



HERBAL MOSQUITO REPELLENT CONES: A SUSTAINABLE ALTERNATIVE TO SYNTHETIC REPELLENTS – A COMPREHENSIVE REVIEW

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ABSTRACT

Mosquito-borne diseases such as malaria, dengue, chikungunya, Zika virus infection, and lymphatic filariasis continue to pose major global public health challenges, causing hundreds of thousands of deaths annually. Conventional mosquito control strategies mainly rely on synthetic chemical repellents and insecticides, including DEET, pyrethroids, and organophosphates. Although effective, their prolonged use is associated with several drawbacks, including environmental pollution, development of insecticide resistance, and potential adverse health effects such as skin irritation, neurotoxicity, and respiratory disorders. These concerns have led to increasing interest in safer, eco-friendly alternatives derived from natural sources. Herbal mosquito repellent cones represent a promising plant-based approach that utilizes bioactive phytochemicals present in medicinal plants such as neem (*Azadirachta indica*), citronella (*Cymbopogon* spp.), tulsi (*Ocimum sanctum*), eucalyptus (*Eucalyptus* spp.), and lemongrass (*Cymbopogon citratus*). These cones release volatile compounds during combustion that interfere with mosquito host-seeking behavior and provide spatial repellency. This review summarizes the importance of mosquito control, limitations of chemical repellents, traditional and ethnobotanical practices of plant-based repellents, formulation techniques of herbal cones, phytochemical mechanisms of mosquito repellency, and commonly used repellent plants. In addition, it discusses methods for evaluating repellent efficacy, recent advances in herbal repellent formulations, and the advantages and limitations associated with herbal cones. Overall, herbal mosquito repellent cones offer a biodegradable, cost-effective, and environmentally sustainable alternative for mosquito control. However, further research is required to address challenges related to standardization, long-term safety, and large-scale commercialization to enhance their application in integrated vector management programs.

INTRODUCTION

A) Importance of mosquito control

Mosquitoes are one of the most deadly human disease carriers in the world,

spreading parasites and viruses that have a major negative impact on public health. Over 700,000 deaths are attributed to mosquito-borne diseases each year, with



malaria alone responsible for about 600,000 deaths, primarily among children under five in sub-Saharan Africa, according to the World Health Organization (WHO, 2023). Dengue, chikungunya, Zika virus infection, yellow fever, and filariasis are among the other serious mosquito-borne illnesses that are prevalent in tropical and subtropical areas (CDC, 2023)¹. In addition to their negative effects on human health, mosquito infestations have financial repercussions, including lower worker productivity, higher medical expenses, and a decline in tourism in endemic regions. With over 230,000 cases recorded in 2022, dengue, for instance, has become a significant public health issue in India, leading to an increasing demand for efficient and reasonably priced control measures (NVBDCP, 2022)². Chemical insecticides like pyrethroids and organophosphates are the mainstay of traditional mosquito control methods. However, overuse of artificial chemicals has resulted in a number of problems, such as: A mosquito populations' ability to resist insecticides (Ranson & Lissenden, 2016)³. pollution of the environment, and adverse health effects on people, such as skin irritation and respiratory problems (Singh et al., 2019)⁴. The emphasis has shifted to safer and more environmentally friendly alternatives, like plant-based interventions and herbal repellents, as a result of this growing concern. Herbal mosquito repellent cones, which combine traditional knowledge with sustainable practices, present a promising solution in this regard⁵.

B) Issues with chemical repellents (toxicity, resistance, environmental harm) Because of their demonstrated effectiveness, chemical insecticides and

mosquito repellents like organophosphates, permethrin, and DEET (N,N-Diethyl-meta-toluamide) are frequently used. However, there are serious concerns about their prolonged and excessive use. Human toxicity can result in allergic reactions, neurotoxicity, eye damage, and skin irritation, particularly after extended exposure (Osimitz & Murphy, 1997; Sudakin & Trevathan, 2003)^{6,7}. For instance, high concentrations of DEET, the most widely used synthetic repellent, have been linked to encephalopathy in children (Koren et al., 2003)⁸. Additionally, a growing worldwide problem is insecticide resistance in mosquito populations. The effectiveness of vector control programs has been limited by mosquitoes' development of resistance to almost all classes of insecticides, including carbamates and pyrethroids (Hemingway et al., 2016; WHO, 2022). Resistance raises dosage needs, which exacerbates ecological and health hazards^{9,10}. Furthermore, the extensive use of synthetic chemicals pollutes the environment and harms beneficial insects and aquatic life, among other non-target organisms (Aktar et al., 2009). Additionally, biodiversity and ecological balance are upset by residual chemical accumulation in soil and water bodies¹¹.

