Methods and applications imparting plant essential oils as mosquito repellency agents on textiles

Parul, SP Singh and Lalit Mohan

DOI: https://doi.org/10.22271/23487941.2022.v9.i3a.613

Abstract
Mosquitoes are blood-sucking insects that spread diseases including Malaria, Dengue, Japanese encephalitis, Yellow fever, etc. Humans must be protected from mosquito bites in order to avoid mosquito-borne diseases. The application of repellents such as lotions and liquidators to the skin or clothing creates a vapor layer with a disagreeable odor or taste that renders a person undesirable for feeding, therefore, repelling mosquitoes. Plant essential oils, in general, have been recognised as a major natural resource for repellents in this area because of their selective characteristics as they are biodegradable, non-toxic and eco-friendly. Textile-based mosquito repellents is one the popular method of protection using cotton, polyester and other textiles. This method requires no additional investment in textile finishing industry, which is a desirable feature in developing countries. This review details the efforts of technocrats who applied mosquito repellents to fabrics and the criteria used to determine repellency.

Keywords: Mosquito repellency, textile based repellency, cage test, cone test, excite chamber, plant essential oils

Introduction
Mosquitoes are nuisance creating ectoparasites, transmit diseases such as Malaria, Dengue, Yellow fever, Japanese encephalitis, etc. [1] and they are responsible for deaths of thousands of people [2]. Hence, protection from mosquito bites is very essential to keep these diseases away from humans. When mosquitoes detect an increase in atmospheric carbon dioxide concentrations, they use the warm and humid convection emanating from the human body as a fatal for contacting humans. Many synthetic repellents were widely used to prevent mosquito bites in people as a medical necessity. N, N-diethyl-methylbenzamide, also known as DEET, picaridin, or lacridin, as well as permethrin and IR3535, has proved to provide effective mosquito protection [3]. Synthetic repellency products like lotions, spray, liquidators, coils, etc. already exist in markets and are effective, However, they have limitations causing side effects to humans as well as to the environment. The synthetic repellents are causing unpleasant effects on humans of the bad aroma, rashes on the skin, eye burning, inhaling, headaches, coughs, sore throats, nausea, dizziness, asthma and respiratory irritation [4]. To avoid these adverse effects chemical repellents may be replaced with botanical agents. Mosquito bites may be avoid by using mosquito repellents on their skin, housemates, clothing and holsters. While repellents are applied to the skin or clothing, they form a vapor layer with an unpleasant natural scent that protects the user from being bitten. One of the revolutionary methods is to use a fabric treated with a mosquito repellent substance [5]. Human cultures in many regions of the world have employed plant products against mosquito vectors from the beginning of time. The phytochemical derived from plant sources may act as larvicidal, adulticidal, insect growth regulators, and repellents and have different activities. Personal protection for humans can be provided by repelling and knocking down the mosquito vectors by creating a textile barrier between host and vector. Moisture sensing pores of mosquitoes help them to detect the live organisms, are closed in olfactory mode, also known as transpiration repellency and they are unable to locate humans.
In tactile mode, repellents act on the neurological system of mosquitoes, causing them to become confused and fight their behaviour at sub-lethal/mortal/toxic levels before being knocked down by fabric contact. Direct-contact repellency is a tactile mode of action that works by forcing mosquitoes away from the surface before they can feed on blood [6]. One of these good techniques is also a long-lasting medicated net (LLIN) which is commonly used in mosquito control programmes. The LLIN is most effective against mosquitoes that bite at night, while textile repellency is a better option for protection during the day [7]. The most difficult aspect of evaluating in a suitable system is that different researchers have assessed the textile repellency of plant essential oils against mosquitoes using different approaches. Cage testing, cone tests, modified excite chamber methods, field tests and other procedures are used to assess the performance of mosquito repellent fabrics. Plant-based essential oils are used by researchers on cotton fabric, polyester, denim, etc, with the help of other techniques and pad dry cure for protection from mosquito bites.

