Essential Oils as Repellents against Mosquitoes and Its Implication for Public Health

Maqsood Ahmad[1,2], Haleema Sadia[1], Aneel Shahzad[2], Muhammad Zeeshan Mubarik[3], Muhammad Umar Ijaz[3], Rameesha Azhar[1], Zainish Shabaz[2], Muhammad Imran[4*]

[1]Department of Epidemiology and Public Health, University of Agriculture, Faisalabad, Pakistan.
[2]Livestock and Dairy Development Department, Punjab, Pakistan.
[3]Department of Zoology, Wildlife and Fisheries, University of Agriculture, Faisalabad, Pakistan.
[4]Department of Parasitology, University of Agriculture, Faisalabad, Pakistan.
*Corresponding author: imran.asghar@uaf.edu.pk

SUMMARY

The enormous number of efforts and developments have been used to make effective and safe repellents against arthropods earlier. The lack of vaccination against the most common arthropod-borne diseases such as dengue, malaria, and yellow fever suggests the need for effective and eco-friendly repellents. However, synthetic repellent safety and environmental concerns arise which creates a research trend and opportunities in the form of plant-based essential oil, an alternative to synthetic arthropod repellent with enhanced safety, and long-lasting repellency. With existing newly developed essential oils and through assessing of mechanism of action and cellular response to different doses, novel repellents can be developed by incorporating formulation technology.

INTRODUCTION

Mosquitoes are one of the most hazardous blood-feeding insects in the world and they are responsible for the spread of diseases such as dengue and malaria (Wooding et al., 2020). Consequently, plant-based essential oils (EOs) that possess strong repelling qualities and minimal environmental and human toxicity have been explored as a substitute for traditional synthetic insecticides. Plant EOs are volatile blends of organic molecules, mainly secondary plant metabolites called terpenoids and related aromatic compounds (Nerio et al., 2010; Khanikor et al., 2013). After more than three thousand EOs from different plants have been examined thus far, about ten percent of them are marketed as possible insecticides and repellents. The chemical components of EOs are what give them their antioxidative, antimicrobial, and pharmaceutical properties. They also have insecticidal and repellent properties that help control harmful arthropod vectors and stop the spread of serious neglected diseases to people all over the world (Pohlit et al., 2011; Conti et al., 2013).

Mosquito-borne diseases have a significant economic impact, reducing productivity and increasing costs. Mosquitoes, on the other hand, are employed in medicine for a number of objectives such as drug development, disease transmission research, and medical device testing (Valtonen et al., 2020). To effectively control mosquito populations, it is important to use repellents that are both effective and convenient. Synthetic products such as DEET have been used since the 1950s, and they are effective at low dosages. However, due to concerns about side effects, ecological toxicity, and the emergence of resistance in certain sectors, there has been a surge in interest in natural, environmentally friendly plant-based mosquito repellents (Iovinella et al., 2022). EOs derived from various plant families, have also been found to be effective against mosquitoes, with the most studied EOs being derived from species belonging to the genus "Cymbopogon", "Ocimum", and "Eucalyptus (Mishra et al., 2023).

These EOs are becoming increasingly popular as natural substitutes to DEET, as they can inhibit the activity of the insect AChE. As a result, they are becoming a potential source of insecticides. Certain constituents of EOs have the potential to

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bind to and modulate the neural activity of insects, as indicated by their ability to bind to and interact with octopamine receptor sites (Esmaili et al., 2021). For example, the EOs of *M. Spicata* have been demonstrated to be highly effective against Ae. Aegypti mosquitoes, with an effective repellency duration of over 45 minutes comparable to that of DEET (Azeem et al., 2019). Additionally, other EOs have been demonstrated to have biological activity, such as the oils of E. Canadensis and P. Herculeophorus, both of which have moderate to high effectiveness in repelling mosquitoes (Asadollahi et al., 2021). Nevertheless, the effectiveness of biological insecticides can be affected by a variety of factors, including environmental conditions, the fitness of the mosquitoes, their resistance to the insecticide, the components of the plant used, the solvents employed in the extraction steps, the insecticide dose, and the duration of exposure. A mortality rate below 98% may be indicative of resistance, which should be confirmed by biochemical and molecular analyses (Deletre et al., 2019).

