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# Natural defenders: Recent discoveries of mosquito-repellent flora in India's seven sister states

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**Abstract**
The northeastern part of India, known as the Seven Sister States comprising Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura exhibits remarkable biodiversity in both plant and animal life. The area's distinctive climate, varied landscape, and abundant biological diversity contribute to its status as a center for endemic plant species, many of which have been utilized for medicinal and other traditional applications by local communities. There has been a notable increase in research dedicated to exploring the mosquito-repellent characteristics of several plants indigenous to this area. With growing apprehensions regarding vector-borne illnesses like malaria, dengue, and chikungunya, the discovery of natural plant-derived mosquito repellents has become increasingly vital. Traditional knowledge and recent scientific studies have highlighted several plant species native to this region that exhibit mosquito-repellent properties. This article discusses the significance of these natural defenders and their prospective applications.

**Keywords:** Mosquito repellents, seven sister states, indigenous plant, dengue, natural defenders

## Introduction

The seven sister states of India are known for their rich biodiversity and unique ecological landscapes. These areas are inhabited by a wide variety of plant species that have adapted and evolved over countless generations. Some of the most interesting plant species are those that have natural mosquito-repellent properties. Recent studies and field research have uncovered a variety of indigenous plants found in this region that contain bioactive compounds capable of repelling mosquitoes, providing a promising and eco-friendly alternative to chemical repellents, which are often associated with negative side effects. Certain mosquito species, including *Aedes aegypti*, *Anopheles stephensi* and *Culex quinquefasciatus* are recognized as vectors for dangerous diseases such as dengue fever, malaria, chikungunya, and lymphatic filariasis. According to estimates from the World Health Organization (WHO) mosquitoes lead to millions of deaths every year through the transmission of various diseases. The global malaria burden includes a significant contribution from India. The World Malaria Report, 2019 from WHO revealed that India was responsible for 3% of the malaria cases reported worldwide [1]. Effective management of mosquito populations and the prevention of bites are essential strategies in combating these vector-borne illnesses. Although chemical repellents like DEET (N, N-diethyl-meta-toluamide) are known for their efficacy, concerns have emerged regarding their potential toxicity, environmental repercussions, and the risk of resistance development in mosquito populations [2]. As a result, there is an increasing interest in exploring plants as alternatives that promise to be safer for human health and more environmentally sustainable. The use of these plants is fundamentally embedded in the traditional knowledge of indigenous tribes who have historically relied on them for defense against mosquito bites as well as for their medicinal properties. This article investigates the recent identification of mosquito-repellent vegetation in India's seven sister states, underscoring the traditional expertise of local communities, recent scientific research, and the potential roles of these natural repellents in the prevention of diseases spread by mosquitoes.

## Recently discovered plants from the seven sister states

### Arunachal pradesh

- ***Litsea cubeba***

The species *Litsea cubeba* known as "cubeb" or "Java pepper," is an evergreen tree that belongs to the Lauraceae family. It is native to Southeast Asia, especially in countries such as China, India, and Indonesia. This plant is notable for its fragrant leaves and small, berry-like fruits, which are used in numerous culinary and medicinal contexts. In the northeastern Indian state of Arunachal Pradesh, *Litsea cubeba* flourishes due to the region's diverse climate and abundant biodiversity. The varying altitudes and rainfall patterns in the state provide an optimal habitat for this species. It is commonly found in subtropical forests, thriving at elevations between 300 and 2,000 meters above sea level. *Litsea cubeba* is an important cultural element for the indigenous populations in Arunachal Pradesh. These communities utilize the plant in their traditional medicinal practices, holding the belief that it offers anti-inflammatory and antimicrobial benefits. In addition, the essential oil extracted from its leaves is used in aromatherapy and perfumery, celebrated for its pleasing fragrance. Boruah *et al.* [3] investigated the chemical makeup of the essential oil obtained from *Litsea cubeba* harvested in Arunachal Pradesh, with the goal of identifying its mosquito repellent capabilities. The analysis revealed that the essential oil of *Litsea cubeba* is predominantly composed of citronellal (17.32%), citronellol (13.85%), nimbiol (9.35%), and myrcenol (7.40%). Furthermore, this essential oil exhibited a mosquito repellent activity for three hours against *Aedes aegypti* mosquitoes.

