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Global Challenges of Plant Based Mosquito Repellents: A Systemic Review

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ABSTRACT
Dengue fever (DF) presents a significant global health challenge as a mosquito-borne viral illness, affecting approximately 390 million individuals worldwide annually. Studies have depicted a concerning trend, of increasing DF cases every decade between 1990 and 2013. Mosquitoes serve as primary vectors for various diseases, including dengue, Japanese encephalitis, chikungunya, malaria, and filariasis, resulting in millions of deaths each year. Notably, Aedes aegypti and Aedes albopictus are major vectors for the transmission of yellow fever and dengue virus, contributing to the spread of diseases such as dengue hemorrhagic fever and chikungunya. Mosquito bites can trigger allergic reactions, ranging from localized dermal responses to systemic manifestations like nettle rashes. Conventional strategies for vector management heavily rely on chemical insecticides containing DEET (N, N-diethyl-3-methyl benzamide), which pose risks of skin penetration and subsequent allergic or toxic reactions. In contrast, traditional plant-based repellents have been historically used to ward off mosquitoes, offering a potential natural alternative to synthetic repellents. Understanding the properties of traditional mosquito repellent plants provides valuable insights for the invention of novel formulations derived from natural sources. This review explores various theories of repellent action, mechanisms underlying plant-based mosquito repellents, and the impact of repellents on olfactory and sensory modalities. These insights lay the groundwork for the advancement of accessible repellents and the innovation of new compounds with novel modes of action, aiming to mitigate the burden of mosquito-borne diseases effectively.
Keywords: *Dengue fever, Insecticides, Aedes aegypti, Repellents, Filariasis, Elephantiasis.*

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INTRODUCTION

Diseases spread by mosquitoes continue to be a major cause of sickness and mortality [1]. Worldwide, mosquito-borne illnesses such as malaria, dengue, filariasis, yellow fever, and chikungunya pose a serious threat to public health [2]. Based on updated data from the World Health Organisation (WHO), there were an expected 241 million cases of malaria in 2020, accounting for over 400,000 malaria-related fatalities. The information also revealed that 40,000 deaths worldwide were attributed to dengue disease alone each year. The Plasmodium parasite, which is conveyed by the bite of female Anopheles mosquitoes, is the source of malaria, the most common disease carried by mosquitoes. Conversely, dengue and chikungunya are viral illnesses spread by mosquitoes and are brought on by the same species of mosquito, *Aedes aegypti* and *Aedes albopictus.* Elephantiasis, or lymphatic filariasis, is another prevalent disease spread by mosquitoes. It is brought on by an infection with filial worms, which enter the body through the bite of the *Culex quinquefasciatus* mosquito [3]. Despite decades of malaria control efforts, 3.3 billion people are at risk of contracting malaria in 106 tropical and subtropical nations and territories [4]. In sub-Saharan Africa, it is one of the leading causes of perinatal and juvenile mortality and morbidity, along with low birth weight, and stillbirths [5]. Over 50 species of Anopheles mosquitoes, out of the 500 species known to exist worldwide, can spread malaria by the bite of an infected female Anopheles spp.

Presently, the vector control is the only effective way to control the spread of malarial infections [6]. Therefore, preventing mosquito bites is one of the best ways to lower the occurrence of disease.

Low volatility chemicals may function as contact repellents, according to Christophers' theory [7]. Repellants have always been recognized as a component of a comprehensive, integrated approach for controlling insect-borne diseases, safeguarding humans against mosquito bites [8]. N-diethyl-meta-toluamide (DEET), allethrin, N-diethyl mendelic acid amide, and dimethyl phthalate are among the chemical ingredients used in the majority of commercial repellents [9]. It has been observed that chemical repellents should be used with prudence as they lead to toxic reactions like dermatitis, allergy, and cardiovascular and neurological side effects [10]. The regular application of chemically derived synthetic repellents to manage mosquito populations has upset natural ecosystems, leading to pesticide resistance emerging, mosquito populations rebounding, and detrimental effects on non-target creatures [11]. Therefore, the concept of creating new eco-friendly repellents by utilizing natural mosquito repellent items as a substitute could be a cooperative way to reduce the negative effects on the environment and human health.