Regrettably, there are no effective vaccines or specific drugs to inhibit the propagation of these viruses. Thus, direct mosquito targeting is necessary to stop the spread of these neglected tropical illnesses. In order to do this, great efforts have been undertaken to create larvicides and/or repellents that are efficient against arthropods. Synthetic repellents like DEET are commonly utilized. It is thought to function by obstructing the odorant receptors (olfactory receptor, ORx) of the insect, which are responsible for detecting l-octen-3-ol, which is present in human sweat and breath, without obstructing the insect's capacity to detect carbon dioxide. However, the use of DEET has sparked a number of worries about the risks to human health and the environment, particularly for young children. Consequently, plant-based EOs that possess strong repelling qualities and minimal environmental and human toxicity have been explored as a substitute for traditional synthetic insecticides. Plant EOs are volatile blends of organic molecules, mainly secondary plant metabolites called terpenoids and related aromatic compounds (Nerio et al., 2010; Khanikor et al., 2013). After more than three thousand EOs from different plants have been examined thus far, about ten percent of them are marketed as possible insecticides and repellents. The chemical components of EOs are what give them their antioxidative, antimicrobial, and pharmaceutical properties. They also have insecticidal and repellent properties that help control harmful arthropod vectors and stop the spread of serious neglected diseases to people all over the world (Mihajilov et al., 2014).

ESSENTIAL OILS AS ARTHROPOD REPELLENTS

It has been proposed that insect repellents like DEET, IR3535, and picaridin, which are specific to these ORx, function as olfactory agonists or antagonists by modifying ORx activity in the presence and absence of indole and octanol (Goodyer & Schofield 2018). There has been debate concerning the mechanism of action of insect repellent, and several ideas have been put forth. Insect repellency's fundamental mechanics remain unclear, nevertheless. Better repellent formulations can be created if we comprehend how insect repellents work and how they affect odor-sensing (Bohbot & Dickens 2010). EOs are intricate blends of plant-derived volatile organic chemicals. EOs with repellent properties often contain citronellal, limonene, α-pinene, and citronellol. Recent research has demonstrated that eucalyptol and linalool, lead to activation of odorant receptor in mosquito's antennal sensilla. The odor-sensing repellent screen platform may offer a fresh approach to creating repellents or chemicals with unique mechanisms of action against arthropods (Sritabutra & Soonwera 2013; Ahmadi et al., 2017).

DEVELOPING ESSENTIAL OIL BASED SAFE AND EFFECTIVE REPELLENTS

There are numerous ways to increase the effectiveness of repellents derived from essential oils. Combining many EOs from various plants is one of the most often mentioned techniques, and it can have a synergistic impact (Deletre et al., 2019). It has been demonstrated that using different components in a synergistic way results in a stronger repellent activity than using them separately. For instance, it was discovered that a combination of sesquiterpenes and monoterpenes found in various EOs effectively increased the repellent effect, equivalent to the impact of the total of the parts. Ae. aegypti's escape response was significantly stronger when mixtures of EOs from L. cubeba, L. salicifolia, and M. leucadendron were used than when each oil was used alone. When it came to killing Ae. aegypti larvae, the essential oils derived from Cryptomeria japonica shown greater efficacy than the amalgamation of 16-kaurene and elemol. Furthermore, studies conducted by Mulyaningsih et al. (2010) and Tak et al. (2016) revealed that several minor compounds, such as 3-carene, terpinolene, and α-terpinene, demonstrated enhanced larvicidal efficacy against mosquito larvae. In certain instances, though, a combination of manufactured pure chemicals did not always have more repellant effects than a single component. Furthermore, compared to their respective EOs, synthetic blends made with main EO components demonstrated far less repelling properties. It's interesting to note that studies on the combined toxicity of manuka, oregano, and clove bud EOs and their constituents against mosquito larvae have shown that manuka and clove bud EOs interact antagonistically, while manuka and oregano interact synergistically. It has been suggested that carvacrol plays a role in the positive interaction between Manuka and oregano essential oils, whereas eugenol plays a role in the negative interaction between Manuka and clove bud EOs (Muturi et al., 2017; Tabanca et al., 2018).