**Fig 1:** *Litsea cubeba*

- ***Stemona tuberosa***

*Stemona tuberosa* commonly known as the "Chinese yam" or "tuberous stemona" is a perennial herbaceous plant belonging to the family Stemonaceae. It is characterized by its fleshy tubers, which are typically found underground, and its erect stems that can reach heights of up to 1 meter. The leaves are alternate, lanceolate to ovate in shape, and the plant produces tubular flowers that are usually pale yellow or white in color. In India, *Stemona tuberosa* is predominantly found in the northeastern states, including Arunachal Pradesh. This region's unique climatic conditions characterized by high rainfall, humidity, and diverse altitudinal gradients—create an ideal habitat for this species. The plant thrives in subtropical forests and grasslands where it can benefit from the rich biodiversity of the area. In Arunachal Pradesh, *Stemona tuberosa* holds significant cultural value among local communities. Traditionally, it has been used in indigenous medicine for its purported therapeutic properties. The tubers are believed to possess various health benefits, including anti-inflammatory and analgesic effects. Local healers often utilize these tubers to treat respiratory ailments such as coughs and bronchitis. The research conducted by Bharali *et al*. [4] highlighted the ethnobotanical applications of the tuberous roots of *Stemona tubarosa*, which are utilized by the Adi tribe of Arunachal Pradesh for multiple purposes, including as an antilice agent, fish poison, preservative, and mosquito repellent.

**Assam**

- ***Brassica rapa***

*Brassica rapa*, commonly known as turnip or field mustard, is a species of plant in the family Brassicaceae. This species is notable for its wide range of cultivated varieties, including turnips, bok choy, and Chinese cabbage. It is a biennial plant that can be grown as an annual crop and is characterized by its edible roots and leaves. The plant thrives in temperate climates and has been cultivated for thousands of years across various regions. Assam's climate features a monsoon season with heavy rainfall followed by a cooler winter period, which provides suitable conditions for growing *Brassica rapa*. In Assam, several varieties of *Brassica rapa* are cultivated, including both leafy greens (like mustard greens) and root vegetables (like turnips). These varieties are often selected based on local preferences and market demand. Baruah *et al*. [5] conducted a study between April and July 2020 to document mosquito-repellent plants found in the fringe villages of Manas National Park, Assam. The survey reported that the smoking of *Brassica rapa* is the most commonly utilized method by the fringe villagers of Manas National Park, while the use of raw plant juices for mosquito repellent purposes ranks as the next most frequently employed method.

**Fig 2:** *Brassica rapa*

- ***Curcuma amada* (Mango ginger)**

*Curcuma amada*, commonly known as mango ginger, is a perennial herbaceous plant belonging to the Zingiberaceae family. This species is native to South Asia and is particularly prevalent in India, where it is cultivated for its rhizomes that possess a unique flavor reminiscent of both ginger and mango. In Assam mango ginger holds cultural significance and is utilized in various culinary applications as well as traditional medicine. Mango ginger grows to about 1-2 meters in height and features broad, lanceolate leaves that can reach up to 60 cm in length. The plant produces yellow flowers that are borne on spikes. The rhizome of *Curcuma amada* is fleshy and aromatic, characterized by a yellowish-brown skin and a pale-yellow interior. Its flavor profile is distinct; it has a mild spiciness akin to ginger but with fruity undertones similar to mangoes. Mango ginger is widely used in Assamese cuisine. It can be consumed raw or cooked and is often grated into salads or pickles. Its unique flavor makes it an excellent ingredient for enhancing curries and rice dishes. Additionally, it can be used to prepare chutneys or infused into beverages for added zest. Hazarika *et al*. [6] performed an investigation into the mosquito repellent activity of essential oils extracted from the regional ginger species *Curcuma amada* which is cultivated in Upper Assam. Findings from this investigation indicated that the essential oil extracted from mango ginger has $LC_{50}$ values of 176.19 and 97.72 mg/L after 24 and 48 hours of exposure respectively, highlighting its effectiveness as a larvicide against *Anopheles stephensi* larvae. Additionally, it achieved an 83% rate of mosquito repellency at a concentration of 100 mg/L within 2 hours.