The use of plant-based repellents has gained popularity again recently due to their abundance of safe, biodegradable phytochemicals. They have potential to produce non-toxic byproducts that can be tested for insecticidal and mosquito-repelling properties. Numerous research investigations have documented the evidence the repellent properties of plant extracts or essential oils' against malaria vectors worldwide. Traditionally, people have used plant-based repellents to protect themselves from various Anopheles species for decades. The creation of novel natural products as an alternative to chemical repellents can be greatly aided by knowledge of conventional repellent plants. Historically, herbal remedies have been utilized for industrial and agricultural applications for millennia as a source of bioactive and medicinal compounds [12]. Medicinal plants and their byproducts have been assessed for their poisonous, fatal, repellent, antifeedant, fumigant, growth-regulating, and deterring properties on implantation in order to evaluate them for various pest control tactics [13-14]. In addition, botanical insecticides that contain combinations of chemical compounds have the ability to influence physiological and behavioral processes, in contrast to conventional insecticides that are based solely on one active ingredient. Therefore, pests have little potential that they may develop resistant to these compounds. Seeking effective bio-insecticides that are both appropriate and adaptable to ecological settings appears to be crucial for achieving adequate insect control [15]. IR3535 [ethyl butyl acetylamino propionate (EBAAP)], N, N-diethyl-meta-toluamide (DEET), allethrin, and picaridin are the chemical repellents that are used in the majority of commercially available mosquito repellents. Nevertheless, these chemical repellents are non-biodegradable and include toxic and hazardous substances, which can disrupt the ecology and result in a number of additional health problems [16]. Therefore, the most effective way to manage mosquito populations and diseases spread by mosquitoes is to apply plant-based repellents. The plant-based substances are biodegradable, species-specific, environmentally benign, and have negligible to no negative effects on people [17].

Theories of repellent action

Some theories related to repellant actions are discussed below:

1. Masking smell receptor neurons from attractants

Firstly, Davis provided a summary of repellents' mechanism of activity [18]. During this time, ORNs on the head of mosquitoes were used for single cell recordings via different techniques and a numerous compounds were tested for their efficacy as repellent on these cells. Davis and his colleagues hypothesized on the basis of these electrophysiological studies, that repellents modified the normal responses of ORNs. DEET reduced the reactivity of ORNs towards lactic acid [19], and towards ethyl proprionate, an ovulation attractant [20].

2. Influenced activation of specific olfactory receptors

Boeckh and his associates [21] demonstrated that ORNs present on the axon of Aedes aegypti were triggered by DEET. They contend that since these particular neurons were not stimulated by attractants, no signal could have been delivered to the central nervous system to counteract the attraction-neutralizing effect of other neurons. Conversely, they follow the hypothesis of Davis and his colleagues [22-23]. According to Syed and Leal (2008), DEET triggered a particular smell receptor of trichoid sensillum present on the antennae of *Culex quinquefasciatus* [24]. Other researchers have shown that DEET stimulated a particular odorant receptor (OR) in Anopheles gambiae larvae [25], which further supports this notion.

3. Confiscated an attractant

Syed and Leal [24] demonstrated that the amount of octenol liberated from the cartridge was declined due to exposure of DEET and attractant component simultaneously. This led to decrease the sensitivity of

Ae. aegypti towards octenol. They also demonstrated that DEET on application to the skin altered the chemical composition of volatile constituents being released and declined the texture of skin. But Pellegrino et al. refused this hypothesis [26].

4. Stimulated a gustatorial receptor neuron

Lee et al. [27] demonstrated that DEET restrains the nourishing activities of *Drosophila melanogaster* (vinegar fly). Gustatory receptors neurons (GRNs) present in short sensilla on the outer labellum of fly reacted to both quinine (bitter feeding deterrents) and DEET.