Role of essential oils as mosquito repellents

Essential oils (EOs) are complex combinations of volatile organic chemicals obtained from plants that have a long history of use in civilization, not only for flavour and aroma but also to guard against ectoparasites and stored goods. They are now widely utilised for flavouring, aromatherapy, medicines and other purposes in cosmetics, meals and beverages. Insecticides, fungicides, herbicides, antibacterials and mosquito repellents are among the many EO-based products in the market. Terpenes and related molecules (terpenoids) and "green volatiles" are the primary chemical ingredients of essential oils. The repellent effects of EOs have been proved to be due to the presence of monoterpenes, sesquiterpenes and phenols [8]. Linalool, a naturally occurring terpene alcohol has recently been proven to activate the odorant receptor neuron in a mosquito's antennal sensilla [9] extracted from a whole plant or plant elements using physical processes (pressing and distillation) (leaf, bark, fruits, flowers, etc). A repellant is a chemical that prevents arthropods from settling in the vicinity of human skin. Female mosquitoes are attracted to carbon dioxide and lactic acid found in sweat and the associated odour is detected by chemoreceptors in their antennae. Insects use odorant receptors, which form complexes with coreceptor, which operate as ion channels, to sense specific scents. When an odorant binds to carbon dioxide, the ion channel's coreceptor open, resulting in the activation of a sensory neuron that detects the odour [10].

There are many plant products and derivatives that act as repellents and insecticides available in the market. The literature revealed that EOs has numerous benefits with no side effects. However, the properties of all essential oils are not the same. Some smells attract mosquitoes, therefore, having those smells in your yard is an invitation to these annoying insects. However, just as there are smells that mosquitoes attract, likewise, some are other smells that hate and make sure to avoid surface landing (Table 1).

| Plant essential oil | Mosquito species | Imparting Technique | References |
|---------------------|------------------|---------------------|------------|
| Cymbopogon commutatus, C. martini, C. pendulosa, C. nardus | An. stephensi, Cx. quinquefasciatus and Ae. aegypti | Volunteers test | [11] |
| Juniperus macrocarpa and Pimpinella anisium | An. stephensi, Ae. aegypti, and Cx. quinquefasciatus | Cardboard sheet | [12] |
| Centella asiatica, Ipomoea caurica, Monordica chartantia, Psidium guajava and Tridax cumbens | Anopheles stephensi | Volunteers test | [13] |
| Zingiber officinalis | Culex quinquefasciatus | Cage test | [14] |
| Lantana camara | Ae. aegypti, Cx. quinquefasciatus, An. culicifacies, An. flavialis and An. Stephensi | Paper Impregnation | [15] |
| Eucalyptus and Azadirachta indica | Culex quinquefasciatus | Volunteers test | [16] |
| Ruta chalepensis | Aedes albopictus | Cage test | [17] |
| Apium graveolens | Aedes aegypti | Paper Impregnation | [18] |
| Cananga odorata, Cymbopogon citrates, and C. nardus | Ae. egypti and Cx. quinquefasciatus | Volunteers test | [19] |
| Juniperus procera | Anopheles arabiensis | Chamber test | [20] |
| Z. nimmonii | An. stephensi, Ae. aegypti and Cx. Quinquefasciatus | Cage test | [21] |
| Artemisia monosperma, Citrus paradise, Origanum vulgare and Schinus terebinthifolius | Culex piipiens | Glass jars | [22] |
| Lippia alba, L. origanoides, Eucalyptus citriodora, Cymbopogon citrates, C. flexuosus, Canellia, sinensis, Chromolaena odorata, Salvia glutinosa, and Tagetes lucida | Aedes aegypti | Volunteers test | [23] |
| Artomisia vulgaris | Aedes aegypti | Cages test | [24] |
| Artemisia verlotiorum, Lavandula dentata, and Ruta chalepensis | Aedes albopictus | Cage test | [25] |
| Piper betle | Aedes aegypti | CDC bottle test | [26] |
| Chenopodium ambrosioides, Conyza sumatrensis, Erigeron canadensis, Eucalyptus canadulensis, Mentha spicata, Parthenium hysterophorus, and Tagetes minuta. | Aedes aegypti | Cage test | [27] |
| Mentha arvensis | Aedes aegypti | Cage test | [28] |
| Origanum vulgare and Thymus vulgaris | Aedes aegypti | Paper Impregnation | [29] |
| Cymbopogon nardus, Syzygium aromaticum, and Citrus sinensis | Aedes aegypti and Culex quinquefasciatus | Mosquito repellency | [30] |
Fabrics coated with essential oils as repellency agents

Methods of imparting essential oils

According to the literature review, the common method to control the mosquito is textile repellency. To impart mosquito repellent characteristics into textiles, spraying, dipping, and pad dry curing procedures are also used. Mosquito repellent finishing compounds were impregnated into the materials and a binder was employed to increase the finish’s longevity.

