



## Herbal repellents as eco-friendly alternatives for malaria vector control: A comprehensive review

Dr. Heena Sachdeva\*, Dr. Manish Sharma

Department of Zoology, Multani Mal Modi College, Patiala, Panjab, India

### Abstract

Malaria remains a major global health burden, exacerbated by the increasing resistance of *Anopheles* mosquitoes to synthetic insecticides and repellents. Conventional chemical repellents such as DEET and permethrin, while effective, pose concerns related to toxicity, environmental impact, and vector resistance. Herbal repellents, derived from plant-based secondary metabolites, offer a promising, eco-friendly alternative with broad-spectrum activity and reduced side effects. This review synthesizes current knowledge on malaria epidemiology, chemical repellent structures and limitations, and highlights various medicinal plants with demonstrated mosquito-repellent properties. Furthermore, it discusses advancements in formulation technologies and the potential integration of herbal repellents into existing malaria control strategies. Emphasis is placed on future prospects, including the identification of novel bioactive compounds and sustainable production methods. Herbal repellents represent a viable complementary tool in integrated vector management, contributing to environmentally sustainable malaria prevention.

**Keywords:** Malaria, mosquito repellents, herbal repellents, DEET, vector control, *Anopheles*, integrated vector management

### Introduction

Malaria, a life-threatening disease caused by *Plasmodium* parasites, continues to pose a significant global health challenge despite decades of control efforts. The disease is primarily transmitted to humans through the bite of infected female *Anopheles* mosquitoes. According to the World Health Organization (WHO), the last few years have seen stagnation in malaria control progress due to multiple converging factors, including vector resistance to insecticides, parasite resistance to antimalarial drugs, and logistical challenges in endemic regions. A critical aspect of malaria prevention is vector control, which remains the most effective means to reduce transmission. Chemical repellents and insecticides are widely used, but they are often associated with side effects, environmental toxicity, and increasing resistance in mosquito populations. These limitations underscore the need for alternative, sustainable solutions.

Plant-based or herbal repellents have gained increasing attention due to their eco-friendly nature, biodegradability, and lower toxicity profiles. Many traditional societies have long used herbs and plant extracts to repel mosquitoes. Scientific studies have validated the efficacy of many such botanicals, yet their potential remains underexploited. This review provides an in-depth exploration of malaria epidemiology, the drawbacks of chemical repellents, and the current and future potential of herbal alternatives for malaria vector control.

### Malaria Epidemiology

**Malaria is caused by five species of the *Plasmodium* parasite:** *P. falciparum*, *P. vivax*, *P. malariae*, *P. ovale*, and *P. knowlesi*. Of these, *P. falciparum* is the most deadly and prevalent in Africa, while *P. vivax* predominates in Asia and South America. Transmission occurs via female *Anopheles* mosquitoes, which are highly sensitive to environmental conditions. According to WHO's 2023 report, malaria caused 608,000 deaths in 2022, with children under the age

of five accounting for approximately 80% of deaths. In sub-Saharan Africa, where the disease is most prevalent, poverty, lack of healthcare access, and tropical climate conditions contribute to sustained transmission. Climate change has exacerbated malaria's geographic spread, with transmission areas expanding into previously malaria-free highland zones in East Africa and parts of South Asia. Urbanization and deforestation further complicate malaria control, altering mosquito breeding patterns and bringing human populations into closer contact with mosquito habitats. Despite the widespread use of artemisinin-based combination therapies (ACTs), the emergence of drug-resistant *Plasmodium* strains in Southeast Asia poses a significant threat. Similarly, the efficacy of long-lasting insecticidal nets (LLINs) and indoor residual spraying (IRS) is being undermined by resistance in mosquito populations. Alternative approaches, including community-based vector management and natural repellents, are increasingly essential in sustaining malaria control gains.

### Chemical Repellents: Structure and Side Effects

The use of chemical repellents has significantly contributed to malaria prevention, particularly in non-endemic travelers and high-risk populations. However, concerns over long-term safety, ecological impact, and chemical resistance have prompted the search for safer alternatives.

#### 1. DEET (N, N-diethyl-meta-toluamide)

developed by the U.S. Army in 1946, remains the most widely used mosquito repellent. Structurally, it is an aromatic amide with a benzene ring and a diethylamide side chain, granting it lipophilic properties that allow for penetration of the mosquito's sensory system. It functions primarily by interfering with the olfactory receptors of mosquitoes, making humans less detectable. Although DEET is highly effective and offers long-lasting protection, its use is not without drawbacks. Prolonged or high-concentration exposure can lead to skin irritation, mucosal inflammation, and in rare instances, neurotoxic effects,

especially in children. Moreover, DEET is known to dissolve plastics and synthetic fabrics, limiting its compatibility with certain materials. From an ecological standpoint, it is mildly toxic to aquatic life and can accumulate in water bodies if not properly disposed of, raising environmental concerns. Picaridin, or Icaridin, is another synthetic repellent structurally derived from piperidine, a natural compound found in black pepper. It is favored for its low odor and material-friendliness. Picaridin acts similarly to DEET by masking human scent and confusing mosquitoes. Although considered safer and more cosmetically acceptable than DEET, it may still cause minor eye and skin irritation and poses a risk to aquatic ecosystems. Permethrin, a synthetic pyrethroid, differs in its mode of action—it acts on sodium channels in insect neurons, causing paralysis and death. It is mainly used to treat clothing and mosquito nets rather than being applied directly to skin. While highly effective, permethrin is a known neurotoxin and is especially hazardous to cats, bees, and aquatic organisms. Dermal sensitivity in humans is relatively rare but possible with repeated exposure. Collectively, these synthetic repellents have played a major role in reducing malaria incidence but face mounting criticism due to resistance development, ecological toxicity, and human health risks, necessitating the exploration of safer and environmentally friendly alternatives such as herbal repellents.