5. Interaction of a botanical repellent to mediate repellency effect

Kwon et al. [28] demonstrated that citronellal directly activated the TRPA1 channel in *An. gambiae*, whereas in Drosophila, it regulated the Ca^{2+} ions stimulated K^{+} channel's activity by interacting with TRPA1. Thus, citronellal has shown interaction with both olfactory co-receptor Orco and with TRPA1 channels in *An. Gambiae* and *D. melanogaster*.

6. Amendment of olfactory receptors and their ligands

Using Xenopus oocytes, Bohbot and Dickens [29] investigated the molecular receptive range of *Ae. aegypti* Ors and showed that a spectrum of insect repellents could alter the activity of ORs. This theory confirmed the findings of a prior study, which suggested that DEET and other repellents may either activate particular ORs or prevent Ae. aegypti ORs from responding to attractants. As a result, the CNS got distorted signals that caused the insect to become disoriented.

7. Persuasion from old insights

Even after 60 years of intensive research, the relationship between DEET and the other repellents' mechanisms remained controversial. Some reports over the past five years have focused on temperature, gustatory, and smell signaling pathways. Even while the goal of these studies is to determine the processes by which insect repellents work, such as how DEET and other repellents interact with various protein receptors? What connection exists between DEET's activation and inhibition of ORs and how it affects insect behavior? The subsequent sections endeavor to tackle these fascinating inquiries by concentrating on the physiological and molecular impacts of repellents on ORs and GRs. [30]

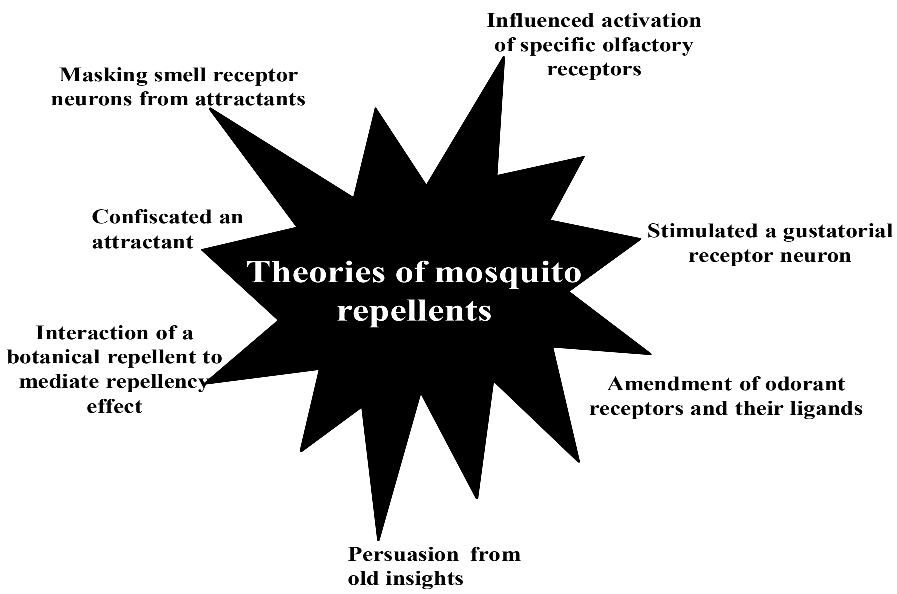

Fig. 1: Theories of repellent action

The Mechanism of Action

The mosquito-repellent properties of these plants have deterred mosquito from landing, probing, or biting due to their unpleasant or irritating smell. Some compounds may interrupt their olfactory receptors confused them to locate their targets, to detect carbon dioxide and other attractants emitted by humans.

Plants showing mosquito repellant activity

Certain significant plant genera, including *Azadirachta, Calotropis, Cinnamomum, Citrus, Eucalyptus, Geranium, Mentha, Lantana, Ocimum, Piper,* and *Zingiber*, have been reported in our ancient texts to possess anti-larval and insecticidal properties. Due to these properties these plants have been used traditionally for generations as a personal defence against mosquitoes that seek out hosts. Table 1,2 and 3 discusses plants that shown higher levels of activity against insects.

Table1: Plants having good mosquitoes and insects repellant activities against Ae. aegypti.