**Manipur**

- **Citronella grass (*Cymbopogon nardus*)**

Citronella grass, scientifically known as *Cymbopogon nardus*, is a perennial grass that belongs to the Poaceae family. It is primarily recognized for its essential oil, which is widely used in perfumery, cosmetics, and as an insect repellent. The plant is native to tropical Asia and has been

cultivated in various regions around the world due to its economic significance. In Manipur citronella grass has gained attention for its potential agricultural and economic benefits. The climate of Manipur, characterized by a subtropical highland climate with distinct wet and dry seasons, provides suitable conditions for the growth of this grass. The state's rich biodiversity and varied topography contribute to the successful cultivation of *Cymbopogon nardus*. The cultivation of citronella grass in Manipur involves several agronomic practices. Farmers typically prefer well-drained soils with good organic content for optimal growth. The planting process usually begins with the selection of healthy seedlings or clumps from mature plants. These are then transplanted into prepared fields during the onset of the monsoon season when soil moisture levels are adequate. The research conducted by Hsu *et al*. [7] involved the use of a Y-tube olfactometer to analyze essential oils from Cymbopogon species, focusing on certain component formulations that serve as repellents for *Aedes aegypti*. The results from this study showed that the modification of citronella grass oil composition formulas had a synergistic effect, making it a more effective repellent against *Aedes aegypti* than N, N-diethyl-3-methylbenzamide (DEET), which achieved 44% and 22% effectiveness with 400 μL.

**Fig 3:** Citronella grass (*Cymbopogon nardus*)

- **Lemon basil (*Ocimum basilicum*)**

The herb known as lemon basil or *Ocimum basilicum* in scientific terms is widely utilized in cooking and traditional medicinal practices. In addition to its culinary benefits, lemon basil has been noted for its potential as a natural repellent against mosquitoes. This property is especially important in regions like Manipur, where the climate is conducive to the breeding of these insects. In Manipur lemon basil holds cultural significance beyond its use as a mosquito repellent. It is often grown in home gardens and is associated with various traditional practices. The locals appreciate its aromatic properties and often use it in religious rituals and ceremonies. Research has demonstrated that essential oils derived from *Ocimum basilicum* exhibit significant insect-repelling properties. The primary active compounds eugenol and linalool are known for their ability to interfere with the sensory receptors of mosquitoes, thereby deterring them from approaching treated areas. Studies indicate that these compounds can provide protection against various mosquito species, including *Aedes aegypti* and *Anopheles stephensi*, which are vectors for diseases such as dengue fever and malaria. The research conducted by Adam *et al*. **[8]** involved the formulation and assessment of a cream utilizing essential oils isolated from *Ocimum basilicum*, with the intent of exploring its repellent effectiveness against Anopheles mosquitoes. The data obtained from this study imply that essential oils extracted from *Ocimum basilicum* possess significant repellent activity against female Anopheles. When utilized in a natural repellent cream, these oils show effective repellency lasting 125.0, 200.0, and 270.0 minutes at concentrations of 2%, 4%, and 6%, respectively.

