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Methods of imparting mosquito repellent agents and the assessing mosquito repellency on textile

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Abstract

This review intends to analyze the distinctive fabric utilized for mosquito repellent studies and forms of treatment mosquito agents on the fabrics. Textile treated with mosquito repellent is a revolutionary innovation to protect human from the bites of mosquito borne disease such as Dengue. This peculiarity was produced as needed in feeling of assurance from mosquitoes in the regions which are territories of the mosquitoes and inclined to disease. To impart this feature, the fabrics are given a treatment of mosquito repellent agent which capable of being utilized and without ruining their characteristics. The utilization of anti-agents to dress and different fabrics is best contrasted with skin application in light of the fact that it lessens the probability of unfavorably susceptible responses. This paper described the textile materials selection, methods of imparting the repellent into the fabrics, types of repellent as well as the repellency test of treated fabrics. The assessments used in the treated textile are summarized and conditions of the assessment of repellency relative to this discussion are presented.

Introduction

Mosquito bites can give an unpleasant feeling and may transmit the vector disease such as dengue or malaria to humankind. Mosquitoes are attracted to human blood containing protein to develop their eggs, biting human to another human, thereby transmitting the vector disease to human. The genus Aedes mosquitoes are responsible to transmit the vector of dengue all over the worlds with billion people suffer from the disease and also death cases reported (Division of Vector-Borne Disease 2012). There are only a few vaccines to treat the virus caused by mosquito bites, however, in the case of dengue, researchers are yet to find the vaccines for it (Farag et al. 2011) the best way is for people to avoid mosquito bites. Repellents are practical products and economical means to prevent the transmissions of the mosquito vector disease (Yang and Ma 2005). Hence, personal protective measure must be taken to protect human from mosquito bites. Applying mosquito repellents either on their skin, house, even on their clothing or upholsteries may help in protecting human against mosquito bites. Repellents that applied to skin or clothing produce a vapor layer that has an offensive smell or taste and makes a person unattractive for feeding and therefore repels the mosquito (Brown and

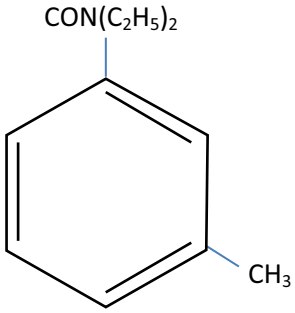
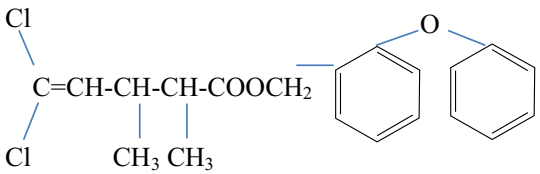
Hebert 1997; Fradin and Day 2002) several studies showed that most repellents was developed in the form of lotions, cream, essential oils, spray, or solution where in most cases require direct application to the human skin (Amer and Mehlhorn 2006; Ariffin et al. 2012; Fei and Xin 2007; Fradin and Day 2002; Snodgrass 1992; Yates et al. 2005). Treating the garment fabrics with repellent agent is another way to avoid mosquito bites as the big proportion of the human skin is covered by the treated garment thus, avoiding it to be exposed to the blood sucking mosquitoes. Imparting the mosquito repellents onto the textile and cloth impregnating laundry emulsions application is one of the innovatory and practical approach in daily routine to driving away the blood sucking arthropods from people (Brown and Hebert 1997; Maheshwari and Ramya 2014). The present inventions of mosquito repellents to be imparted into the fabric can be produced using various techniques such as addition during rinse cycle, direct coating, finishing like cloth impregnating laudry emulsions and others (Anitha et al. 2011; Anuar and Yusof 2016; Farag et al. 2011; Fei and Xin 2007; Snodgrass 1992; Sumithra and Vasugi Raja 2012; Troutman 2009; Van Winkle 2002). The textiles with mosquito repelling features exhibit a character that can drive the mosquito away from the treated textile, or by knocking down the mosquitoes when it is in contact with the treated textiles. The applications of the mosquito repellent feature must not damage the original characteristic of the textile materials itself. The value added of repellent properties also for textile material is a novel approaches as it by means can help to reduce the statistics of vector disease cases without giving a side effect to the wearer. According to a study by (Stajkovic and Milutinovic 2013), the recommendation regarding usage of repellent product for textile materials is "the product should be applied in a thin layer on the skin surface, clothing or both, it should not be applied under clothing".