### Herbal Repellents

Natural Alternatives Plant-derived repellents have been utilized for centuries in traditional medicine systems. They often work by masking human scent or directly repelling mosquitoes through phytochemicals present in essential oils. The growing body of literature on herbal repellents supports their efficacy, although standardized studies are still required for many plant species.

#### 1. Citronella (*Cymbopogon nardus*)

Is among the most well-studied herbal mosquito repellents. Its essential oil is rich in citronellal, citronellol, and geraniol—compounds known to interfere with mosquito olfactory reception. These oils act by forming a volatile barrier around the body, effectively masking attractants like carbon dioxide and lactic acid exhaled by humans. Citronella oil is used in various formulations including sprays, candles, and topical applications. Although generally safe, prolonged use on sensitive skin may cause irritation or dermatitis.

#### 2. Neem (*Azadirachta indica*)

Oil is another potent botanical repellent, containing azadirachtin and other limonoids that offer multi-modal action including repellent, ovicidal, and larvicidal effects. Neem oil disrupts insect hormonal systems, impairs feeding, and reduces egg-laying behavior in mosquitoes. It is frequently incorporated into soaps, lotions, and mosquito coils and is especially popular in rural India and parts of Africa where commercial repellents are inaccessible. However, its strong odor may limit user compliance.

#### 3. Lemon eucalyptus (*Corymbia citriodora*)

Yields an essential oil from which PMD (para-menthane-3,8-diol) is derived. PMD is one of the few plant-based ingredients endorsed by both CDC and WHO due to its repellent efficacy comparable to 20–25% DEET

concentrations. It offers extended protection, often lasting between 6–8 hours under favorable conditions. Unlike DEET, PMD is less irritating to the skin and does not damage synthetic materials.

#### 4. Basil (*Ocimum spp.*)

Particularly species like *O. basilicum* and *O. gratissimum*, produce essential oils rich in eugenol, linalool, and methyl chavicol, all of which exhibit mosquito-repellent properties. These compounds disrupt the mosquito's chemosensory pathways, leading to repellency and disorientation. In addition to sprays and skin oils, basil can also be planted around homes as a natural deterrent.

#### 5. Garlic (*Allium sativum*)

Has a long-standing reputation in traditional medicine for its broad-spectrum antimicrobial and insect-repelling effects? The active compound allicin emits a strong sulfur-based odor that is unappealing to mosquitoes. Although garlic extracts can be formulated into topical applications or sprays, the pungent odor significantly limits user acceptability. Nevertheless, garlic oil is used in agricultural or open-air settings where olfactory comfort is less of a concern. Collectively, these herbal repellents provide a safer, more sustainable alternative to synthetic chemicals and show promise for inclusion in integrated vector management strategies.

### Future Prospects of Herbal Repellents

The future of mosquito control, particularly against malaria vectors, lies in sustainable and eco-friendly strategies. Herbal repellents offer a natural, biodegradable, and often culturally acceptable alternative to synthetic chemicals. In recent years, the emphasis has shifted towards identifying and validating new plant species with strong repellent activities. Emerging candidates include *Cymbopogon winterianus* (Java citronella), *Pelargonium graveolens* (rose geranium), *Murraya koenigii* (curry leaf), *Mentha arvensis* (wild mint), *Carum copticum* (ajwain), *Pongamia pinnata* (karanja), and *Acorus calamus* (sweet flag), among others. These plants have shown promising bioactivity due to their high content of essential oils rich in monoterpenoids, phenolics, and terpenes.

Research into nano-formulations, such as encapsulating plant essential oils into nanocarriers or biopolymers, aims to prolong the repellent activity and stability under field conditions. Genetic engineering may also play a role in enhancing the yield of key bioactive compounds in medicinal plants. Moreover, integrating herbal repellents into wearable textiles, creams, or sprays could improve compliance and protection in malaria-endemic zones. Traditional knowledge should be preserved and scientifically validated through ethnobotanical studies and randomized controlled trials to explore plant-based solutions. Regulatory approval, quality control, and formulation standardization remain key challenges in commercializing herbal repellents. Nonetheless, with increasing resistance to chemical insecticides and growing awareness of environmental health, herbal repellents are poised to become a cornerstone of integrated vector management (IVM) strategies.

### Conclusion

Malaria remains a formidable global health challenge, underscored by persistent transmission, emerging insecticide resistance, and environmental changes that

facilitate vector proliferation. Conventional chemical repellents, while effective, face limitations due to toxicity, environmental concerns, and resistance development, highlighting an urgent need for safer, sustainable alternatives. Herbal repellents, derived from a diverse array of plant species with bioactive compounds such as essential oils and terpenoids, present a promising solution. Their eco-friendly nature, cultural acceptability, and potential for reduced side effects make them attractive candidates for integrated malaria vector control strategies. Advances in phytochemical research and formulation technologies can address the current constraints of herbal repellents, particularly their limited duration of action. Furthermore, rigorous evaluation and standardization of these plant-based repellents are essential to ensure consistent efficacy and safety. The incorporation of herbal repellents into existing vector control programs, alongside other measures such as insecticide-treated nets and environmental management, could significantly enhance malaria prevention efforts. Looking forward, multidisciplinary research integrating ethnobotany, chemistry, entomology, and public health is critical to unlock the full potential of herbal repellents. Their role as complementary tools offers a sustainable pathway to reduce malaria burden while mitigating the risks associated with synthetic chemicals. Thus, herbal repellents represent a vital frontier in the ongoing global fight against malaria, aligning with goals for environmentally sustainable and community-friendly disease control.

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