Plant name (Common name)	**Tested mosquito species**	**Plant part used**	**Active compound**	**References**
Carica pubescens (Mountain papaya)	*Ae. aegypti*	Seeds	Oleic acid and palmitic acid	[31]
Ageratum houstonianum (Floss flower)	*Ae. aegypti*	Leaves	Bioactive phytochemical constituents	[32]
Ageratum conyzoides (Goat weed plant)	*Ae. aegypti*	Leave, flower, stem and root	Chromene, precocene I, precocene II with others	[33]
Citrus aurantifolia (Key lime)	*Ae. aegypti, An. stephensi*	Stems and leaves	Geijerene, limonene and germacerene D	[34]
Citrus reticulate (Mandarin orange)	*Ae. aegypti*	Fruit peel	D-limonene and γ-terpinene	[35]
Zeylanicum (Ceylon cinnamon)	*Cx. quinquefasciatus, An. tessellatus and Ae. aegypti*	Leaves and Barks	Cinnamaldehyde	[36]
Cymbopogon winterianus (Java citronella)	*Ae. aegypti*	Leaves	Citronellol and geraniol	[37]
Cymbopogon citartus (Lemongrass)	*Ae. aegypti*	Leaves	Citral, neral and β-myrcene	[38]
Mentha arvensis (Corn Mint)	*Ae. aegypti*	Leaves	Tannins, saponins, flavonoids and terpenoids	[39]
Ocimum americium (Lime basil)	*Ae. aegypti*	Leaf	6-methyl cinnamate	[40]
Mentha piperita (Peppermint)	*Ae. aegypti*	Leaves	Phytochemical constituents	[41]
Lantana camara (Sage)	*Ae. aegypti*	Leaves, flower	Caryophyllene, eucalyptol and bicyclogermacerene	[42]
Pelargonium graveolens (Rose geranium)	*Ae. aegypti*	Leaves	Geraniol, citronellol	[43]
Pinus merkusii (Sumatran pine)	*Ae. aegypti*	Bark	Phytochemicals	[44]
Nepeta cataria (Catnip)	*Ae. aegypti*	Leaves	Phytochemicals	[45]
Mentha spicata (Spearmint)	*Cx. quinquefasciatus, Ae. aegypti and An. stephensi*	Leaves	R-carvone and limonene	[46]
Ocimum grattisicum (African basil)	*Ae. aegypti*	Leaf and branches	Euganol	[47]
Piper aduncum, P. arboretum, P. crassinervium, P. gaudichaudianum and P. marginatum (Brazilian pepper)	*Ae. aegypti*	Leaves	β-asarone, (E)-anethole, (E)-β-caryophyllene, γ-terpinene, p-cymene, limonene, α-pinene and β-pinene	[48]
Piper caninum and P.montium (Wild pepper)	*Ae. aegypti*	Leaves and/or stems	β-caryophyllene, β-bisabolene, α-pinene, and β-pinene	[49]
Piper crocatum (Red betel)	*Ae. aegypti*	Leaves	Bioactive phytochemical constituents	[50]
Piper retrofractum (Javanese long pepper)	*Cx. quinquefasciatus and Ae. aegypt*	Fruits	Bioactive phytochemical constituents	[51]
Solanum lycopersicum (Tomato)	*Ae. aegypti*	Leaves	Phytochemicals	[52]
Rosmarinus officinalis (Rosemary)	*Ae. aegypti*	Leaves	α-pinene, 1,8-Cineole, 1-Verbenon, Borneol,Geraniol	[53]
Solanum villosum	*Ae. aegypti*	Fruit/Berries	Phytochemicals	[54]
Syzygium polyanthum (Indonesian bay leaf)	*Ae. aegypti*	Leaves	Saponins, triterpenes, alkaloids and essential oil	[55]
Tagetes erecta (Mexican marigold)	*Ae. aegypti*	Leaves and stems	Ppiperitone, D-limonene and piperitenone	[56]
Zingiber offincinale (Ginger)	*Ae. aegypti*	Rhizome	Zingiberene, kaemferol and zingibberol	[57]

