Nevertheless, plant extracts sometimes exhibit lower immediate potency or shorter duration of action than conventional insecticides, which can limit their standalone effectiveness in some settings (Pavela et al., 2019; Ahamd et al., 2023). Combining botanical products with other control methods or improving formulations can help overcome these limitations while preserving their eco-friendly benefits. Overall, plant-based mosquito control agents represent promising alternatives or complements to chemical insecticides by offering effective vector management with fewer environmental and health risks.

8 Discussion and Conclusion

The experimental evaluation of plant-based extracts against *Anopheles gambiae* mosquitoes demonstrated significant larvicidal and adulticidal activities, confirming the potential of botanical compounds as effective mosquito control agents. Extracts from plants such as *Parthenium hysterophorus* and *Nicotiana tabacum* showed high toxicity with low LC50 values, indicating strong potency even at low concentrations. These findings align with broader literature reporting that secondary metabolites like alkaloids, terpenoids, and flavonoids disrupt mosquito physiology through multiple mechanisms including neurotoxicity and enzyme inhibition. The observed synergistic effects between different plant extracts or when combined with conventional insecticides further enhance their efficacy, suggesting opportunities for integrated approaches to overcome resistance issues. However, while laboratory results are promising, the translation to field conditions remains limited due to factors such as environmental degradation of active compounds and variability in mosquito populations. Stability challenges of some plant extracts under natural conditions can reduce residual activity, necessitating improved formulations or delivery systems to maintain effectiveness over time. Additionally, sublethal effects on mosquito development and reproduction observed in some studies indicate that botanical extracts may contribute to population suppression beyond immediate mortality, which is important for sustainable vector control strategies.

Plant-based extracts offer a valuable alternative or complement to synthetic insecticides due to their biodegradability, lower toxicity to non-target organisms, and reduced risk of resistance development in mosquitoes. Their broad-spectrum activity against various mosquito life stages-including larvae, pupae, and adults-makes them versatile tools for integrated vector management programs. Moreover, the availability of many effective plants locally supports cost-effective production and use in endemic regions where resources are limited. Advances in formulation technologies such as nanoencapsulation and synergistic blends have improved stability and potency, enhancing field applicability. Despite these advantages, challenges remain for large-scale implementation including standardization of extract composition, regulatory approval processes, and ensuring consistent efficacy across diverse ecological settings. Field validation studies are urgently needed to assess epidemiological impacts and optimize application protocols. Combining plant-based products with other control measures like insecticide-treated nets or biological agents could maximize overall effectiveness while minimizing environmental impact. Thus, plant extracts hold considerable promise as eco-friendly components of sustainable mosquito control strategies.

This study's primary limitation lies in its laboratory-based design which may not fully capture the complexities encountered under field conditions such as environmental variability and interactions with other biotic factors. The stability and persistence of active compounds in natural habitats require further investigation to ensure practical utility. Additionally, the potential development of resistance against botanical insecticides has not been extensively studied and warrants long-term monitoring. Future research should focus on large-scale field trials to validate laboratory findings and evaluate the epidemiological benefits of plant-based interventions . Exploring synergistic combinations among different plant extracts or with conventional insecticides could improve efficacy while reducing doses required. Advances in formulation science aimed at enhancing stability, controlled release, and target specificity will be critical for successful deployment. Finally, comprehensive safety assessments on non-target organisms and environmental fate studies must accompany efficacy evaluations to support regulatory approval and public acceptance.