**Meghalaya**

- ***Zanthoxylum acanthopodium***

*Zanthoxylum acanthopodium*, commonly known as the prickly ash or toothache tree, belongs to the Rutaceae family. This genus is characterized by its aromatic properties and is widely distributed in tropical and subtropical regions. The species name "acanthopodium" derives from Greek roots meaning "thorny foot," which aptly describes the plant's distinctive thorny branches. *Zanthoxylum acanthopodium* is a deciduous shrub or small tree that can reach heights of up to 10 meters. The leaves are compound, typically pinnate with 5-9 leaflets that are glossy green and have a serrated margin. The thorns on the branches can be quite pronounced, contributing to its common name. Flowers are small, yellowish-green and occur in clusters; they are usually unisexual, with some plants being dioecious (having male and female flowers on separate individuals). This species is native to the northeastern region of India, particularly Meghalaya where it thrives in subtropical forests. The climate in Meghalaya, characterized by heavy rainfall during monsoon seasons, supports the growth of this species. In local cultures within Meghalaya, *Zanthoxylum acanthopodium* has been utilized not only for its medicinal properties but also as a spice in culinary practices. In Meghalaya local communities have recognized the utility of *Zanthoxylum acanthopodium* not only for health-related purposes but also as a natural mosquito repellent. The use of botanical extracts for repelling mosquitoes is rooted in both cultural practices and scientific inquiry. The volatile compounds released by *Zanthoxylum acanthopodium* may interfere with the sensory receptors of mosquitoes, thereby deterring them from approaching humans or livestock [9]. This characteristic makes it an attractive alternative to synthetic repellents that may pose health risks or environmental concerns. Research indicates that certain phytochemicals present in Zanthoxylum species exhibit insecticidal and repellent activities. For instance, compounds such as alkaloids and terpenoids have been shown to possess significant bioactivity against common mosquito vectors like *Aedes aegypti* and *Anopheles stephensi*. Begum *et al*. [10] conducted research aimed at developing and evaluating a mosquito repellent ointment that incorporates essential oil extracted from the fruits of *Z. acanthopodium*. The analysis conducted in this study indicates that *Z. acanthopodium* possesses significant potential as a mosquito repellent when developed into an ointment for topical application. Consequently, the findings affirmed that the ointment formulations derived from the essential oil of *Z. acanthopodium* fruits are both safe and effective in providing substantial mosquito repellent properties.

**Fig 4:** *Zanthoxylum acanthopodium*

- ***Eupatorium odoratum***

*Eupatorium odoratum* commonly known as the "Ageratum" or "Tropical American Ageratum," is a perennial herbaceous plant belonging to the family Asteraceae. This species is native to tropical regions of the Americas but has been widely introduced in various parts of the world, including Southeast Asia and India. *Eupatorium odoratum* typically grows up to 1-2 meters tall and features opposite leaves that are ovate to lanceolate in shape. The plant produces small clusters of white to pale lavender flowers that bloom throughout the year under favorable conditions. The leaves are aromatic when crushed, which is one of the reasons this plant is considered for use as a natural insect repellent. In Meghalaya *Eupatorium odoratum* has gained attention not only for its ornamental value but also for its potential use as a mosquito repellent. In this region the local population has traditionally utilized *Eupatorium odoratum* not only for its aesthetic appeal but also for its practical benefits in pest management. The plant thrives in the humid climate of Meghalaya and can often be found in gardens and along roadsides. Its ability to grow in diverse soil types makes it an accessible option for many households looking to deter mosquitoes without resorting to chemical repellents. A study was carried out by M. F. Alam to assess the repellent properties of essential oils derived from the leaves of *Eupatorium odoratum* against the vectors responsible for malaria, filaria, and dengue [11]. The study's results indicated that at a concentration of 10%, the complete protection times (Mean ± S.D) were 160.2 ± 2.77 minutes for *Anopheles stephensi*, 139.4 ± 1.14 minutes for *Aedes aegypti*, and 125.6 ± 3.13 minutes for *Culex quinquefasciatus*.

