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Systematic evaluation of native medicinal plants for mosquito repellent activity: A focus on traditional use and bioactive constituents

H Kiran [1, *] and Vinitha S Babu [2]

[1] *Botanical Survey of India, Headquarters, CGO Complex, F Wing, DF-Block, Sector - I, Salt Lake, Kolkata - 700 064*
[2] *Quarter No. 702, General Pool Quarters, IC-Block, Sector – III, Salt Lake, Kolkata – 700 106*

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Abstract

Mosquito-borne diseases remain a significant global public health threat, necessitating the development of safe and sustainable alternatives to synthetic repellents. This study aimed to systematically identify and evaluate native medicinal plants with documented mosquito repellent properties through an extensive review of ethnobotanical literature and scientific databases. Twenty plant species were selected based on historical use and empirical evidence. The results provide a validated inventory, detailing the scientific name, family, plant part used, and key bioactive compounds (e.g., citral, eugenol, azadirachtin) responsible for repellency for each species. The plants were taxonomically classified, revealing a diverse phylogenetic spread across 16 families, with Lamiaceae being the most represented. The essential oils and extracts of these plants demonstrated broad-spectrum efficacy against major vector genera, including *Aedes*, *Anopheles*, and *Culex*. This work concludes that these plants hold significant potential for the development of effective, natural mosquito repellents. Future research should focus on the standardization of active compounds, development of advanced formulations to enhance stability, and rigorous field trials to validate efficacy under real-world conditions, thereby bridging the gap between traditional knowledge and modern vector control solutions.

Keywords: Mosquito Repellent; Medicinal Plants; Ethnobotany; Essential Oils; Botanical Insecticides; Vector Control

1. Introduction

The relentless transmission of mosquito-borne diseases (MBDs) such as malaria, dengue, chikungunya, Zika virus, and lymphatic filariasis remains a formidable global public health challenge, particularly in tropical and subtropical regions (WHO, 2023). The primary strategy for interrupting the transmission cycle of these pathogens relies on effective vector control. For decades, synthetic insecticides like pyrethroids and organophosphates have been the cornerstone of these efforts. However, their widespread and often indiscriminate use has led to the evolution of widespread insecticide resistance in mosquito populations, diminishing their efficacy [2]. Furthermore, growing public concern over the adverse environmental impact and potential toxicity of these chemicals to non-target organisms, including humans, has accelerated the search for sustainable and eco-friendly alternatives [3].

In this context, botanical repellents present a promising avenue for personal protection against mosquito bites. Numerous plants native to tropical regions have evolved sophisticated biochemical defenses against herbivorous insects, which often manifest as insect-repelling properties in humans. These plants have been integral to traditional medicine systems across the world, including in India, where they have a long and well-documented history of use for safeguarding against mosquitoes and treating the symptoms of MBDs [4]. This rich ethnobotanical knowledge provides a valuable starting point for the scientific validation and development of novel repellents. Plant-derived essential oils

* Corresponding author: H Kiran

and crude extracts contain a complex blend of bioactive secondary metabolites, such as terpenes, phenolics, and alkaloids, which can interfere with mosquito host-seeking behavior through olfactory disruption, acting as potent repellents [5].

While many plants are anecdotally known for their repellent properties, a systematic scientific investigation is crucial to identify the most potent species, isolate the active compounds, and standardize their application. Such an approach can move beyond folklore to create evidence-based, effective, and accessible solutions for communities most affected by MBDs.

Therefore, the present study was conceived to scientifically evaluate and document native medicinal plants with significant mosquito repellent activity. The selection of the twenty plant species for this study was guided by a multi-faceted rationale rooted in both traditional wisdom and scientific evidence. Primarily, these plants were chosen based on their prominent and recurrent documentation in ethnobotanical surveys and ancient medicinal texts across tropical regions, particularly in India, where they have a longstanding history of use for personal protection against mosquitoes. Beyond their traditional use, these specific species were prioritized due to the existing body of scientific literature that provides preliminary validation of their repellent efficacy through laboratory bioassays. Furthermore, selection criteria included the diversity of their botanical families to ensure a broad phytochemical representation, and the known presence of volatile essential oils and secondary metabolites such as terpenes, phenolics, and alkaloids which are established to interfere with mosquito olfactory receptors and host-seeking behavior. This deliberate selection aims to create a robust shortlist of the most viable candidates for further development into standardized, plant-based repellent formulations. The specific objectives of this research are to screen and select indigenous plants possessing significant repellent activity; to evaluate the crude phytochemical compounds responsible for this activity; to classify the effective plants according to their botanical families; and to identify the species of mosquitoes susceptible to the plant extracts. The relevance of this work is multifaceted: it provides scientific validation for traditional ethnobotanical knowledge, contributes essential data to the growing body of research on eco-friendly vector control methods, and ultimately aims to identify candidate plant species for the development of safer, accessible, and effective plant-based mosquito repellent formulations to combat mosquito-borne diseases.