Repellents can come from natural sources such as plant and chemical source such as DEET (N,N-dietyl-m- toluamide) the DEET along with other synthetic such as Permethrin, Allethrin and Malathion, has been proven to be the most effective commercial repellent formulation used in lotions, gels, solution, cream and aerosols. Permethrin has been used on thousands of US Military uniforms as insect repellent agent in the military uniform.

The most common synthethic repellents used to be applied on fabric are DEET and Permethrin as done by (Fei and Xin 2007; Frances 1987; Schoepke et al. 1998; Sholdt et al. 1989). The structure of DEET and Permethrin are in the Table 1 below.

However, the use of synthetic repellents such as DEET and other synthetic repellent has been proven to cause negative effect on human (Abou-Donia 1996; Koren et al. 2003; N'Guessan et al. 2008; Stajkovic and Milutinovic 2013). Permethrin, for example, is toxic in high doses, and constant skin contact can result in dermatitis (Brown and Hebert 1997). Regulation of absorption, ingestion and uptake of synthetic repellents such as Permethrin was set up by the US Environmental Protection Agency. According to EPA calculation of the cancer risk is based on the likelihood of one to three people in 1 million ($1–3 \times 10^{-6}$) developing as a negligible risk. The military and non military workers were calculated at (1.2×10^{-6}) and (3.6×10^{-6}) which fall below the EPA level of concern (Agency 2007; Banks et al. 2014). The side effect of synthetic repellents made the medicinal plants as an alternative for mosquito repellents sources. There are a lot of medicinal plants having potential to repel mosquito such as marigold, basil,

Table 1 The structure of the most common synthetic repellent applied on fabric (Stajkovic and Milutinovic 2013)

Substances (INCI name)	Structural formula
Diethyl toluamide (DEET)	
Permethrin	

chrysanthemum, citronella lavender including geranium (Rajkumar and Jebanesan 2007; Sritabutra et al. 2011). Repellents derived from plant sources, exhibit essential oils demonstrated it has short lasting protection due to oxidation of essential oils, lasting from a few minutes to as long as 2 h (Fradin and Day 2002; Kongkaew et al. 2011; Rajkumar and Jebanesan 2007; Sritabutra et al. 2011) however, these disadvantages can be overcome by the addition or modification of the essential oil. The microencapsulation of the herbal oil can secure the oil from getting easily oxidized when exposed to the environment before imparting the solution to fabric (Brain et al. 2007; Maheshwari and Ramya 2014; Sumithra and Vasugi Raja 2012). The addition of vanilla essential oil is claimed to prolong the efficacy of the oils (Tawatsin et al. 2001).

The efficacy of the mosquito repellents can be evaluated using a standard methods according to World Health Organization (WHO) (WHO 1996), and American Society for Testing Materials (ASTM) (Standards 2006). The most commonly used method for mosquito repellents which is cage test. For impregnated textiles, there are several methods to determine the effectiveness of the treated textiles. The methods are cone test, cage test, field test and excito chamber (Sritabutra et al. 2011; Standards 2006; Tawatsin et al. 2001; WHO 1996). The methods and the assessment of repellency test were discussed further in this review.

Review of methods

The following search engines were used to obtained information on different test method of insect repellency assessment: Google Scholar, Springer Link and PubMed. The terms used for the search are: 'mosquito repellent finishes', 'impregnated textiles', 'insecticide fabric', 'arm-in cage test', 'WHO cone test' and '*Aedes aegypti*'. The published articles that were referred dated between 1992 and 2014. The textile materials used in previous mosquito repellent studies, and the techniques of imparting the repellent onto the textile materials were reviewed. The three methods of mosquito repellency assessment

that were discussed are the cage test, the cone test, and the modified excito chamber. Of late, there are many textiles products that are claimed to be able to repel mosquito away from human. This paper also includes a review on some of the products available for that purpose.