Essential oils are known for their repellent effects against insects (Kalita et al., 2013). But because they are so erratic, the effects usually wear off fast. EOs are often only active for a brief time and act mostly in the vapor phase. For example, because citronella oil is so volatile, insect repellents that contain citronella oil as a main ingredient must be reapplied every 20 to 60 minutes. Up to 64% of the naturally occurring component p-menthane-3,8-diol (PMD), which is mostly in charge of the repellent's effectiveness and protection against insects and biting arthropods, is present in commercial citronella mosquito repellent (Misni et al., 2017). Further advancement in formulation technology is needed to make the active ingredients stay on the skin for longer periods of time, which will help address the short protection time. It was discovered that formulations based on cream and polymer mixtures increased the repelling effect. A petroleum jelly-based topical formulation of lemongrass oil has been found to provide long-lasting protection against insects without any side effects (Oyedele et al., 2002; Islam et al., 2017). It has been demonstrated that microencapsulating EOs like Z. limonella oil in glutaraldehyde crosslinked gelatin increases the repellent action against mosquitos (Maji and Hussain 2009). In a similar vein, thyme oil microcapsules made with a melamine-formaldehyde prepolymer have proven to exhibit long-lasting repellency and sustained release characteristics. It's interesting to note that adding fixative substances like salicyluric acid, liquid paraffin, and vanillin has been shown to boost the repellent effectiveness of EOs. The most popular fixative agent is vanillin, and mixing vanillin with EOs significantly extended their repellency against arthropods, such as Ae. aegypti. For example, adding vanillin increased the protection duration of Citronella oil and Zanthoxylum piperitum oil to 4.8 hours and 2.5 hours, respectively. Furthermore, it has been discovered that combining vanillin treatment with microencapsulation or nanoemulsification lengthens the duration of repellent effects. Geranium EOs' effectiveness against Culex pipiens can be credited to the development of microemulsion formulations built around nonionic surfactants like Tween 80 (Nuchuchua et al., 2009; Misni et al., 2017).

These days, a lot of nanotechnology is utilized to create repellents with essential oils for increased effectiveness. There are various benefits of using plant-based nanoparticles as stabilizing and reducing agents instead of traditional techniques (Esmaili et al., 2021). By penetrating the exoskeleton and interacting with functioning proteins, nanoparticles can disrupt the proton motive force and membrane permeability. Depending on the plant sources utilized as stabilizing and reducing agents, nanoparticles' size, shape, and effectiveness against arthropods change (Govindarajan & Benelli 2017). For example, the majority of the silver nanoparticles made with neem were spherical, while the majority of the silver nanoparticles made with Carissa spinarum leaves were cubic. Additionally, the cost, steps in the development process, and dangers related to pressure, temperature, and energy might all be decreased by using nanotechnology for EO delivery. Recently, EO-based polymeric patches embedded in polyvinylpyrrolidone (PVPK-30) and ethylcellulose polymers were created. After evaluating the physicochemical characteristics and oil release efficacy against A. albopictus, it was discovered that the EO-repellent patch formulation was safe for animal models with respect to respiratory, hematological, and biochemical parameters (Govindarajan and Benelli, 2017, Benelli, 2018).