C) Need for Herbal Alternatives

In light of these drawbacks, natural and environmentally friendly mosquito repellents—especially those made from plants—are becoming more and more popular. Herbal repellents are thought to be less likely to cause the development of resistance, safer, and biodegradable (Moore et al., 2007)¹². Numerous plant-based substances have demonstrated efficacious larvicidal or mosquito-repelling qualities, including citronellal,



eugenol, limonene, and azadirachtin (Amer & Mehlhorn, 2006; Maia & Moore, 2011)¹³. In many nations, including India, where neem, tulsi, and lemongrass have long been used as vector control herbs, plant-based mosquito control also fits with traditional knowledge systems. They are promising substitutes for synthetic repellents due to their low toxicity profile, affordability, and renewability (Isman, 2006)¹⁴.

D) Scope and objectives of the review

The purpose of this review is to evaluate the potential of herbal mosquito repellent cones as a substitute for manufactured goods.

The scope consists of: Providing an overview of the phytochemistry and mechanism of common repellent plants describing the methods used in the formulation of herbal cones Examining safety profiles, limitations, and efficacy studies Emphasizing current market trends and the need for further research.

This review aims to advance environmentally friendly and health-conscious mosquito control methods by combining traditional knowledge with recent scientific discoveries¹⁵.

MOSQUITOES AS VECTORS OF DISEASES

Because they are carriers of numerous deadly diseases, mosquitoes are regarded as some of the most dangerous insects on the planet. They spread pathogens, such as viruses and protozoa, which cause diseases that are endemic in over 100 countries and impact more than half of the world's population (WHO, 2023a).

Common Illnesses Spread by Mosquitoes

A. Zika Virus

Zika, which is mostly spread by *Aedes* mosquitoes, is particularly worrisome because it has been linked to birth defects and microcephaly. Guillain-Barré syndrome and other neurological complications were brought to light by the 2015–2016 outbreak in the Americas (WHO, 2023a)¹⁶.

B. Malaria

Plasmodium parasites, which are spread by the *Anopheles* mosquito, are the cause of malaria. An estimated 249 million cases of malaria and 608,000 fatalities occurred in 2022, primarily in sub-Saharan Africa (WHO, 2023b). Approximately 80% of malaria deaths occurred in children under the age of five¹⁷.

C. Dengue

Aedes aegypti and *Aedes albopictus* mosquitoes are the vectors of the virus that causes dengue. In addition to flu-like symptoms, it can develop into severe dengue, or hemorrhagic fever, which can be lethal. In 2022, there were 4.2 million cases worldwide, a ten-fold increase over the previous 20 years (WHO, 2023a). In 2022, more than 230,000 dengue cases were reported in India (NVBDGP, 2022)¹⁸.

D. Lymphatic filariasis

Culex mosquitoes transmit lymphatic filariasis, which is brought on by parasitic worms. affects 120 million people worldwide, primarily in South Asia and Africa, and causes severe disfigurement (elephantiasis) (CDC, 2023).

E. Chikungunya

Another virus that is spread by *Aedes* mosquitoes and causes fever, rash, and excruciating joint pain is chikungunya. Outbreaks, which were



initially discovered in Africa in the 1950s, are now frequent in Asia and the Americas. Due to chronic arthritic symptoms, chikungunya considerably lowers quality of life even though it is rarely fatal (CDC, 2023)¹⁹.

IMPACT ON GLOBAL HEALTH

Because they spread dangerous diseases, mosquitoes rank among the deadliest animals on the planet. Globally, they result in over 700,000 fatalities and hundreds of millions of illnesses annually (WHO, 2023)