Textile materials used in mosquito repellency studies

Both natural and synthetic fabrics have been experimented in previous studies. Vigneshkumar and Specos et al. reported the use of scoured and bleached cotton knitted fabric in a study determining the "Repellence effect of microencapsulated citrinellea oil on tretated textile fabrics against *A. aegypti* mosquitoes" and "Microencapsulated citronella oil for mosquito repellent finishing of cotton textiles" (Specos et al. 2010; Vigneshkumar and Vijaykumar Vediappan 2012). Other study by Maheshwari et al. (Maheshwari and Ramya 2014) utilized the same textile materials of cotton fabric which made from rib knitted and experiencing the scouring, bleaching and dyeing process in a study to determine eco friendly mosquito repellent fabric finished with natural plant. This requirement can give the significance means of the fabric selection when conducting the repellency test. The greigh fabric can be controlled relying upon their suitability of studies as the finishing proses could be possible to imitate the daily utilization of article of clothing wear (Vigneshkumar and Vijaykumar Vediappan 2012). Two studies reported the use of synthetic fabric which is 100 % polyester fabric which made in the form of mosquito nets and other one is curtains. For the application of synthetic repellent such as DEET, Brown reported that DEET had been reported safe for cotton, wool and nylon fabrics types, but may damage the spandex, rayon and acetate due to the chemical content. In flammability test, DEET applied on polyester acrylic cloth ignited immediately when near a flame (Brown and Hebert 1997).

Farag et al. in a study to determine the longer-lasting repellence cellulosic based curtain fabrics reported employed the various types of textile materials which are cotton, polyester and linen forming a blended woven curtain fabric (Farag et al. 2011). A recent study by Mweresa et al. conducted in Kenya utilized various fabric selection which are polyester, cotton, cellulose with polyacrylate and nylon textiles as substrate for dispensing a synthetic odour blend to lure malaria mosquitoes (Mweresa et al. 2014). Athe Sumithra et al. uses the blended fabrics, cotton, polyester, spun lycra and poly lycra which the end use in the form of denim product (Sumithra and Vasugi Raja 2012).

In view of the past reported studies, the most utilized material fabric is cotton. In some of the studies, the greigh fabric have been processed through the textile finishing processes for making a finished fabrics. Textile finishing usually involved treatments such as scouring, desizing, bleaching, mercerizing and dyeing process. Textile finishing usually involved treatments such as scouring, desizing, bleaching, mercerizing and dyeing process (Hall 1966). None reported the cotton fabric experiencing the finishing process mercerizing process. It is remarkable that the wet preparing of cotton fabrics prompts its shrinkage, expanding the yarn number, mass every unit territory, and fabric thickness (Tarbuk et al. 2014). Mercerised cotton fibre will be round and hollow rather than strip like shapes, and the cross-segments of the filaments change from kidney like to roundabout molded. The primary explanation behind this is the cotton fibre swelling amid the mercerisation process. Amid mercerization, Sodium Hyroxide (NaoH) infiltrated into

the lumen of the cotton strands and swelled. Mercerizing process is the act of chemical treatment on cellulosic fibre to improve the properties of the fibre in term of tensile strength, absorption properties and also greater affinity of dyes and various chemical finishes. Mercerized cotton holds the properties of higher mass per unit area, thickness, breaking force and elongation, luster, with a change of surface charge that ensures further quality improvement and also higher adsorption of anionic auxiliaries.

Mosquito repellent textile products

Textiles can act as a physical barrier to the entry of insects, mosquitoes and other anthropoids. At the moments, textile products developed as protective textile against mosquito are extensively used by consumers. The outlines of existing things are recorded in the Table 2 beneath.

Clothing can be treated with anti-agents to keep mosquitoes from arriving or encouraging, on the other hand, with fast acting aerosol spray of the pyrethroid gathering, for example, permethrin. These recent mixes does not repulse the mosquitoes yet permit them to reach with the fabric and aggravate or killing them before they figure out how to bolster. The application of anti-agents to dress and different fabrics is desirable over skin application on the grounds that it diminishes the probability of hypersensitive responses. Former USSR have been developed a vest that claimed as anti-mosquito garment which consist of long sleeves made from wide mesh materials with 0.5 cm fibres thick (Rozendaal 1997). Study by Shannon identifies that garment piece with defensive pieces of clothing adjusted to be worn by outdoorsmen give protection against mosquitoes and different arthropods without any repellent treatment on the fabric. The garment comprises the multilayer of fabric consist of outer and inner layers which are connected at the seams (Shannon 1988). The upholsteries and outdoor textile items as listed on the Table 1 are existing products that have been developed to be used as individual outdoorsmen, housewife and also family. Most of protective mosquito textiles were treated using DEET or Permethrin by spraying the repellents from a pressurized can or by dipping it in the aqueous emulsion. For the netting jackets head nets, the materials are made from a blend of polyester/cotton, which being treated with DEET for easy absorption of the mosquito agent. The disadvantage of the netting jacket is that the