Table2: Plants having good mosquitoes and insects repellant activities against *An. stephensi*

Plant name (Common name)	Tested mosquito species	Plant part used	Active compound	References
Ageratum houstonianum (Floss flower)	*An. stephensi,*	Leaves	Bioactive phytochemical constituents	[32]
Calendula officinalis (Marigold)	*An. stephensi*	Aerial parts	Phytochemicals	[58]
Azadirachta indica (Neem)	*An. stephensi*	Leaves and Seed oil	Azadirachtin, salanin, gedunin and deacetylnimbin	[59]
Eucalyptus globules (Blue gum)	*An.stephensi*	Leaf	1,8-Cineol, α-pinene	[60]
Myrtus communis (Myrtle)	*An. stephensi*	Aerial parts	Phytochemicals	[58]
Mentha spicata (Spearmint)	*An. stephensi*	Leaves	R-carvone and limonene	[46]
Syzygium aromaticum (Clove)	*An. stephensi*	Flower bud	Essential oil such as 2-methoxy-3-(2-propenyl)	[61]
Calotropis procera (Milk weed, Aak)	*An. aerabiansis, Cx. quinquifasciatus*	Leaf	Saponins, flavonoids, tanin	[62]
Cinnamomum verum (Ceylon cinnamon tree)	*Cx. quinquefasciatus*	Bark	Cinnamaldehyde	[63]
Carica papaya (Papaya)	*Aedes spp.*	Leaves	Phytochemicals	[64]
Cinnamomum osmophloeum (Pseudocinnamomum)	*Ae. albopictus, Cx. quinquefasciatus and Armigeres subalbatus*	Leaves	Alpha-methyl cinnamaldehyde, benzaldehyde and trans-cinnamaldehyde	[65]
Citrus sinensis (Sweet orange)	*Cx. pipiens*	Fruit peel	Limonene	[66]
Zeylanicum (Ceylon cinnamon)	*Cx. quinquefasciatus, An. tessellatus and Ae. aegypti*	Leaves and Barks	Cinnamaldehyde	[67]
Cymbopogon giganteus (Kachi grass)	*An. gambiae*	Leaves	Limonene	[68]
Jatropha curcas (Purging nut)	*Cx. pipiens and Cx. quinquefasciatus*	Leaves and seed	Alkaloids, steroids, flavonoids, oleic acid and linolenic acid	[69]
Juniperus virginiana (Eastern red cedar)	*An. gambiae*	Aerial green parts	Essential oil	[70]
Eucalyptus tereticornis (Forest red gum)	*Cx. quinquefasciatus*	Leaf	β--pinene	[71]
Juniperus procera (African pencil-cedar)	*An. arabiensis*	Leaves	Phytochemicals including alkaloids, carbohydrates, glycosides, proteins, phenols, phytosterols, saponins and tannins	[72]
Pinus brutia, P. canariensis, P. halepensis, P. nigra, P. stankewiczii, P. strobus and Pinus pinaster (Greek Pinus)	*Ae. albopictus*	Fresh needles from branches	Caryophyllene, K–terpineole, eugenyl acetate, eugenol, isoeugenol, camphor, K–pinene, β–pinene and cineole	[73]
Ocimum basilicum (Sweet basil)	*Ae. albopictus, Cx. triaeniorhynchus*	Leaf	Linalool and methyleuganol	[47]
Olea europaea (Common olive)	*An. arabiensis*	Leaves	Phytochemicals	[74]
Piper retrofractum (Javanese long pepper)	*Cx. quinquefasciatus and Ae. aegypt*	Fruits	Bioactive phytochemical constituents	[75]
Piper betle (Betel pepper)	*Cx. quinquefasciatus*	Leaves	Alpha-cubebene, alpha-caryophyllene, caryophyllene, cyclohexane, 1,6-cyclodecadiene, 4,7-	[76]