Table 1: Major Mosquito-Borne Diseases and Their Global Impact

Disease	Causitive agent	Estimated Annual Cases	Estimated Annual Deaths	Affected regions
Malaria	Plasmodium species, (via Anopheles mosquitoes)	249 million (2022)	6,08,000	Sub-Saharan Africa, South Asia, Parts of Latin America
Dengue	Dengue virus (via Aedes aegypti, A.albopictus)	390 million infections (96 million symptomatic)	20,000 Deaths	Southeast Asia, Latin America
Chikungunya	Chikungunya virus (via Aedes mosquitoes)	1 million outbreaks	Rarely fatal but causes chronic joint pain	Africa, Asia, America
Zika	Zika virus (via Aedes mosquitoes)	Thousands in outbreaks (notable 2015-2016)	Linked to birth defects (microcephaly)	Americans, Asia, Africa
Yellow fever	Yellow fever virus (via Aedes aegypti)	200000 cases per year(estimated)	30,000 deaths per year	Africa, South America

TRADITIONAL AND HERBAL APPROACHES TO MOSQUITO REPELLENCY

Historical Use of Plant-Based Repellents

Humans have depended on nature to protect them from insects, particularly mosquitoes, since the beginning of time. Long before chemical insecticides were

developed, many cultures used substances derived from plants as repellents. Ancient Egypt and India: According to historical accounts, Egyptians used incense made from aromatic plants, such as myrrh and frankincense, to ward off mosquitoes. Neem (*Azadirachta indica*) leaves and oil are used as a skin treatment to ward off insects in India, according to Ayurvedic texts such as the Charaka Samhita. China



and Southeast Asia: Wormwood (*Artemisia* spp.) and camphor have long been used in Chinese homes to ward off insects. In Southeast Asia, citronella grass (*Cymbopogon nardus*) was also burned to keep mosquitoes away. Africa: Clove, eucalyptus, and lemongrass were applied topically by many communities²⁰.

Folk Practices and Indigenous Knowledge

Indigenous communities have passed down extensive knowledge regarding natural mosquito repellents through oral traditions. These practices are region-specific and adapted to local plant availability.

Tribal Knowledge in India: Indigenous tribes such as the Gonds, Santhals, and Bhils use plants like Tulsi (*Ocimum sanctum*), Lantana camara, Vitex negundo, and Neem for fumigation or as ointments. Crushed leaves or plant extracts are often applied to the skin or burned in the evening to repel mosquitoes.

Amazonian Tribes: Tribes in the Amazon basin use resins and oils extracted from plants like Andiroba (*Carapa guianensis*) and Copaiba as topical mosquito repellents. These oils have been scientifically shown to contain limonoids and terpenoids with mosquito-repellent activity.

African Traditional Medicine: *Ocimum suave*, *Tagetes minuta*, and *Tithonia diversifolia* are used by indigenous people in sub-Saharan Africa as mosquito repellents. Frequently, crushed leaves are placed in living areas or rubbed on the skin.

Aboriginal people in Australia: Eucalyptus species, particularly *Eucalyptus citriodora*, are used by Aboriginal communities because they release citronellal, a powerful insect repellent²¹.

FORMULATION OF HERBAL MOSQUITO REPELLENT CONES

Overview of Cone Preparation Process

Cone Preparation Process Overview
Inspired by traditional fumigation methods, herbal mosquito repellent cones are a smoke-based, environmentally friendly solution. Without the negative side effects of chemical repellents like DEET or allethrin, these cones are made to burn slowly and release volatile plant-based compounds that effectively ward off mosquitoes. Typically, the preparation procedure entails: A flammable base, natural binders, herbal powders, and essential oils are among the ingredients that are chosen and combined. Cone-shaped molding can be done by hand or with cone molds. Cones can be dried in a low-heat oven or in the sun to eliminate moisture and prepare them for burning. To maintain efficacy and scent, store and package in dry, airtight containers²².

Formulation of Herbal Mosquito Repellent Cones

Components

Four primary ingredient categories are typically used in the formulation of herbal mosquito repellent cones: base materials, binders, herbal powders, and essential/volatile oils. Every component has a distinct functional role in the operation of the cone.

a. Combustible substances, or base materials: They serve as carriers for the active ingredients, guarantee slow burning, and make up the cone's main structure.

- Cow dung has long been used for fumigation in rural areas; it emits thick smoke that deters insects²³.
- Sawdust: Preserves structural integrity and increases combustibility²⁴.
- Powdered charcoal: helps ignite and burns steadily²⁵.

b. Binders

Binders offer structural stability and aid in holding the powdered ingredients together.

Common natural binders include maida (refined wheat flour), gum arabic, or corn starch²⁶.

c. Powdered herbs (active ingredients) b.