**Mizoram**

- ***Artemisia vulgaris***

*Artemisia vulgaris*, commonly known as mugwort, is a perennial herbaceous plant belonging to the Asteraceae family. This species is native to Europe, Asia, and North America but has found its way into various ecosystems around the world, including the northeastern Indian state of Mizoram. *Artemisia vulgaris* can grow up to 1.5 meters tall and features deeply lobed leaves that are dark green on the upper side and silvery-white beneath due to fine hairs. The plant produces small yellowish-green flowers that bloom in clusters during late summer to early autumn. Its aromatic foliage contains essential oils that contribute to its insect-repelling properties. Mizoram's climate is conducive to the growth of *Artemisia vulgaris*; it thrives in well-drained soils with ample sunlight. Local farmers have begun cultivating this plant not only for personal use but also for commercial purposes due to increasing awareness of organic farming practices and natural pest control methods. The cultivation of *Artemisia vulgaris* aligns with sustainable agricultural practices by reducing reliance on chemical pesticides while providing additional income sources for farmers. In Mizoram, local communities have utilized *Artemisia vulgaris* not only for culinary purposes but also for its medicinal benefits. The leaves are often used in traditional remedies for ailments such as digestive disorders and respiratory issues. However, one of the most significant applications of this plant in the region is its use as a natural mosquito repellent. The mosquito-repelling capabilities of *Artemisia vulgaris* can be attributed to its essential oil composition, which includes compounds such as camphor, thujone and cineole [12]. These compounds have been shown to possess insecticidal properties that deter mosquitoes from approaching or landing on treated surfaces. In regions like Mizoram where mosquito-borne diseases such as malaria and dengue fever pose significant health risks, the use of *Artemisia vulgaris* offers an eco-friendly alternative to synthetic repellents.

**Fig 5:** *Artemisia vulgaris*

**Nagaland**

- ***Homalomena aromatic Schott***

*Homalomena aromatic Schott* commonly referred to as the mosquito repellant plant, is a member of the family Araceae. This plant is particularly noted for its potential use in traditional medicine and pest control, especially in regions like Nagaland, India. The genus Homalomena comprises various species that are primarily found in tropical and subtropical climates. The leaves of H. aromatic possess a distinctive aroma, which is believed to be responsible for its insect-repelling properties. Homalomena aromatic typically features broad, heart-shaped leaves that can grow up to 30 cm long. The foliage is lush and green, contributing to its ornamental value in gardens and landscapes. The plant thrives in humid environments and prefers well-drained soil with partial shade. It can be propagated through division or by planting seeds. In Nagaland, H. aromatic holds cultural significance among local tribes who utilize it not only for its aesthetic appeal but also for its practical applications. Traditionally, the leaves are crushed and applied to the skin or placed around living spaces to deter mosquitoes and other pests. This practice aligns with the broader ethnobotanical knowledge where indigenous plants are harnessed for their medicinal and protective properties. The mosquito-repelling capabilities of Homalomena aromatic can be attributed to specific volatile compounds present in its leaves. Research

indicates that these compounds may include essential oils that exhibit insecticidal properties. While detailed phytochemical studies on this particular species are limited, similar species within the genus have shown promising results against various insect pests. Laboratory studies have demonstrated that extracts from *H. aromatic* can significantly reduce mosquito attraction when applied topically or used as a fumigant in enclosed spaces. This makes it an attractive alternative to synthetic repellents, particularly in rural areas where access to commercial products may be limited. Dutta *et al*. [13] conducted a research investigation aimed at extracting essential oils from the peels of *Citrus macroptera* and the rhizomes of *Homalomena aromatica Schott.* The study assessed the efficacy of these oils as mosquito repellents against *Aedes aegypti* and further examined their potential to inhibit mosquito odorant receptors. The study revealed that the oils extracted from both plants contained notable concentrations of limonene (86.76%) and linalool (52.35%), respectively. The combination of these oils in a 1:1 ratio demonstrated mosquito repellent efficacy lasting approximately 6.33 ± 0.23 hours. Molecular docking studies indicated that the key components of these oils have the capacity to inhibit mosquito odorant receptors, showing a blocking potential similar to that of N, N-diethyl-meta-toluamide (DEET), which supports the rationale for their extended repellent action. Furthermore, both oils were confirmed to be non-cytotoxic to HDFa cells after 24 hours of exposure.