Table 2 Classification of mosquito repellent textile products (Rozendaal 1997)

Clothing	Upholsteries/outdoor
Treated jacket	Detachable patches of fabric
Netting jackets	Hammock
Bands and anklets	Curtain
Headnets	Bed sheets
Vest	Bedcurtain
Tshirt and trousers	Mosquito nets (netting models)
	Rectangular net
	Circular net
	Wedge-shaped net
	Self supporting (baby net)
	Hammock net

structure of the jacket which is made of a wide mesh can be easily entangled. Another limitation is the netting materials must be wrapped in a plastic bag when not in use. Another example of mosquito repellent associated with fabric is the detachable patches with Velcro strips, press buttons or adhesive sticker. The treated patches can be easily removed and do not have a direct contact with the skin, therefore provides safety protection against mosquito Hammocks are made from textile materials for resting and sleeping, especially in jungle areas by outdoormens. It will be hung onto the tree or anything that is tall enough to keep off the ground from soil, crawling insect, snake, scorpions and anything small insects. However, hammock does not protect users from the flying insect such as mosquitoes. Mosquitoes often attack hammock user from the lower part of the hammock where the body presses the textile. There are a few suggestions to make hammock more protective against mosquito. Application of repellent such as spraying to the lower part of the hammock may avoid the mosquito to get near. A more economical method which requires a less repellent agent is by attaching the netting materials such as a piece of cloth which has been treated with repellent agent at the lower part of the hammock. This method can provide partial protection from biting mosquitoes. Another way for long lasting protection is to impregnate the whole hammock with the repellent. Another protective mosquito textiles are mosquito nets. The traditional netting materials are made from raffia (palm fibre), linen or hemp compared to the modern net which made from cotton and man-made fibre such as nylon, polyester or polyethylene. The mesh size of mosquito nets is between 1.2 and 1.5 mm, (if more that 2 mm most mosquitoes can enter). The structure of the netting materials can be woven or knitted. In terms of colour, white color is more preferred as mosquitoes that entered the nett can be easily noticed compared to a darker colour netting. For more protection, the mosquito net can be treated with mosquito repellent agent during the production as it can act as physical barrier to the entry of the mosquitoes (Rozendaal 1997).

Insecticide-treated bed nets are likely among the most well studied examples and good indication of their viability against bites and their significant effect on pathogen transmission has been accounted for by WHO (Banks et al. 2014). The concerns regarding treated clothes with repellents such as DEET, are they really not irritate human skin of applied at to the cloth or direct contact to skin. Are they pleasant to use in daily wear such as odour problem, greasiness or colour changes on the textile.

Methods of imparting repellent on textile materials

Based on the review of literatures, there were various techniques to impart the mosquito repellent agents into the fabrics. Table 3 below shows the various studies of imparting techniques onto the textile materials.

According to Banks et al. (2014) there are four main techniques to achieve the method of repellent textile which are absorbed, incorporation, polymer coating and microencapsulation. The absorption technique comprises the method of spraying, dipping or pad dry cure to fabrics, along with the use of repellent agent. While the corporation technique mainly used in carpets industry involves the process of pretreatment carpet during the manufacturing or dyeing process (McCamy and Clark 1996). The polymer coating and microencapsulation having similar technique which exhibit a layer of polymers coated onto the textiles fibre, but the microencapsulation must be in capsule form that

Table 3 Summary table showing an overview of studies imparting techniques onto the textile materials