The use of matrix-type patches for delivering repellents into the surrounding environment has been found to be an effective approach (Chattopadhyay et al., 2015). Anopheles stephensi was used to test cotton's ability to repel mosquitoes after it was functionalized with inclusion complexes of β-cyclodextrin citrate and EOs. Using inclusion complexes of β-cyclodextrin, peppermint and lavender were found to be efficient as possible repellents in cotton. Research is currently being done on economically viable and environmentally sustainable EOs that have the ability to combat arboviruses like the Ross River virus. Three EOs have been tested for its ability to resist the RRV-T48 strain: Cymbopogon citratus, Pelargonium graveolens, and Vetiveria zizanioides. The outcomes demonstrated the antiviral properties of these EOs in terms of obstructing viral entrance and reproduction. Furthermore, it was shown that combining 35 EOs and piperonyl butoxide (PBO) with permethrin, a typical synthetic pyrethroid, increased permethrin's effectiveness against Ae. aegypti and *Anopheles gambiae*. According to the findings, EOs can be employed as a natural substitute for traditional chemical synergists like PBO (Gross et al., 2017, Khanna and Chakraborty, 2018).

Developing new and more potent insect repellents has proven to be more difficult with the tools now in use. Utilizing these data to the fullest in order to create highly effective and practical repellents is imperative due to the growing number of disease-causing viruses (Iovinella et al., 2022). In order to cure neglected diseases, new technical approaches are needed to comprehend the complicated and diverse qualities of EOs, which exhibit severe difficulties due to their diverse constituent molecules. Human cells have been assessed using gene expression studies linked to transcriptome analysis utilizing RNA-seq and molecular pathway analysis (Ahmadi et al., 2017). Furthermore, novel approaches to chemical toxicity pathway-based testing, like gene expression profiling based on microarray technology and chemical testing against insect vectors, may find use in assessing the toxicity of novel EO varieties. In order to create insect repellents, the effects and possible toxicities of orange and rosemary oils were examined using Ingenuity Pathway Analysis. Finding innovative EO-based repellents appears to be a viable application of multi-omics technology for pathway-based evaluation of possible hazards and favorable effects. The current advancements in insect-repellent development have ushered in a new age for the rising application of revolutionary technology (Kiyama 2017, Ahmadi et al., 2017).

FORMULATION OF ESSENTIAL OIL ENCAPSULATED MOSQUITO REPELLENT GEL

A polyherbal insect repellent gel has been developed to provide consistent, durable, and complete protection against mosquito bites by eliminating them. The composition of the mosquito repellent gel contained polymers such as tween 80, span 20, carbopol 934, and triethanolamine in addition to three EOs. Patients get better and quicker outcomes when they use Mosquito repellent gel Carbopol 934 with the essential oil with the mosquito-repellent gel Carbopol 934 (Kumar et al., 2022).

COMPARISON BETWEEN SYNTHETIC INSECT REPELLENTS AND ESSENTIAL OIL

Although synthetic insect repellents are quite effective, there are ecological and environmental concerns associated with their resistance to degradation, high toxicity, and bioaccumulation. DEET, Icaridin, and IR3535 are used widely and are major synthetic insects. Insect repellents made of natural materials are receiving increased attention as a result of the negative consequences of synthetic repellents (Asadollahi et al., 2019). Because EOs are non-toxic and biocompatible, they are one of the most popular types of natural insect repellents on the market. In comparison to natural insect repellents, synthetic repellents typically have a higher potency and produce faster results. EOs solve the problem of "high volatility" and are a safer and better option than synthetic repellents. The extended-release of essential oil by the use of inorganic and polymeric components in slow-release formulations lengthens the application's useful life (Chinthaka et al., 2023).