Although many researchers focused on the use of commercial binders, one study found that using natural plant essential oils as a binder had a higher efficacy in terms of the anti-mosquito finish’s durability when applied by pad dry cure on cotton fabric [33] and technocrats have focused their attention towards the evaluation of repellent property of plant essential oils coated fabrics against different mosquito species (Table 2).

Table 2: An overview of the studies imparting techniques on repellency treatment of textiles

| Repellent type                          | Imparting Technique | Type of fabric                  | Evaluation method                      | Outcome                      | Reference |
|----------------------------------------|---------------------|---------------------------------|----------------------------------------|------------------------------|-----------|
| Eucalyptus Oil/ N, N-Diethylphenylacetamide (DEPA) | Impregnation        | Cotton and Trevira knitted fabrics | Cage, cone, indoor, field tests        | Mosquito repellency          | [34]      |
| Mint leaves                            | Pad dry cure        | Cotton fabric                   | Cage test                              | Repellent activity           | [35]      |
| Ricinus communis, Senna auriculata, and Euphorbia herita | Pad dry cure        | Denim fabric                    | Excito chamber test                    | Mosquito repellency          | [36]      |
| Microencapsulation Andrographis paniculata | Pad dry cure        | Bamboo/ Cotton fabric            | Excito test chamber                    | Repellent activity           | [37]      |
| Chrysanthemum oil nanoemulsion         | Layer by Layer Technique | Nylon net fabric               | Excito chamber test and Cone test      | Repellency and mortality     | [38]      |
| Neem leaf extract                      | Direct coating      | Cotton                           | Experimental descriptive method         | Mosquito repellency          | [39]      |
| Microencapsulated Cymbopogon nardus    | Pad and dry cure method | Cotton fabrics                   | Cage test                              | Mosquito repellency          | [40]      |
| Clove, cedarwood, eucalyptus, peppermint, lavender, and jasmine oils | Pad and dry cure method | Woven Cotton                     | Cage test                              | Mosquito repellent and mortality | [41] |
| Microencapsulation Cymbopogon citratus (lemongrass) essential oil | Pad and dry cure method | Cotton, single jersey fabric     | Excito chamber test                    | Mosquito repellency          | [42]      |
| Eucalyptus and rosemary essential oil  | Pad and dry cure method | Cotton fabric                   | Cage test                              | Mosquito repellency          | [43]      |
| Citrus bergamia, Litsea cubeba, C. aurantiunvar sinensis, Mentha piperita, Rosmarinus officinalis, Anibaros aeodora and Thymus serpyllum | Soak–pad and dry cure method | Cotton and polyester fabrics      | Experimental demonstrated method  | Gram-positive and gram-negative bacteria, Mosquito repellency | [44] |

Essential oil containing repellency products available in the market

People can get inspiration from nature in abundance. In today’s world, the medical use of plant essential oils, particularly mixes of terpenoids and related aromatic chemicals, which are secondary plant metabolites, has attracted global interest for scientific and technological innovations. So far, over 3000 EOs from diverse plants have been studied, with around 10% of them being commercially marketed as insect repellents and insecticides. Essential oils from plants such as Cymbopogon nardus, Eucalyptus maculata, Mentha piperita, Azadirachta indica and others are used in commercially available repellents (Table 3). Cymbopogon nardus is a weak repellent when compared to other natural options, however it is widely acknowledged in the United States as being safe to use on children and pets. Some metabolites in essential oils, such as the monoterpenes pinene, cineole, eugenol, limonene, terpinolene, citronellol, citronellal, camphor and thymol have anti-mosquito activity. Other than humans, some mammals have used mosquito repellents derived from natural sources (plants and animals).