Powders made from plants are added because of their bioactive repellent properties. Frequently utilized:

- Powdered neem (*Azadirachta indica*) leaves contain azadirachtin, which has been shown to have insecticidal effects.
- Eugenol and other volatiles are abundant in tulsi (*Ocimum sanctum*) powder.

- Terpenoids with repellent properties are present in lantana camara leaf powder.

- Citronellal and geraniol are found in lemongrass (*Cymbopogon citratus*)²⁷.

d. Volatile and Essential Oils

Essential oils improve scent and repellency. Typical options: Clove oil (2–5% concentration), lemongrass oil, eucalyptus oil, and citronella oil²⁸.

Drying and Shaping Methods

A. Shaping:

Form: A dough-like consistency is achieved by kneading the prepared mixture (base + binder + herbal powders + oils + water). formed by hand or using cone molds. Cones usually have a broad base for stability and a height of 5 to 8 cm²⁹.

B. The drying process:

Sun drying: economical and appropriate for small-scale rural production, it takes 24 to 48 hours in direct sunlight. Low-heat oven drying: 40–50 °C for 4–6 hours; used for commercial production or for consistent drying in humid environments. In addition to preventing mold growth during storage, adequate drying guarantees slow, even burning³⁰.

Table 2: Example of Typical Herbal Cone Composition

Ingredient	Function	Proportion (%)
Cow dung / Sawdust	Combustion base	30–50
Charcoal powder	Burning aid	10–20
Herbal plant powders	Active agents	10–20
Binder (gum arabic, maida)	Binding agent	5–10
Essential oils	Repellent activity	2–5
Water	Mixing medium	As required



Benefits of Herbal Mosquito Repellent Cones over Sprays, Coils, and Creams. Comparing herbal mosquito repellent cones to traditional sprays, coils, and topical creams reveals a number of benefits. These advantages stem from cultural acceptance, cost-effectiveness, safety, and environmental sustainability.

1. Less toxicity from chemicals

Long-term exposure to synthetic mosquito repellents, such as coils impregnated with allethrin or sprays containing N, N-diethyl-meta-toluamide (DEET), can result in neurotoxic effects, respiratory problems, or skin irritation (Fradin & Day, 2002; Liu et al., 2012). Plant-based ingredients like citronella, neem, or lemongrass oils, which have relatively lower toxicity when used properly, are the foundation of herbal cones (Maia & Moore, 2011)³¹.

2. Less harmful to the respiratory system than synthetic coils

During combustion, commercial mosquito coils emit particulate matter, formaldehyde, and polycyclic aromatic hydrocarbons, all of which have been connected to respiratory conditions and the development of cancer (Liu et al., 2003; Chen et al., 2008). When made without artificial pyrethroids, herbal cones typically emit fewer toxic smoke and volatile organic compounds (Kamaraj et al., 2011)³².

3. Direct skin contact is not necessary

Cones work by fumigation, as opposed to creams and lotions, which can result in allergic dermatitis or systemic absorption of active ingredients (Wang et al., 2018). This makes them appropriate for people with sensitive skin, kids, and those who are allergic to topical repellents³³.

4. Prolonged defense without the need for frequent reapplication

Because of evaporation or sweat, topical repellents usually need to be reapplied every two to four hours (Debboun & Strickman, 2013). Depending on its size and composition, a single herbal cone can offer consistent protection for three to six hours (Govindarajan et al., 2013)³⁴.

5. Biodegradable and environmentally benign

Unlike aerosol cans or plastic packaging from creams, herbal cones made from cow dung, sawdust, or plant powders are biodegradable and generate less non-biodegradable waste³⁵.

6. Traditional integration and cultural acceptance

Fumigation with herbal materials has long been a culturally accepted method of controlling mosquitoes in many rural and traditional communities (Kweka et al., 2008). Adoption of herbal cones is not difficult and can be readily incorporated into such practices³⁶.

PHYTOCHEMICAL BASIS OF REPELLENCY

1. Active Components: Essential Oils

Essential oils, which are complex mixtures of volatile secondary metabolites like monoterpenes, sesquiterpenes, phenolics, and aldehydes, are responsible for many plants' ability to repel mosquitoes. Among the most researched plant sources are

2. **Aedes, Anopheles, and Culex** species are strongly repelled by citronellal, citronellol, and geraniol, which are found in citronellal oil (Cymbopogon



nardus, *Cymbopogon winterianus*) (Maia & Moore, 2011)³⁷.