			methanoazulene, benzene, 1H-cyclopropa(a) naphthalene, 2H-2,4a-methano naphthalene, and 1H-cycloprop(e) azulene	
Piper nigrum (Black pepper)	*An. arabiensis, An.coluzzii, An. funestus, An. gambiae and An. quadriannulatus*	Fruits	Piperine	[77]
Solanum nigrum (Makoi or black nightshade)	*Cx. quinquefasciatus*	Fruit/Berries	Phytochemicals	[78]
Piper longum (Long pepper)	*Cx. pipiens pallens*	Fruits	Pipernonaline	[79]
Solanum xanthocarpum (Yellow-berried Nightshade)	*An. stephensi and Cx. quinquefasciatus*	Fruits	Phytochemicals	[80]
Solanum trilobatum (Purple fruited pea egg plant)	*Cx. quinquefasciatus and Cx. tritaeniorhynchus*	Leaves	Phytochemicals	[81]
Thymus vulgaris (Garden thyme)	*Cx. pipiens pallens*	Aerial parts	Carvacrol, p-cymene, linalool, α-terpinene, and thymol	[82]

1. Allium sativum L.

Globe-shaped, brightly coloured flowers that sway in the breeze is the hallmark of alliums. Allium bulb odour is unpleasant to mosquitoes. A. sativum has shown a variety of insecticidal properties on a broad spectrum of insect pests; for instance, its juice exhibited insecticidal properties against *Musca domestica* and *Delia radicum* [83]. *Tetranychus cinnabarinus* has been demonstrated to be susceptible to the larvicidal effects of garlic extract [85], as well as the larvicidal effects of *Culex quinquefasciatus* and *Anopheles stephensi* mosquitoes [85]. Furthermore, *Callosobruchus maculatus* eggs, larvae, and adults have been demonstrated to be susceptible to the larvicidal effects of clove extract [86]. In case of Culex pipiens, essential oil bulbs have depicted larvicidal activity [87], fumigant toxicity [88], insecticidal and [89], and acaricidal potential [90] against all levels of *Boophilus annulatus*. Additionally, the agglutinins from *A. sativum's* leaves (ASAI) and bulbs (ASAII) have shown insecticidal efficacy against Spodoptera littoralis, a cotton leafworm [91]. The ASAI, ASAII, and garlic lectins, have also shown insecticidal properties against *Acyrthosiphon pisum* (pea aphids) [92].

2. Citrullus colocynthis L. Schrad.

Citrullus colocynthis leaf extracts have demonstrated ovicidal, larvicidal, and repellent qualities against *Culex quinquefasciatus* mosquitoes [93-94]. They have also demonstrated larvicidal activities against *Culex quinquefasciatus* and Aedes aegypti premature fourth place instar larvae. Numerous researches have looked at the entire plant extract, and they have found larvicidal action against the larvae of *Culex quinquefasciatus*, *Anopheles stephensi*, and *Aedes aegypti* [95]. Its fruit extracts have demonstrated insecticidal efficacy against *Tribolium custaneum* [98], induced lethality against adolescent phases of *Lipaphis erysimi* [97], and inhibited *Bactrocera zonata's* overall capacity to lay eggs [96, 97]. The third instar larvae of *Anopheles stephensi*, *Aedes aegypti* and *Culex quinquefasciatus*, have been shown to be susceptible to the larvicidal qualities of the seed extracts [99].

3. Laurus nobilis L.

Aphidicidal activity against Brevicoryne brassicae has been demonstrated by the purified essential oil of Laurus nobilis [100]. Additionally, the essential oil extracted from the leaves has demonstrated fumigant toxicity against all stages of *Tribolium confusum* [101], repellent potential against *Tribolium custaneum, Rhyzopertha dominica*, and *Tenebrio molitor* larvae [102], insecticidal effects against adult Sitophilus zeamais [104], *Rhyzopertha dominica*, and *Tribolium castaneum* [105], and cytotoxicity towards Artemia salina [106]. Finally, the dust of the leaves has potential to kill *Sitophilus zeamais* adults and the essential oil extracted from branches repelled *Aedes aegypti* [107-108].