**Fig 6:** *Homalomena aromatic Schott*

**Tripura**

- ***Clerodendrum viscosum Vent***

This plant commonly known as the "sticky clerodendrum," is a plant belonging to the family Lamiaceae. It is native to tropical regions and has been recognized for its various medicinal properties, including its potential use as a mosquito repellent. In Tripura the use of this indigenous plants for pest control and traditional medicine is prevalent among local communities. *Clerodendrum viscosum* is characterized by its aromatic leaves and flowers, which are often used in traditional remedies. The plant can grow up to 2 meters tall and features opposite leaves that are ovate to lanceolate in shape. The flowers are typically white or pale blue and are borne in clusters, attracting various pollinators. In Tripura, local populations have utilized *Clerodendrum viscosum* not only for its medicinal properties but also for its effectiveness against mosquitoes. The leaves of the plant are often crushed to release their essential oils, which are believed to possess insect-repelling qualities. This practice aligns with traditional knowledge systems where natural resources are employed for pest management. Recent studies have begun to explore the efficacy of *Clerodendrum viscosum* as a mosquito repellent through both laboratory and field trials. The essential oils extracted from the leaves have shown promising results in repelling various mosquito species, including *Aedes aegypti* and *Anopheles stephensi*, which are vectors for diseases such as dengue fever and malaria. The active compounds identified within *Clerodendrum viscosum* include terpenoids and phenolic compounds, which contribute to its insect-repelling properties. These findings suggest that integrating *Clerodendrum viscosum* into local pest management strategies could provide an eco-friendly alternative to synthetic repellents. Waliullah *et al*. [14] conducted a study on the insecticidal and repellent properties of *Clerodendrum viscosum Vent*. against *Tribolium castaneum*. The research involved the use of the ethyl alcohol extract of *C. viscosum* to assess repellent activity, and it was found that these extracts exhibit a robust insecticidal and repellent effect on *T. castaneum*.

**Fig 7:** *Clerodendrum viscosum Vent*

**Scientific validation of mosquito-repellent properties**

Recent scientific investigations have placed a growing emphasis on substantiating the mosquito-repellent characteristics of numerous plants and herbs that have been traditionally utilized by indigenous populations worldwide, especially in ecologically rich areas such as the seven sister states of India. Growing concerns about the health and environmental effects of synthetic repellents have prompted a renewed interest in plant-based alternatives, which are viewed as safer and more environmentally responsible choices. Below are the outlined steps for the scientific assessment of the mosquito-repellent properties inherent in various plants and herbs-

- **Surveys of ethnobotanical practices and the criteria for plant selection**

Ethnobotanical surveys frequently serve as the starting point for the scientific validation process. During these surveys, researchers obtain insights from indigenous communities concerning plants that have historically been employed to deter mosquitoes. This preliminary stage is essential for identifying promising candidates for further study.

- **The methodology for extracting and isolating bioactive substances**

After identifying promising plant species, researchers proceed to extract essential oils and bioactive compounds from various parts of the plants, including leaves, stems, flowers, and roots. The extraction techniques commonly

employed are hydro-distillation, steam distillation, and solvent extraction. These methods effectively isolate active components like citronellal, eugenol, limonene, and geraniol, which are recognized for their effectiveness in repelling mosquitoes.

- **Chemical Characterization and Identification of Bioactive Compounds**

Utilizing sophisticated methods like Gas Chromatography-Mass Spectrometry (GC-MS) for chemical profiling enables the identification and quantification of the various chemical constituents found in extracted oils. This process is vital for assessing which compounds are most potent in combating mosquitoes.

- **Testing for Effectiveness in Laboratory and Field Settings.**

The compounds that have been extracted are rigorously evaluated against a range of mosquito species. Typical laboratory methods utilized include:

- **Arm-in-cage trails:** This method involves volunteers or animal models placing their arms inside a cage populated with mosquitoes to examine the repellent characteristics of plant extracts. Researchers record the time until the initial bite and the frequency of landings to determine the effectiveness and duration of the repellent action.

- **Y-Tube olfactometer trials:** These tests evaluate the response of mosquitoes to varying concentrations of plant extracts, measuring their attraction or repulsion in a controlled experimental setup.

**Advantages of plant based repellents over synthetic repellents**

- **Non-Toxic to Humans and Animals:** Plant-based repellents are often considered to be safer for humans, pets, and livestock in comparison to synthetic repellents. While synthetic options like DEET are effective, they can lead to skin irritation, allergic reactions, and even neurotoxicity if used in high concentrations or for prolonged periods. In contrast, plant-based repellents, which may include citronella, neem, or eucalyptus oils, are less likely to cause harmful effects, making them a better choice for sensitive groups, such as children and pregnant women.