3. **Azadirachtin, nimbin, and salannin**, which are abundant in neem oil (*Azadirachta indica*), have insect-repelling and growth-regulating properties (Schmutterer, 1990; Amer & Mehlhorn, 2006)³⁸.
4. **Eucalyptus citriodora, or eucalyptus oil**: contains p-menthane-3,8-diol (PMD), a highly effective repellent approved by the U.S. Centers for Disease Control and Prevention (Trigg, 1996; Carroll & Loye, 2006), along with citronellal³⁹.
5. **Citral**, a combination of geranial and neral, is found in lemongrass oil (*Cymbopogon citratus*) and has been shown to have mosquito-repelling properties (Oyedele et al., 2002)⁴⁰.
6. **Eugenol**, which is abundant in clove oil (*Syzygium aromaticum*), effectively repels a variety of mosquito species and interferes with their ability to perceive smells (Trongtokit et al., 2005)⁴¹.

MECHANISM OF ACTION

Olfactory interference and, in certain situations, neurotoxic effects on insects are the main mechanisms by which these phytochemicals repel mosquitoes.

1. Interference from smells

- By using olfactory cues to detect volatiles released by the skin, lactic acid, and carbon dioxide, mosquitoes are able to locate their hosts. These cues can be obscured or blocked by essential oils by: blocking the detection of host

odors by attaching itself to odorant-binding proteins (OBPs) in the mosquito's antennae (Logan et al., 2010)⁴². altering the host-seeking behavior of particular odorant receptors (ORs) by activating or inhibiting them (Ditzen et al., 2008)⁴³.

- By activating mosquito TRPA1 channels, which are linked to irritation responses, citronellal and PMD, for instance, promote avoidance behavior (Kwon et al., 2010)⁴⁴.

2. Effects of neurotoxicity on mosquitoes

- Certain substances derived from plants target the nervous system of mosquitoes to produce insecticidal or knockdown effects:
- Clove's eugenol and thyme's thymol have the ability to alter octopamine receptors and interfere with neurotransmission (Enan, 2001)⁴⁵. Neem's azadirachtin disrupts the neuroendocrine regulation of mosquito feeding and reproduction (Schmutterer, 1990)⁴⁶.
- Some monoterpenes, such as menthol and limonene, interfere with neural signaling by acting on acetylcholinesterase or GABA-gated chloride channels (Priestley et al., 2003)⁴⁷.

COMMONLY USED PLANTS AND THEIR PROPERTIES

1. *Azadirachta indica*, or neem

One of the most researched plants for keeping mosquitoes away is neem. Bioactive limonoids like azadirachtin, nimbin, and salannin, which are found in



its seed oil, interfere with mosquito feeding habits and regulate insect growth (Schmutterer, 1990; Amer & Mehlhorn, 2006). When applied topically, neem oil can offer several hours of protection from *Anopheles* and *Aedes* mosquitoes^{48, 49}.

2. Citronella (Cymbopogon winterianus, Cymbopogon nardus)

Citronella, citronellol, and geraniol, which are found in citronella oil, disrupt the mosquito's olfactory system and lessen its desire to seek hosts (Maia & Moore, 2011). It has been shown that citronella candles, sprays, and impregnated fabrics are effective against *Culex quinquefasciatus*, *Anopheles stephensi*, and *Aedes aegypti*.

3. **Ocimum sanctum**, also known as *Ocimum tenuiflorum*, or tulsi Eugenol, methyl eugenol, and linalool—compounds with potent anti-*Aedes aegypti* and anti-*Anopheles culicifacies* properties—are found in tulsi leaves and essential oil (Sukumar et al., 1991; Kamaraj et al., 2010). Tulsi oil has antibacterial and anti-inflammatory qualities in addition to its repellent qualities⁵⁰.

4. **Eucalyptus (Eucalyptus citriodora, Eucalyptus globulus)** Citronella and its hydrated form, p-menthane-3,8-diol (PMD), a naturally occurring mosquito repellent approved by the CDC, are abundant in eucalyptus oil, especially that derived from *E. citriodora* (Trigg, 1996; Carroll & Loye, 2006). It provides protection for an extended period of time, frequently longer than citronella oil^{51, 52}.