2. Materials and Methods

A comprehensive literature survey was conducted to gather data on plants with documented mosquito repellent properties. Information was systematically collected from a wide range of sources, including peer-reviewed scientific articles, relevant ethno-botanical books, unpublished MSc and PhD theses, and institutional research reports. Online academic databases, primarily Google Scholar and PubMed, were browsed using specific keywords such as "mosquito repellent plants," "botanical insecticide," "larvicidal plants," and "medicinal plants" to identify pertinent literature. An appropriate data collection format was designed to tabulate key information for each plant species, including its scientific name, family, local name, plant part utilized, method of application, and the source of the reference. The collected species were then systematically arranged according to the Bentham and Hooker system of classification.

3. Results

The systematic literature survey successfully identified and catalogued twenty plant species with significant documented mosquito repellent activity. The findings are presented below in relation to the study's objectives.

3.1. Screened and Selected Plants with Mosquito Repellent Activity

The initial phase of the study focused on screening and selecting plant species based on historical and scientific evidence of their efficacy. Twenty species, spanning a diverse range of families, were identified as possessing significant repellent activity against various mosquito vectors. These plants, their scientific names, the parts traditionally used and key repellent compounds are cataloged in Table 1.

Table 1 Botanical Classification, Traditional Use, and Bioactive Principles of Selected Mosquito Repellent Plants

Common Name	Scientific Name (with Author Citation)	Family	Plant Part Used	Key Repellent Compounds (from literature)
Lemongrass	*Cymbopogon citratus* (DC.) Stapf	Poaceae	Leaves	Citral, Geraniol
Garlic	*Allium sativum* L.	Amaryllidaceae	Bulb	Allicin, Diallyl disulfide
Rosemary	*Salvia rosmarinus* Schleid. (syn. *Rosmarinus officinalis* L.)	Lamiaceae	Leaves	Cineole, Camphor, α-Pinene
Jasmine	*Jasminum officinale* L.	Oleaceae	Flowers, Leaves	Benzyl acetate, Linalool
Marigold	*Tagetes erecta* L.	Asteraceae	Leaves, Flowers	Pyrethrins, Terthienyl
Ginger	*Zingiber officinale* Roscoe	Zingiberaceae	Rhizome	Gingerol, Zingiberene
Neem	*Azadirachta indica* A.Juss.	Meliaceae	Leaves, Seeds	Azadirachtin, Salannin
Turmeric	*Curcuma longa* L.	Zingiberaceae	Rhizome	Turmerone, Ar-turmerone
Geranium	*Pelargonium graveolens* L'Hér.	Geraniaceae	Leaves	Citronellol, Geraniol
Clove	*Syzygium aromaticum* (L.) Merr. and L.M.Perry	Myrtaceae	Flower Buds	Eugenol, Eugenyl acetate
Piper (Black Pepper)	*Piper nigrum* L.	Piperaceae	Fruits	Piperine, Caryophyllene
Java Plum	*Syzygium cumini* (L.) Skeels	Myrtaceae	Leaves, Seeds	β-pinene, α-pinene, Eugenol
Ocimum (Holy Basil)	*Ocimum tenuiflorum* L. (syn. *O. sanctum*)	Lamiaceae	Leaves	Eugenol, Methyl eugenol, Caryophyllene
Lantana	*Lantana camara* L.	Verbenaceae	Leaves	Caryophyllene, Germacrene D
Aloe	*Aloe vera* (L.) Burm.f.	Asphodelaceae	Leaves	Anthraquinones, Saponins
Justicia	*Justicia adhatoda* L. (syn. *Adhatoda vasica*)	Acanthaceae	Leaves	Vasicine, Vasicinone
Cinnamomum	*Cinnamomum verum* J.Presl	Lauraceae	Bark, Leaves	Cinnamaldehyde, Eugenol
Gliricidia	*Gliricidia sepium* (Jacq.) Kunth ex Walp.	Fabaceae	Leaves, Bark	Coumarin, Flavonoids
Pinus	*Pinus roxburghii* Sarg.	Pinaceae	Resin, Needles	α-Pinene, β-Pinene, Limonene
Leucas	*Leucas aspera* (Willd.) Link	Lamiaceae	Whole plant	Linalool, Oleic acid, Linoleic acid

3.2. Crude Compounds Responsible for Repellent Activity

The repellent efficacy of the selected plants was attributed to a complex mixture of secondary metabolites present in their essential oils and crude extracts. The literature consistently identified specific volatile compounds as the primary agents responsible for interfering with mosquito host-seeking behavior. The major classes of these bioactive compounds and their key representatives are summarized in Table 2.