4. Ocimum basilicum L.

The essential oil extracted from *Ocimum basilicum* plant has shown lethality potential against *Myzus persicae*, *Acyrthosiphon pisum*, [109], and *Musca domestica* [110]. It also depicted repellent potential against *Aedes aegypti*, *Anopheles stephensi*, *Culex quinquefasciatus* [111], and adult female *Culex pipiens* [112], as well as has antifeedant properties against *Lymantria dispar* [113]. Furthermore, volatile toxicity against *Rhyzopertha dominica*, *Cryptolestes pusillus* and *Sitophilus oryzae* has been observed [114]. Additionally, the larvicidal efficacy against *Culex quinquefasciatus* has been revealed by the stem extracts [115].

5. LAVENDER

Lavender plants produce lavender oil from flowers on distillation. Its active compound like linalool and linalyl acetate can be used as a mosquito repellent [116]. It has been found that insects and other animals like rabbits can never decimate lavender plant because of the lovely fragrance of its essential oils found in the leaves. It has been demonstrated that lavender oil hinders a mosquito's ability to smell. This plant established in drought-resistant areas, and required full sun and good drainage.

6. MARIGOLD

Marigolds is an easy-to-grow annual flower, emit a smell that deters mosquitoes. According to NYBG, they kept the mosquitoes away and also persuaded against thrips, aphids, whiteflies, squash bugs, Mexican bean beetles, and tomato hornworms. The researchers intended to use parts of marigold plant (*Tagetes erecta*) as suitable components of the mosquito coil/ incense stick to be produced. It does not contain harmful chemicals and repels mosquitoes without causing any harm to the environment. Its particular smell due to presence of a-terthienyl chemical proved unappetizing for many insects that made it a natural insecticidal [117].

7. Citronella Grass (Lemon Grass)

Citronella grass (or lemon grass) is also used as natural mosquito repellent due to its distinct smell. The Brooklyn Botanic Garden recommended implantation of lemon-scented plants like citronella grass to keep mosquitoes at bay. The living plants are most effective to repel pests. This low-maintenance plant does best in large planters and can be planted directly in a sunny area in the ground. The repellence activity of citronella was studied in numerous studies. The essential oil is extracted from the stems and leaves of different species of lemongrass (*Cymbopogon* spp.) [118]. Ansari *et al*. [119] found that citronella obtained from lemongrass has a 100% insect repellent effect against *Anopheles culicifacies*. According to Amer *et al*. [120] and Tawatsin *et al*. [121] citronella could provide protection against *Anopheles stephensi* and *Anopheles dirus* for 8 and 6 h, respectively. Moreover, small quantity of essential oil extracted from citronella grass has also shown repellent activity against *An. minimus* [122] and *An. dirus* [123], respectively. They evidence that that repellence potential of plant is based [124] on the concentration of extracts.

8. CATMINT

Catnip (catmint) is a perennial plant that belongs to the mint family and grows abundantly both as a commercial plant and as a weed. They are amazing mosquito repellants and another recommendation from the BBG. According to research conducted in Iowa State University, catmint was found to be ten times more effective than DEET as insect repellants. This herb is spread from central Europe to central Asia and the Iranian plateaus. According to Amer et al. [125], 20% oil solution of catnip has shown full efficacy against *An. stephensi*. Birkett *et al*. [126] in Kenya reported that the repellency potential of catnip against Anopheles gambiae is dose-dependent.

9. ROSEMARY

Rosemary is herb that has woody scent to keep mosquitoes as well as cabbage moths and carrot flies away. Rosemary is an evergreen aromatic shrub with a Mediterranean origin, which belongs to Lamiaceae (Labiatae) family [127]. They grow effectively in hot and dry climates and flourish in containers, which may be ideal for areas with winters. They can also be pruned into all sorts of shapes and sizes and make great borders or decorations. According to Amer *et al.* [128], dilute solution of rosemary oil has shown inhibition against *An. stephensi*. Govindarajan *et al*. [129] reported that the efficacy of rosemary is concentrations dependent.