EVALUATION OF EFFICACY

1. Arm-in-cage (or "cage") tests in the lab
The WHO Guideline (gold standard)

includes procedures, endpoints, and an analysis of repellency percentage and Complete Protection Time (CPT). WHO. Guidelines for Assessing the Effectiveness of Human Skin Mosquito Repellents. (2009). Iris Organization for World Health AIC and what it does and does not capture regarding mode of action are explained in a recent method paper. (Arm-in-cage overview) Fatou, M. et al. (2024) Sci. Rep. Nature Traditional experimental application of human-derived repellents (AIC) against *Anopheles*, *Culex*, and *Aedes*. Logan et al. (2010) J. Chem. Ecol. (open access). PMC Alternative laboratory techniques and comparative evaluations: landing-rate assays versus AIC. M. Moreno-Gómez et al. (2021) Entomol. J. Med. Oxford Academic (Lab vs. field comparison) Colucci, B. et al. (2018) Sci. Rep. Nature Kaplan-Meier for CPT is part of the regulatory protocol, U.S. EPA OPPTS 810.3700 (harmonized with WHO)^{53,54,55}

2. Field trials and semi-field systems
WHO Guidelines for spatial repellents in lab, semi-field, and field settings; endpoints include mortality, entry/exit, blood-feeding inhibition, and knockdown (KD). WHO. Guidelines for Testing the Effectiveness of Spatial Repellents (2013). WHO Applications Organization for World Health Traditional factory-grounded repellents are estimated in the field (Bolivian Amazon). Moore and associates (2007) mortal wharf catches and protection are handed by the J. Am. Mosq. Control Association. PubMed development of semi-field tests for repellents. Structured semifield protocol Yoon, J.K. et al. (2014) J. Med. Entomol. Oxford



University Factory bank's effectiveness in the field (Ethiopia). Wendimu and associates (2021) Heliyon quantified reduction in smelling caused by factory bank. ScienceDirect The following typical parameters were reported duration of protection under natural pressure, defensive efficacy, mortal-biting rate, and chance reduction in wharf/ biting. (Yoon 2014; Moore 2007; WHO 2013)^{56,57,58}.

3. Cones, coils, and additional smoke/emanator items KD, mortality, exposure durations, and health/smoke considerations are compiled in this systematic review (coils & passive emanators). Parasites & Vectors, Ogoma, S.B. et al. (2012). Central BioMed Lab studies on plant-based coils and cones: measure burn time and smoke duration, percentage of repellency, KD. Kamaraj, C., and others (2011) Plant-based coils for parasitology research. Nature Expert evaluation of spatial repellents, such as coils and metafluthrin, as well as chamber tests for particulate emissions and KD/mortality. Expert Review of the IVCC (2020) (PDF). Consortium for Innovative Vector Control The following typical parameters were reported: 24-hour mortality, room concentration, KD at fixed intervals (e.g., 10-30 minutes), smoke duration/burn time, blood-feeding inhibition, and user acceptability/irritancy. (IVCC 2020; Ogoma 2012)^{59, 60}.

ADVANTAGES AND LIMITATIONS OF HERBAL CONES

1. Advantages of Herbal Cones

Herbal cones' benefits include low toxicity, biodegradability, and

environmental friendliness. Herbal mosquito repellent cones made from natural ingredients (such as citronella, eucalyptus, and lemongrass) are safe, affordable, biodegradable, and environmentally friendly, making them good substitutes for synthetic repellents, according to a formulation study. IJCRT It was discovered that a herbal incense-cone formulation was economical, portable, environmentally friendly, and linked to "nil untoward health effect," all of which contributed to the creation of healthier indoor environments. IJFMR Herbal sticks' biodegradability, ease of use, and good safety profile were highlighted in another evaluation, which positioned them as appropriate for controlling mosquitoes in homes^{61,62,63}.

2. Limitations of Herbal Cones

Herbal Cones' Drawbacks: Skin and Respiratory Irritation Some formulations included irritation tests, smoke visibility, odor, and burning time—but stressed the need for additional evaluation of irritancy under real-use conditions, even though many studies concentrate on safety. IJPDA Despite their natural origins, herbal alternatives must also be assessed for possible irritation, according to a frequently cited review that mentions the known irritant and toxic effects of synthetic repellents^{64,65, 66}.

3. Issues with Stability and Shelf-Life

Significant obstacles to standardization, chemical stability, and long shelf-life were noted in a more comprehensive review of plant-based repellents, which restricts their widespread use. Another article emphasizes how unstable active compounds and variations in plant extract composition make formulation consistency difficult and restrict long-term efficacy⁶⁷.