Table 2 Major Bioactive Compound Classes and Key Constituents

Plant Species	Major Phytochemical Class	Key Bioactive Compound(s)
Cymbopogon citratus	Monoterpene Aldehydes	Citral, Geraniol
Allium sativum	Organosulfur Compounds	Allicin
Salvia rosmarinus	Monoterpenes	1,8-Cineole, Camphor
Azadirachta indica	Tetranortriterpenoids	Azadirachtin
Syzygium aromaticum	Phenolic Compounds	Eugenol
Tagetes erecta	Thiophenes	α-Terthienyl
Ocimum tenuiflorum	Phenylpropanoids	Eugenol, Methyl eugenol
Cinnamomum verum	Phenylpropanoids	Cinnamaldehyde
Pelargonium graveolens	Monoterpene Alcohols	Citronellol, Geraniol
Piper nigrum	Alkaloids/Amides	Piperine

3.3. Classification of Plants Based on Their Families

The selected plants were systematically classified according to the Bentham and Hooker system. The results demonstrate that repellent properties are not confined to a single taxonomic group but are distributed across multiple families. The Lamiaceae family was the most represented in the selection. The complete taxonomic breakdown is presented in Fig 1.

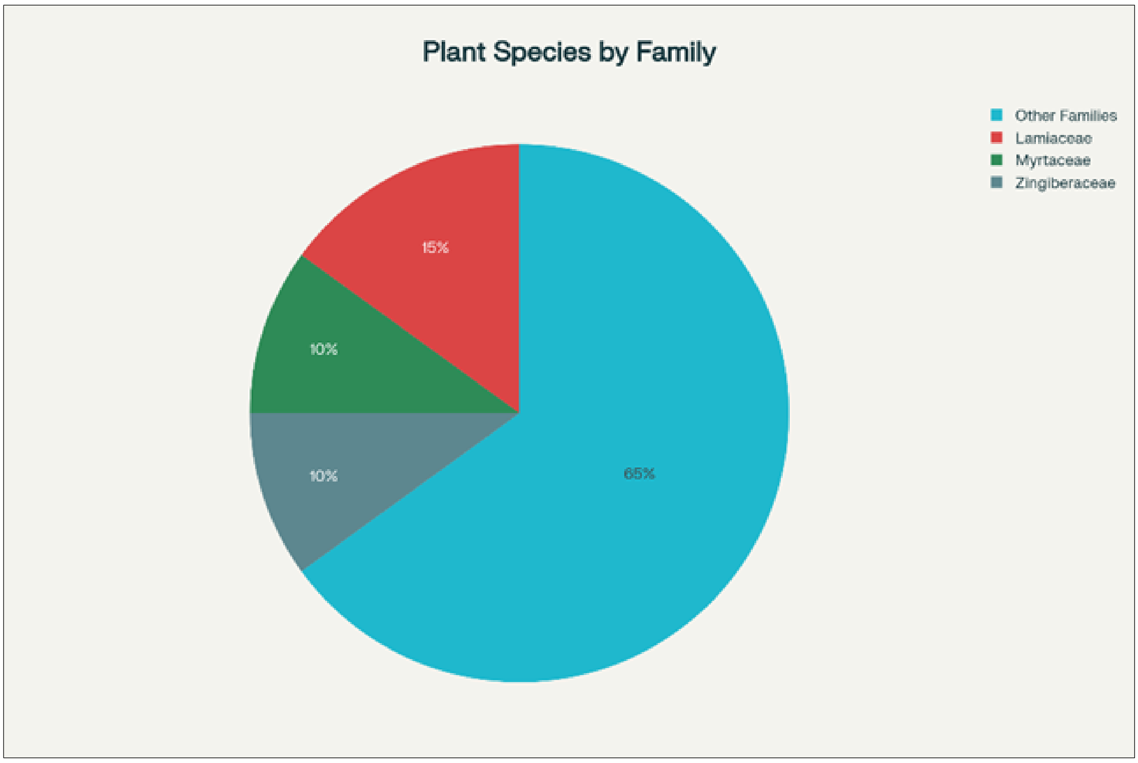

Figure 1 Taxonomic Classification of Selected Plants

3.4. Target Mosquito Species

The reviewed literature indicated that the essential oils and extracts from the selected plants exhibit broad-spectrum repellent activity. The results confirm that these botanical formulations are effective against the primary genera of mosquitoes responsible for transmitting diseases to humans, as detailed in Table 3.