SAFETY OF ESSENTIAL OILS AS REPELLENTS AGAINST ARTHROPODS

The resources available today are insufficient to develop new and improved insect repellents. With the growing number of viruses that cause disease, it is imperative to make the most of these facts in order to create repellents that are both extremely powerful and practical. In order to cure neglected diseases, new technical approaches are needed to comprehend the complicated and diverse qualities of EOs with a diverse range of constituent chemicals. These EOs exhibit severe complexity. (Ahmadi et al., 2017). Furthermore, toxicity pathway-based assessments of novel EO types against insect vectors could make use of microarray-based gene expression profiling and pathway-based chemical testing (Plant & Stephens 2015; Liao et al., 2016). In order to create insect repellents, the effects and possible toxicities of orange and rosemary oils were examined using Ingenuity Pathway Analysis. Finding innovative EO-based repellents appears to be a viable application of multi-omics technology for pathway-based evaluation of possible hazards and favorable effects. The current advancements in insect-repellent development have ushered in a new age for the rising application of revolutionary technology (Han & Parker 2017; Kiyama, 2017).

Although plant EOs are usually thought to be safe, their extensive use is limited because certain of their constituents may induce adverse effects, such as skin irritation. Not all natural products are safer than synthetic ones, and some may have unfavorable side effects. This is something to keep in mind (Diaz, 2016). Moreover, there are instances when the toxicity and safety data that is now accessible is conflicting and incomplete. Although the EOs from Dacrydium franklinii, Melaleuca bracteata, and Rosmarinus officinalis were shown to have promising repellant effects, they were not appropriate for human usage due to their tendency to cause skin irritation, contact dermatitis, and asthma. Nowadays, synthetic repellents are more commonly employed than EOs, which presents a number of issues for the environment and public health (Nerio et al., 2010, Govindarajan and Benelli 2016). Topical insect repellents like DEET are tested and approved for use by the FDA in the United States. EPA-registered essential oils such as citronella, lemon, and eucalyptus have been shown safe for topical application on humans. The only plant-based repellent that the CDC recommends for general public usage is PMD (p-menthane 3,8-diol), which has been shown to be safe for human health. A naturally occurring substance derived from the wild tomato plant Lycopersicon hirsutum, undecanone is a biopesticide product that is less hazardous than traditional pesticides. Only the EPA-registered BioUD product contains undecanone as an insect repellent. EOs are thought to be useful for between 30 minutes and two hours (Witting-Bissinger et al., 2008).

Under the direction of the US Environmental Protection Agency, citronella oil, also known as lemongrass oil or Cymbopogon citratus, has been applied topically to protect children and other vulnerable groups from insects while adhering to the necessary precautionary labeling. Citronella oil is regarded by the US Food and Drug Administration as generally recognized as safe. While it can prevent mosquito bites for up to two hours, citronella oil is not as effective as DEET at keeping mosquito bites at bay for as long. Regulators' concerns have prevented the use of citronella as an insect repellent in Canada and Europe, though. The absence of safety evidence and the presence of methyl eugenol are the reasons behind Canadian regulatory concerns regarding citronella as an insect repellent. The International Agency for Research on Cancer (IARC) (2013) classified methyl eugenol as a group 2B substance, probably harmful to humans, based on substantial evidence in experimental animals showing carcinogenicity; human data are not available. Furthermore, the US National Toxicology Program (NTP) states that methyl eugenol is "reasonably anticipated to be a human carcinogen" because it causes cancer in other rodents but not in rats. With certain safety concerns around the presence of methyl eugenol, citronella oil is classified as a category 3 chemical and has not been sold as an insect repellent in the European Union since 2006 (Kongkaew, Sakunrag et al., 2011; Sharma et al., 2019).

