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

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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-3-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).

Table 1: An overview of the laboratory studies imparting techniques on repellency treatment of essential oils

Plant essential oil	Mosquito species	Imparting Technique	References
Cymbopogon commutatus, C. martini, C. pendulus, C. nardus	*An. stephensi, Cx. quinquefasciatus* and *Ae. aegypti*	Volunteers test	[11]
Juniperus macropoda and Pimpinella anisum	*An. stephensi, Ae. aegypti*, and *Cx. quinquefasciatus*	Cardboard sheet	[12]
Centella asiatica, Ipomoea cairica, Momordica charantia, 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. fluvialitis and An. Stephensi*	Paper Impregnation	[15]
Eucalyptus and *Azadirachta indica*	*Culex quinquefasciatus*	Volunteers test	[16]
Rutacha lepensis	*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 pipiens*	Glass jars	[22]
Lippia alba, L. origanoides, Eucalyptus citriodora, Cymbopogon citratus, C. flexuosus, Camellia. sinensis, Chromolaena odorata, Salvia glutinosa, and *Tagetes lucida*	*Aedes aegypti*	Volunteers test	[23]
Artemisia 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 camaldulensis, 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 sinesis*	*Aedes aegypti and Culex quinquefasciatus*	Mosquito repellency	[30]

Zingiber cassumunar	*Aedes albopictus*	Cage test	[31]
Allium sativum, Anethum graveolens, Camellia sinensis, Foeniculum vulgare, Nigella sativa, Salvia ofcinalis, Thymus vulgaris, and *Viola odorata*	*Culex pipiens*	CDC bottle test	[32]

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. aurantiumvar 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

Odomos natural mosquito repellent	Cream/lotion and gel	It is safe for skin application	Citronella and Aloe vera
Good night personal repellent	Cream/gel	It is safe for skin application	Aloe vera
Dr. Zach's mosquito repellent	Lotion	It is safe for skin application	Lemon, eucalyptus, turmeric, and coconut
Mother sparshrepellent	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* (Kasthuri manjal), 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 microencapsulated *Senna auriculata* (Amanakku Avaram) and *Euphorbia thymifolia* (Amman pacharisi) extracts on textile using excito chamber test reported against *Anopheles* mosquitoes[46]. *Cymbopogon citros* oil using textile on pure cotton fabric through pad dry cure method and applied by mosquito repellent fabric cage tests [47]. Research conducted in Kenya on various fabrics (polyester, cotton, and cellulose with polyacrylate, etc textiles) as the substrate for dispensing a synthetic odor fabric, Ifakara blend made from 10 chemicals against malaria species against *Anopheles gambiae*, *Anopheles funestus* [48]. The mosquito repellency effect of marigold leaf extract coated on the cotton fabric with the help of the pad-dry-cure method has been studeid[49]. The use of synthetic pyrethroid (permethrin) in six different military uniforms were used as personal protection agents against *Cx. pipiens* in Tehran's metropolitan regions, and the natural population biting was observed [50]. The uses of synthetic pyrethroids deltamethrin (25% EC), lambda-cyhalothrin (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[51]. The longer-lasting repellency of cellulosic-based 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 [52].

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 effectiveness of the treated and untreated fabrics inside the cage [53].

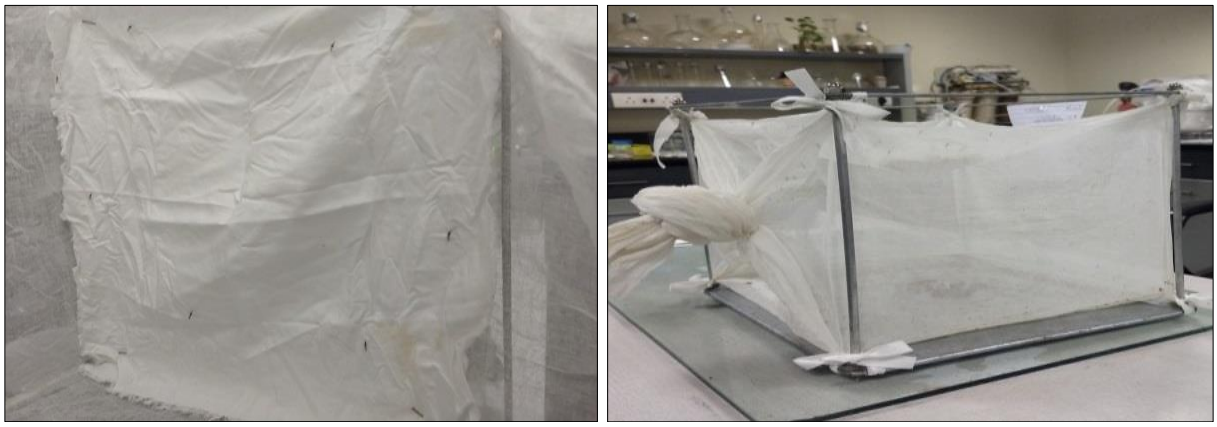

Fig 1: Mosquito repellency behavior evaluation using cage test method.

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 consider for the effectiveness of the treated and untreated fabric [54].

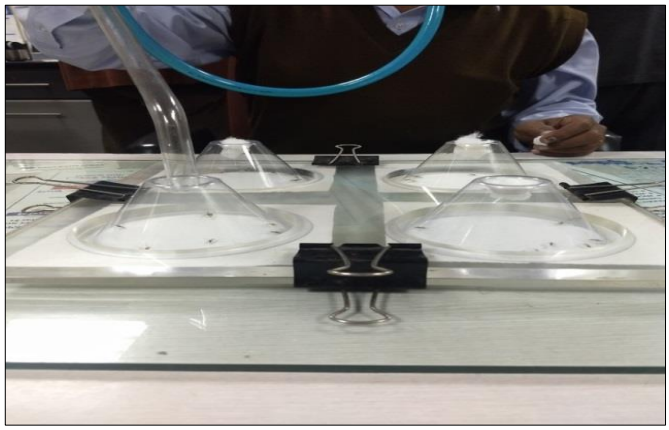

Fig 2: Mosquito repellency behavior evaluation using cone test method.

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].

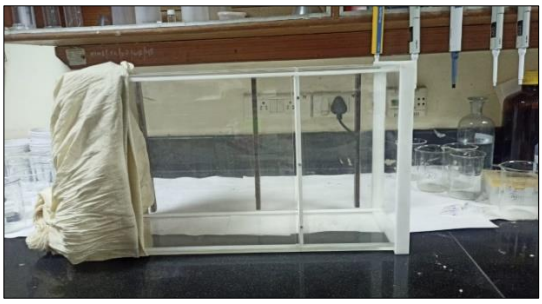

Fig 3: Mosquito repellency behavior evaluation using the Excito chamber test method.

Wash durability of treated fabric

The wash durability of repellent treated fabric is also reported. After the febric 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 repellant. 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 mosquitos 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 repellant. 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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