Table 3: An overview of natural repellents that are commercially available

| Trade name                  | Formulation type | Purpose                                                                 | Origin                                     |
|-----------------------------|------------------|------------------------------------------------------------------------|--------------------------------------------|
| Herbal strategi repellent   | Spray            | This product can be used as a room spray, car spray, or as a mosquito-repelling bracelet | Lemongrass                                 |
| Mamaearth natural insect repellent | Lotion          | It is safe for skin application                                        | Castor, lemongrass, soybean, cedar, citronella, and peppermint |
| Bodyguard natural anti-mosquito repellent | Spray         | In addition, these repellents are pediatrician-certified, which ensures that your child is completely protected. | Eucalyptus, peppermint, and lemongrass |
| Aamir machhar repellent     | Lotion           | It is safe for skin application                                        | Cedar and lemongrass                      |
| Mom and world baby mosquito repellent | Spray         | Small babies can safely use it in their room because the scent is so mild. | Rosemary, basil, neem, eucalyptus, citronella, and lemongrass |
Table: Textile fabrics studied for mosquito repellency

| Product Name                          | Formulation   | Description                                                                 | Repellent Ingredients                                                                 |
|---------------------------------------|---------------|----------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Odomos natural mosquito repellent     | Cream/lotion  | It is safe for skin application                                             | Citronella and Aloe vera                                                                 |
| Good night personal repellent         | Cream/gel     | It is safe for skin application                                             | Citronella and Aloe vera                                                                 |
| Dr. Zach’s mosquito repellent         | Lotion        | It is safe for skin application                                             | Lemon, eucalyptus, turmeric, and coconut                                                |
| Mother sparsh repellent               | Cream / lotion| It is safe for human and baby application                                  | Eucalyptus, citronella and lemon grass                                                |
| The mom's co. natural mosquito repellent | Spray       | It is safe for babies                                                       | Citronella oil, Lemon grass oil, Eucalyptus oil, Soyabean oil, and Cedarwood oil       |
| The better home mosquito repellent    | Spray         | It is safe for skin application                                             | Lemongrass, Peppermint, and Citronella                                                |
| Most quick natural mosquito repellent | Oil           | Repels Mosquitos, Insects, Cockroaches, Flies, etc                          | Lemongrass and Citronella                                                               |
| Vitro naturals anti-mosquito          | Spary/gel/cream| Bio safe natural product                                                     | Lavender, eucalyptus, and lemongrass essential oil                                     |
| Forest essential oil mosquito repellent | Spray       | It is safe for skin application                                             | Citronella, lemon grass. Basil, castor, neem                                            |
| Care us Dr. Mosquito repellent        | Oil           | It is safe for babies                                                       | Lemongrass, Neem, coconut, and citronella oil                                         |
| Aromasin anti-mosquito repellent      | Spray         | It is safe for kids and adults                                              | Eucalyptus, peppermint, olive, rose                                                    |
| Elem REPL Mosquito repellent          | Spray         | The perfect mosquito repellent in the home or outdoors.                    | lavender, eucalyptus, citronella, and tea tree                                         |

Textile fabrics studied for mosquito repellency

Extracts of *Curcuma aromatica* (Kashthuri manjil), herbal powders of *Camellia sinensis* (Green tea), and *Azadirachta indica* were used to make 100% bamboo and 100% organic model fabrics (Neem) and the particles were prepared using microencapsulation on the fabrics tested for repellency behavioural testing from three materials such as sodium alginate, gum acacia, and neem gum using a method of modified excito chamber test against *Anopheles stephensi* [45]. The use of denim fabric for repellency behavioral effect of *Culex pipiens* (2.5% EC) and etofenprox (10% EC) as mosquito repellency agents applied with impregnation technique on polyester, nylon and cotton fabrics bed nets aimed to determine the distribution of knock downtime and under laboratory conditions with a basic netting equipment[53]. The longer-lasting repellency of cellulotic-basined curtain fabrics used on various types of textile materials was investigated (cotton, polyester, and linen) and compared to curtain fabrics made of 100% cotton, cotton/viscose, or polyester-based curtain fabrics, the results revealed that curtain fabrics made of cotton/linen have the highest mosquito repellent retention capacity and the highest resistant to washing [53].