Syzygium aromaticum, Eugenia caryophyllata, or Eugenia aromaticum are the sources of clove oil, which is widely used in cuisine, cosmetics, medications, and insect repellents. One of the minute amounts of clove oil, methyl eugenol, has, however, sparked worries in some reports that it may be carcinogenic. Three main ingredients in clove oil are caryophyllene, eugenol, and eugenol acetate. The FDA has classified clove oil as generally recognized as safe (GRAS), meaning that it is acceptable to add in both natural and synthetic forms to food intended for human consumption. Furthermore, the FDA approved the use of clove oil as a scent in personal care and aromatherapy products, as well as in dentistry as an analgesic and in dental cement and transdermal medication delivery systems. Clove oil was placed on the US Environmental Protection Agency's (EPA) Section 25(b) list of minimum-risk pesticides, which exempts it from the majority of pesticide registration requirements, including the need for rigorous toxicity testing. On the other hand, the US National Library of Medicine listed a few adverse effects of clove oil, such as headaches, skin irritation, and increased bleeding because of a diminished ability to coagulate blood. In conclusion, using clove oil or eugenol may be safe, but further research is needed to see whether it has any negative consequences, including the possibility of cancer.

One of the main repellant ingredients, PMD (p-menthane-3,8-diol), is derived from the leaves of Corymbia citriodora, Eucalyptus citriodora, and lemon eucalyptus. It can be chemically produced to be used in products that are sold as repellents. In addition to PMD, eucalyptus extracts contained citronellol, limonene, and linalool (Maia & Moore, 2011). Products that contain PMD are required to have a "warning" label on them because they may irritate the eyes. Studies on PMD's acute toxicity have revealed modest toxicity, but epidemiologic information about PMD's impacts is scarce. The EPA has classified PMD as a GRAS active ingredient, which is used in numerous consumer products and to flavor food and medications. Children under the age of three should not use PMD, according to FDA recommendations. Utilizing PMD products is advised by the Centers for Disease Control and Prevention because they shield users against mosquito bites (Diaz, 2016).

UNDERSTANDING OF NATURAL REPELLENTS

Plant-based repellents are generally considered to be more secure than synthetic products, as they are thought to have a much shorter lifespan in the human body and on foodstuffs. The chemical components of EOs, terpenes, related compounds, and green volatiles are the most active in terms of protection. Terpenoids are more active than green volatiles in terms of protection, while green volatile compounds are more active than terpenoids. Examples of EOs used as repellents include citronella, which is well-known for its ability to repel insects. Additionally, there are a variety of other active ingredients, such as EOs from plants, which are commonly used for flavoring and fragrance. Additionally, some mammals, other than humans, may also use natural defensive chemicals, such as DEET, to repel mosquitoes (Andreazza et al., 2021).

WHY ARE PLANTS SO REPELLENT TO BLOOD-FEEDING INSECTS

The presence of EOs in plants is responsible for their distinctive odor, which can be obtained through a variety of methods (Maia & Moore 2011). These oils contain volatile organic compounds, which are produced as secondary metabolites, and play a key role in the defense of plants against insects. These chemicals can be divided into four main categories: repellent, feeding deterrent, toxin, and growth regulator. Nitrogen compounds (in particular alkaloids) are the most common, while terpenoids and phenolics are also present. Proteinase inhibitors and growth regulators are also present. Blood-feeding in insects may be caused by the loss of innate aversion to vertebrate odors, which increases the likelihood of interaction with animals and provides an opportunity for blood-feeding. The physiological composition of the secondary metabolites may differ depending on the stage of growth of the plant and can be affected by external elements such as the temperature, the time of day, the stage of growth, the type of soil, and the weather. It is possible to standardize plant-derived components of EOs for commercial repellents by conducting research in this field. Neural network models have been developed to compare biological activity (e.g., duration and effectiveness of repellence) and molecular properties, leading to the discovery of a number of highly effective new molecules. Several terpenes, naturally occurring in plants, have been tested in the laboratory to demonstrate their repellent properties (Chinthaka et al., 2023).