10. BASIL

Basil is another herb that can also be used as pest repellent. Their pungent smells keep the pests away. Basil is an annual plant of the Ocimum genus, which belongs to the Lamiaceae family and is used as traditional medicine in different parts of the world [130]. Different studies were conducted to investigate the effectiveness of basil as repellent against different Anopheles species. Amer et al. [131], demonstrated its effectiveness against *An. stephensi*. Phasomkusolsil et al.[132] used basil oil in different concentrations against *An. dirus* reported dose dependent efficacy. Another study reported that 0.1 ml dose can [133] repel Anopheles only for sometimes, whereas, Tawatsin et al. [134] demonstrated that hairy basil oil provides complete protection against *An. dirus*. In contrast, Seyoum *et al.* [135], neglected their repellency effect against An. gambiae.

11. *Horsemint (Bee Balm)*

Horsemint, also known as Monarda or bee balm is a perennial herb that typically grows between 2 to 4 feet tall. It has square stems, lance-shaped leaves with serrated edges. It has tubular flowers in clusters that can range in color from pink and purple to red and white. The essential oils extracted from horsemint have bioactive molecules like carvacrol, thymol, and pulegone, responsible for it medicinal efficacy. Their anti-inflammatory, antimicrobial, and antiseptic properties proved them beneficial to cure insect bites, minor skin irritations, and wounds. Their tea or infusions have been used to relieve symptoms of colds, flu, and digestive discomfort. They can attract pollinators (like bees) but repels mosquitoes. They provide a strong, incense-like odor that masked the smells given off by humans and confused the pests [136].

12. MINT

Peppermint is a hybrid mint obtained by cross-breeding of spearmint (Mentha spicata) and water mint (*Mentha aquatica*). It contains biologically active constituents like menthol, menthone, and methyl esters. The plant is indigenous to Europe but now it's cultivation spread worldwide [137]. Three studies were conducted to explore the repellency effect of peppermint on Anopheles. Ansari et al. [18] in a field trial revealed that small amount of concentrated peppermint oil completely inhibits *Anopheles annularis, An. culicifacies* and *Anopheles subpictus*. Another study [138] demonstrated the effectiveness of peppermint essential oil against *An. dirus*. Mint is an excellent nontoxic option for keeping mosquitoes, flies and even ants away. Its pungent aroma kept the bugs away. We can even dry the leaves and use them inside our home as a natural pest control method.

13. **FLOSS FLOWER (AGERATUM)**

Ageratum is an attractive annual flower. Floss flower contains coumarin, that repels mosquitoes but it can be toxic if ingested by pets or humans. Ageratum is a naturally occurring mosquito repellent because of their unpleasant odour. Asteraceae contains the annual herbaceous plant *A. conyzoides*, which is found throughout the world, especially in tropical and subtropical climates [139]. There are thirty species in the genus Ageratum. Only a small number of species, nevertheless, have been found to display phytochemical activity [140]. These plants are ornamental and have a wide variety of morphologies. For instance, the blooms could be a variety of colours, from purple to white. Furthermore, the plant may readily adapt to a variety of ecological circumstances [141]. It is a weed that has spread into grazing and farming areas. Traditionally, it has also been used as a purgative, febrifuge, anti-ulcer drug, and wound dressing in Africa; as a bactericide, anti-dysenteric, and anti-lithic in India; to treat fever measles and snake bites in Togo; and to heal wounds, treat diarrhoea, and relieve pain in children's navels in Nigeria [142].

CONCLUSION

Plants have long been recognized for their different properties, including their ability to repel insects like mosquitoes. Lavender, citronella, marigold, catnip, peppermint, and basil are among the most commonly used plants for their mosquito-repellent properties. These plants contain specific bioactive compounds that irritate the mosquitoes, effectively discourage them from biting or landing. The recent studies have focused on the investigation of new natural repellents but only few natural products have been developed till now. Natural repellents have provide a good alternative to synthetic chemical, in terms of good efficacy, less allergic tendency, and less impact on environment when incorporating them into mosquito control strategies. This review has focused the attention of entomologists and people in the field of mosquito-transmitted diseases on the fact that by harnessing the power of nature, we can prepare harmless and more sustainable solutions to protect us against mosquito-borne diseases.

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