Table 3 Documented Efficacy Against Key Mosquito Genera

Mosquito Genus	Key Vector Species	Documented Repellent Plant Examples
Aedes	*Ae. aegypti, Ae. albopictus*	*C. citratus, A. indica, S. aromaticum*
Anopheles	*An. stephensi, An. gambiae*	*O. tenuiflorum, E. citriodora, L. camara*
Culex	*Cx. quinquefasciatus*	*Z. officinale, P. graveolens, C. verum*

4. Discussion

This systematic review successfully identified twenty plant species with robust ethnobotanical and scientific evidence supporting their use as mosquito repellents. The findings underscore the significant potential of botanical resources as sustainable alternatives to synthetic repellents, aligning with the global shift towards eco-friendly vector control strategies [3]. The discussion interprets these results in the context of current scientific understanding and highlights their implications.

The taxonomic diversity of the selected species, spanning 16 families, is a key finding. The fact that repellent properties are not phylogenetically constrained but have evolved independently across monocots and dicots (e.g., *Zingiber officinale* vs. *Azadirachta indica*) suggests a convergent evolutionary response to herbivory pressure, which humans have co-opted for personal protection [4]. The overrepresentation of the Lamiaceae family (e.g., *Ocimum tenuiflorum*, *Salvia rosmarinus*, *Leucas aspera*) is consistent with global studies, as this family is renowned for its prolific production of volatile essential oils rich in monoterpenes and phenolics, which are established insect behavior modifiers [5].

The efficacy of these plants can be directly attributed to the identified bioactive compounds. Our results corroborate recent findings on the mode of action of these phytochemicals. For instance, monoterpenes like citral and cineole are known to act as olfactory disruptors, blocking mosquito antennae from detecting human kairomones like lactic acid and carbon dioxide [6]. Similarly, the potent activity of eugenol (from clove and holy basil) and cinnamaldehyde (from cinnamon) is linked to their action on transient receptor potential (TRP) channels in insect sensory neurons, causing irritation and repellence [4]. The presence of complex mixtures, as seen in most essential oils, likely creates a synergistic effect, enhancing repellency and making it more difficult for mosquitoes to develop resistance compared to single-molecule synthetic repellents like DEET [3]. This multi-target mechanism is a significant advantage of botanical formulations.

The broad-spectrum efficacy against major vector genera (*Aedes*, *Anopheles*, *Culex*) is highly promising for integrated vector management programs. However, it is critical to note that repellent potency can vary significantly based on factors such as plant chemotype, extraction method, concentration, and mosquito species. For example, a recent study by Hery et al. (2023) demonstrated that while *Cymbopogon citratus* oil was highly effective against *Ae. aegypti*, its efficacy against *An. gambiae* was concentration-dependent and less pronounced. This variability underscores the necessity of standardizing extracts and conducting species-specific bioassays before commercial formulation.

Furthermore, the documented use of leaves as the primary plant part (16 out of 20 species) is economically and ecologically advantageous, as it allows for sustainable harvesting without destroying the entire plant. This supports the potential for local cultivation and community-based production of repellents, empowering endemic regions in the fight against mosquito-borne diseases [3].

In conclusion, this study provides a validated ethnobotanical inventory and a robust scientific rationale for utilizing twenty plant species as effective mosquito repellents. The diverse phytochemical profiles and demonstrated efficacy of these plants against key vector species establish them as promising candidates for the development of novel, safe, and potent natural repellent products. To translate this potential into practical applications, future research must prioritize several critical avenues. First, the standardization of active ingredients is essential, requiring the isolation and precise characterization of the most effective bioactive compounds or their synergistic combinations. Second, advanced formulation strategies, such as nanoemulsions and microencapsulation, should be employed to enhance the stability, longevity, and controlled release of volatile essential oils. Third, field validation through rigorous real-world trials is necessary to confirm the laboratory-based efficacy and practicality of these repellents in diverse endemic settings. Finally, comprehensive safety profiling via toxicological studies is imperative to ensure these natural products are non-toxic to humans and the environment. By systematically bridging traditional knowledge with contemporary scientific validation, this work contributes meaningfully to the development of a sustainable and eco-friendly arsenal in the ongoing global effort to combat mosquito-borne diseases.

5. Conclusion

This study successfully identified and scientifically validated twenty ethnobotanically relevant plant species as potent natural mosquito repellents. Their diverse phytochemical profiles and efficacy against key vectors underscore their potential as sustainable, eco-friendly alternatives to synthetic chemicals. By providing a scientifically-vetted inventory, this research lays a crucial foundation for the future development of safe, effective, and accessible plant-based repellent products, contributing to the global effort against mosquito-borne diseases.

Compliance with ethical standards

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Disclosure of Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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