The use of natural repellents has been increasing in recent years, and more options are expected to be commercially available as chemical prospecting continues. These natural repellents have been demonstrated to inhibit the activity of AChe, block octopamine receptor, and GABA-Gated chloride channels, and induce hyper-excitability of the central nerve system, resulting in the death of mosquitoes. Additionally, they have been demonstrated to disrupt the host-seeking behaviors of mosquitoes when used on human skin or in indoor spraying systems. Studies have shown that some of the known natural repellents stimulate an odourant neuron dose-dependently. Furthermore, some volatile compounds have also been identified as attractive to *A. guagiae* at host or oviposition sites. Quantitative structure-activity relationships must be further developed in order to comprehend the activity and predictive value of the molecules. Here are some of the advantages and disadvantages associated with green repellent (Liu, 2015).

Insecticide resistance

Insecticide resistance can be defined as the ability of insects to withstand a standard dose of an insecticide due to changes in their physiology or behavior. Despite the effectiveness of mosquito control strategies based on insecticides, their continued use has been met with criticism due to their high cost, toxicity, and susceptibility to resistance. Various mechanisms of resistance have been identified, such as metabolic, target-site, penetration, and behavioral. Phytochemicals derived from plants are used as insect repellent, toxin, feeding deterrent, and growth regulators against insects. These compounds offer a range of benefits over synthetic compounds, including toxicity, small-scale effectiveness, biodegradability, and less insect resistance. Current research is focused on the discovery of natural compounds with potential impacts on mosquitoes (Katsavou et al., 2020).

Public health implications

Plant repellents work by either masking the chemical cues that help locate a host or inducing host avoidance, which are olfactory responses. Some plant-based active ingredients may not only repel insects but also activate gustatory receptors (Maia & Moore 2011). They are potentially triggering a switch from host-seeking to sugar-feeding behavior. Mosquito biting behavior has been observed to be increased in mosquitoes that have been infected with a plant-based active ingredient, as well as in mosquitoes that have not been infected. Repellents have also been tested or applied in low doses as an attractant in combination with various types of traps to attract insects, including mosquitoes. Additionally, some repellents have been shown to have an oviposition deterrent effect, with the application rate of repellents against oviposition being significantly lower than that of skin-on-skin repellents. Because of the body's temperature and humidity, oviposition repellents provide substantially longer protection than skin repellents. Furthermore, adult mosquito mortality was considerably different 24 hours after treatment (Rani et al., 2013).

FUTURE PROSPECTS FOR NATURAL PERSONAL PROTECTION PRODUCTS

Given the public's interest in repelling candles, torches, coils, and other devices, highly effective area-repelling active substances would likely have a strong market. Construction and screening are established technological fields, but protective gear is expanding quickly. In terms of topical repellent, we can anticipate the introduction of new active compounds with significantly greater intrinsic protection, like DEET. A substance active at pharmaceutical levels could be up to 10,000 times more effective than DEET against biting arthropods. A minimal amount of such a chemical might be employed to produce excellent, simple-to-use formulations (Agrawal et al., 2018).

In addition to being a great way to keep mosquitoes away, some plant compounds can also be really effective against them. Carvacrol, for example, has been tested in field trials and it's shown to be both repellent and harmful to mosquitoes. EOs from different plants, like *Cinnamumum verum*, *citrus aurantifolia* and *aluminum cyminum*, as well as some other plants like *Syzygium aripipa*, *Laurus nobleilis*, *lippia berlandier*, and *Pimpinea anisum*, have also been found to have strong anti-mosquito and larvicidal effects (Maia and Moore 2011)**.**

CONCLUSION

The application of essential oil as a natural insect repellent is highly efficient due to biocompatibility and less toxicity as compared to synthetic repellants which have more degradation resistance, bioaccumulation and ecological issues. The slow-releasing formulation of essential oil zeolites, montmorillonite, β-cyclodextrin, polymeric materials, and electrospun nanomaterials determines the mechanism of action. Given the widespread spread of arthropod-borne diseases like dengue and malaria, which must be controlled with appropriate measures, as well as the catastrophic damage caused by severe infestation of insect pests on crops and stored food, there is a growing need to develop insect repellents with highly effective sustained release properties.

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