Methods for determining repellency

Cage test

The cage test method is a unique way to examine mosquito activity and is used to evaluate the effectiveness of mosquito repellents on both treated and untreated materials (Figure 1). Cage testing is a low-cost way of determining mosquito repellency. This method replicated the real-life condition of a mosquito probing and biting a human, as well as allowing direct observation of mosquito behaviour toward treated materials. Before being exposed, mosquito cages are devoid of all food and water for at least 4 hours. Treated and untreated fabrics are prepared in advance to apply to the wall of cages and 20 mosquitoes are considered for observing the behavior of the treated and untreated fabrics inside the cage [53].

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Fig 1: Mosquito repellency behavior evaluation using cage test method.

Cone test
WHO cone test is considered using a plastic cone on the fabric to evaluate the toxicity of the plant's essential oil-treated fabrics against mosquitoes. It may also look into the toxicity of other impregnated (textile) surfaces (Figure 2). The test is used for treated fabric monitoring in mosquito vectors, bioefficacy and persistence of plants' essential oils on treated surfaces. According to the test procedure, mosquitoes are introduced into the cone and exposed for 3 minutes and repeated thrice on each cone fixed. Ten to twenty female using an aspirator, mosquitoes are exposed to the coated fabric surface in the cone. The number of mosquitoes counted and considered for the effectiveness of the treated and untreated fabric [54].

Fig 2: Mosquito repellency behavior evaluation using cone test method.

Excito chamber test
Excito repellency test chambers (Figure 3) are created specifically for measuring the effectiveness of repellent action on fabrics. The excito repellency testing device's wooden outer chamber measures and confronts the front panel with the single escape entrance. A rear door cover, inner plexiglass, a glass panel with a rubber latex sealed door, a plexiglass holding frame, a screened inner chamber, an outer chamber, a front door, and an exit portal slot are all included in the box. The number of mosquitoes that escaped to another location and the number of mosquitoes that remained inside the chamber filled with treated items were observed. After 10 and 30 minutes of exposure, the results are recorded [55].

Fig 3: Mosquito repellency behavior evaluation using the Excito chamber test method.

Wash durability of treated fabric
The wash durability of repellent treated fabric is also reported. After the fabric is washed and dried, to see if the finish is durable, it was tested for mosquito repellency. Mosquito knockdown (KD) effects and mortality effects are observed on phytomedicine-treated fabrics respectively as per the WHO technique. After washing, the fabric again showed the KD effect [56].

Benefits of repellent coating fabrics
Due to the growth of vector-borne diseases like Malaria, Japanese encephalitis, and Dengue Fever, mosquito resistance has been increasingly sought after. Plant-based insect repellents have recently been launched to the market for customers who want a natural option without pesticides or other chemicals. A new sort of material is used to treat fabrics with an organic repellent. The fabrics are then put through an in-cage test, cone test, and Excito chamber test, which is the most typical procedure for mosquito repellents. The treated materials repelled mosquitoes for up to 8 hours after repellent infusion.

Future prospective of fabrics coated with repellents
Vector-borne diseases are major problems that arise continuously. Fabrics can act as a physical barrier between human skin and the blood-sucking mosquito, preventing disease transmission to other humans. Apart from industrial applications, mosquito repellent textile finishes have become indispensable in our daily lives in order to live in a disease-free and sanitary environment. The finish has a wide range of applications, including textiles, baby care goods, and nightwear. Even though many items have been introduced, many consumers are unaware of them. Textile researchers still have a lot of room to grow in this sector.
Conclusion
According to the review of the study Mosquito-borne diseases are not free from hazards to humans. To avoid these dreadful diseases, the treated fabrics will act to drive away the blood-sucking vector from the human body with an herbal product. Humans will be able to avoid using the most cost-effective textile materials, such as cotton, polyester, and mixed fabrics, to impart mosquito repellent. How are the plant’s essential oil finishing agents applied to the fabric? The essential oil of plants has good repellent properties that are eco-friendly.

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