- **Reduced Risk of Allergic Reactions:** Compared to synthetic repellents, plant-based options are generally less prone to causing skin irritations or allergic responses. Essential oils, when used in diluted concentrations, help to lower the risk of negative reactions while still offering reliable protection against mosquitoes.

- **Environmentally Sustainable:** Synthetic repellents often persist in the environment and can adversely affect non-target organisms, whereas plant-based repellents are biodegradable and naturally decompose, leaving no harmful residues behind. This property makes them an excellent choice for application in natural habitats and ecologically sensitive locations [15].

- **Less Harmful to Beneficial Insects and Wildlife:** The use of synthetic repellents can pose risks to beneficial insects, including bees and butterflies, as well as to aquatic organisms. On the other hand, plant-based repellents, sourced from natural materials, are typically less harmful to these non-target species, fostering biodiversity and supporting ecological stability.

- **Complex Chemical Profiles:** Many synthetic repellents depend on a single active ingredient, which can contribute to the eventual development of resistance in mosquito populations. Conversely, plant-based repellents are composed of diverse mixtures of volatile organic compounds, making it more challenging for mosquitoes to build resistance. Neem oil, for example, contains various active compounds like azadirachtin and nimbin, which provide a multi-target strategy against mosquitoes, thereby lowering the risk of resistance [16].

- **Natural Variability:** The diverse composition of plant-based repellents contributes an extra dimension of complexity, making it harder for mosquitoes to adapt and consequently decreasing the risk of resistance.

- **Aromatic and Pleasant to Use:** A variety of synthetic repellents possess strong chemical fragrances that can be unpleasant for users. In contrast, plant-based alternatives often offer delightful, natural scents derived from essential oils like lavender, eucalyptus, and lemongrass. This characteristic makes them more attractive for regular application, especially within household contexts.

- **Multipurpose Benefits:** Many plant-based oils not only serve to repel mosquitoes but also exhibit a range of other beneficial characteristics, such as antibacterial, antifungal, and antioxidant effects. For example, both tea tree oil and peppermint oil provide repellent and antimicrobial benefits, making them applicable in numerous contexts beyond just repelling insects.

- **Diverse Product Forms:** The formulation of plant-based repellents can result in diverse products like sprays, lotions, creams, candles, and incense sticks, demonstrating their versatility. This range allows for a customized application that aligns with the unique needs and preferences of each user.

- **Self-Reliance and Local Production:** Unlike synthetic repellents, which necessitate complicated production processes, plant-based alternatives can be manufactured locally, thereby supporting small businesses and minimizing dependence on industrial chemicals. Furthermore, communities can craft their own repellent solutions from locally sourced plants, which bolsters self-reliance and sustainability.

**Conclusion**

In conclusion, the exploration of mosquito-repellent flora in India's Seven Sister States highlights the significant role that indigenous plants can play in combating mosquito-borne diseases. Recent discoveries underscore the potential for these natural defenders to serve as sustainable

alternatives to synthetic repellents, promoting both public health and biodiversity conservation. These discoveries emphasize the immense potential of leveraging traditional knowledge combined with modern scientific approaches to combat vector-borne diseases such as malaria, dengue, and chikungunya. Unlike synthetic repellents, which can pose health risks and contribute to environmental pollution, plant-based repellents are safer, biodegradable, and less likely to cause resistance in mosquito populations. Moreover, promoting the use of local plants for mosquito control can boost local economies, empower indigenous communities, and encourage sustainable practices. As research continues to unveil the chemical properties and ecological benefits of these plants, there is an opportunity for local communities to harness this knowledge for effective pest management strategies. Future research should focus on further isolating and understanding the active compounds in these plants, optimizing their formulations, and ensuring their widespread accessibility and affordability. By tapping into these natural resources, India can lead the way in developing eco-friendly mosquito management strategies that are as culturally respectful as they are scientifically robust.

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**Conflicts of interest**
The authors declare no conflicts of interest related to this review article.

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