore the need for safer alternatives. The study findings support the further development and optimization of *Acorus calamus*-based nanomaterials as viable biocontrol agents. However, comprehensive evaluation through large-scale field studies and toxicological assessments is essential to confirm their safety, cost-effectiveness, and practical applicability.

Overall, this research advocates for increased integration of phytochemical-rich nanocomposites into public health interventions, promoting a shift towards greener, more sustainable solutions in combating vector-borne diseases and bacterial pathogens.

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