4. Standardization Issues: According to the same review, it is challenging to standardize herbal repellent products in terms of efficacy and safety due to the complex composition of plant extracts and their inherent variability. A methodological review on stability assessment and shelf-life determination for herbal drugs notes that strict quality control, which includes active compound assays, purity, contamination checks, and stability testing, is essential but challenging to implement^{68,69,70}.

RECENT RESEARCH AND DEVELOPMENTS

Summary of Recent Studies

Ligusticum sinense Nanoemulsion Gel (LHE- NEG) This innovative system successfully formulated a nanoemulsion gel of *Ligusticum sinense* hexane excerpt and compared it to DEET in arm- in- pen tests. similar to DEET, LHE- NEG handed median protection times (MPTs) of 5.5, 11.5, and 11.25 hours against *Aedes aegypti*, *Anopheles minimus*, and *Culex quinquefasciatus*, independently. Crucially, it remained nicely stable following heat- cooling cycles and was safe in mortal skin tests, albeit with a slight drop in efficacy⁷¹.

Innovations in Formulation

Nanostructured Lipid Carriers (NLCs) and Nanoemulsions The synergistic advantages of exercising lipid- grounded nanocarriers similar as NLCs or nanoemulsions in confluence with essential canvases (similar as *Eucalyptus globulus* and *Syzygium aromaticum*) were stressed in a recent review. The stability, effectiveness, and continuity of the repellent action are

bettered by these delivery styles. The MDPI Nutmeg Oil Nanoemulsion Compared to plain nutmeg oil painting, a nutmeg oil painting- loaded nanoemulsion showed controlled release and lesser mosquito repellent efficacy. A promising step toward scalable nanoformulated repellents, the phrasings achieved drop sizes below 500 nm, low surfactant use (< 10) and high stability^{72,73}.

FUTURE PERSPECTIVES

1. Research gaps (e.g., standardization, long-term efficacy, safety)

- **Standardization:** Variability in efficacy arises from the absence of standardized procedures for the selection of plant materials, extraction techniques, and cone formulation. For constant repellency, active compounds (such as citronellal, eugenol, limonene, and linalool) require quantification and standardization⁷⁴.
- **Long-term efficacy:** The majority of research focuses on brief exposure times (2–4 hours). Not enough research has been done on repeated use, sustained release, and long-term protection⁷⁵.
- **Safety:** There are few toxicological studies on the long-term inhalation of smoke from herbal cones. Safety evaluations are necessary, particularly for vulnerable populations (pregnant women, children, and asthmatics)⁷⁶.

2. Potential for Scale-Up and Commercialization

- **Challenges:** Good Manufacturing Practices (GMP) for uniformity and dependable medicinal plant supply chains are necessary for



large-scale production. Scalability may be impacted by variations in essential oil yield brought on by location, season, and farming methods⁷⁷.

- Possibilities: There is significant commercialization potential due to the rising consumer demand for environmentally friendly, chemical-free repellents. Cone design optimization, herbal blends, and microencapsulation are examples of innovations that could increase stability and acceptability⁷⁸.

3. Integration in Public Health Programs
Community-level interventions: Especially in rural and resource-constrained areas, herbal mosquito cones could be promoted as part of integrated vector management (IVM) strategies. Their low cost and locally sourced raw materials make them suitable for community adoption. They can work in tandem with other measures, such as bed nets, larviciding, and environmental management. Also, they may help lessen reliance on synthetic coils, which are linked to negative health effects^{79,80}.

CONCLUSION

Comparing herbal mosquito cone repellents made from plant-based essential oils, extracts, and powders to synthetic agents like DEET and pyrethroids, the current review shows that the former have promising mosquito repellent activity with few side effects. Numerous studies' conclusions show that phytochemicals such as terpenoids, alkaloids, flavonoids, and phenolics greatly enhance these botanicals' ability to repel and kill insects. Herbal cones are also safe for the environment, people, and animals, and they are biodegradable. Given the current

situation, where chemical repellents are linked to toxicity, allergic reactions, and environmental risks, and where resistance to conventional insecticides is growing, the focus on safe and sustainable mosquito control is especially pertinent. Herbal mosquito cone repellents can be used as sustainable, cost-effective, and efficient substitutes in vector control programs by fusing traditional wisdom with contemporary scientific verification. To guarantee consistency and dependability, more study is necessary on standardization, long-term safety, and widespread commercialization^{81, 82, 83}.

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