Study (year)	Imparting technique	Types of fabric	Repellents type	Evaluation type	Outcomes
Natural repellents					
Maheshwari and Ramya (2014) Tamil Nadu, India	Pad dry cure	Scoured, bleached and dyed 100 % cotton rib knitted	Microencapsulation *Andrographis paniculata*	Modified excito chamber	% mosquito repellency
Vigneshkumar and Vijaykumar Vediappan (2012) Tamil Nadu, India	Direct coating	Scoured and bleached cotton fabric	Microencapsulation Cymbopogon citrosa/citronella	Cage analysis field analysis	% insect landing % mosquito repellency
Sumithra and Vasugi Raja(2012) Tamil Nadu, India	Pad dry cure	Blended denims	*Ricinus communis* *Senna auraculata* *Euphoria herita*	Modified excito chamber	% mosquito repellency
Anitha et al. (2011) Tamil Nadu, India	Pad dry cure	100 % polyester	Microencapsulation lemon grass	Modified excito chamber	% mosquito repellency
Synthetic Repellents					
Farag et al. (2011) Cairo, Egypt	Pad dry cure	Blended of natural and synthetic fabric	Monochlorotriazenyl β-cyclodextrin Permethrin	Cone test	% mosquito knockdown
**Paya et al. (2010) Portland, USA	Attached by resin solution	Natural and synthetic fabric	Microencapsulation Permethrin	–	–
Pennetier et al. (2010) Bennin, France	Impregnation	Battle field uniform 65 %/35 % cotton/polyester	KBR3023	Field test	% mortality
**Troutman (2009) South Carolina, USA	Rinse cycle laundry additives	Non-woven fabric (dryer sheet)	Pyrethrum	–	–
Fei and Xin 2007 Hong Kong	Aerosols	Cotton fabric	Microencapsulation DEET	Cage test	% mosquito repellency
**Chen et al. (2006) New York, USA	Dipping process	Cotton yarn	Permethrin	–	–
Yates et al. 2005) London, UK	Dipping process	Polyester nets	KO tab Permanet	Chemical test Susceptibility kits	% mosquito mortality
**Van Winkle (2004) Ohio, USA	Rinse cycle laundry additives	Various clothing	DEET	–	–

** This study does not show the mosquito repellency assessment

mixed to binding solution (Appel et al. 2008; Banks et al. 2014; Faulde and Uedelhoven 2006). Five studies (Anitha et al. 2011; Fei and Xin 2007; Paya et al. 2010; Vigneshkumar and Vijaykumar Vediappan 2012) reported the treated textile with mosquito repellents use the method of pad dry cure method of the microencapsulation repellents either from natural or chemical sources. The existing developments using synthetic repellent including insect textile repellent as mention above. This is done by impregnated the textile

with the synthetic repellent formulations, however this product are normally applied directly onto the skin, constant contact of the synthetic repellent which are high doses and toxic resulted in skin problem such as dermatitis. The other way using the DEET on textiles is the addition of the chemical during the rinse cycle of laundering as stated in a previous research study by Van Winkle (Van Winkle 2004). The application of the DEET is done by imparting the chemical repellents with fabric softener at the stage of rinse cycle in automatic washing machine to fabric for providing soft treated garment that repel mosquitoes. The other way is providing mosquito repellent to yarn and fibre during the manufacturing of the mosquito repellent garment. The yarn and fibre are coated during the finishing process using the Permethrin at the stage of dipping process. The fabric is claimed to have a Permethrin compounds even after 25 launderings (Pennetier et al. 2010). But, the same major problems arise regarding the use of synthetic repellents which is harmful and toxic to human especially to children (Appel et al. 2008).

Present inventions of mosquito repellent using the natural essential oil imparted on textile substrate are using various medicinal herbs that claimed to repel mosquito. The essential oils are citronella oils to repel mosquito, cinnamon oil to kill mosquito larvae, including Geranium oil to prevent mosquito (Patel et al. 2012). Four studies (Anitha et al. 2011; Maheshwari and Ramya 2014; Sumithra and Vasugi Raja 2012; Vigneshkumar and Vijaykumar Vediappan 2012) used the plant sources as a natural repellent to be imparted into the textile material. The plant essential oils were microencapsulated to prevent the easily evaporation process before the impart to fabric by pad dry cure method or addition to rinse cycle. Study by Specos stated that textile treated with microencapsulated citronella performed the higher and and longer lasting protection against mosquitoes compared to sprayed fabric with ethanol solution of essential oil (Specos et al. 2010).

Study by Geethadevi reported that fabric treated with natural repellent using exhausted method from combination of essential oil such as thyme oil, cypress oil and grapefruit oil applied on bamboo/tencell fabric with 50/50 presented the longer efficacy of mosquito repellent up to 30 washes with no allergic reaction to wearer. (Geethadevi and Maheshwari 2015) oil the table below shows the summarized of the this review.

Methods of mosquito repellency assessment

There are several methods to evaluate the treated textile with mosquito repellent. The most used techniques are cage test, cone test, and excito chamber. This paper only further discussed the most three used mosquito repellent assessments.

Cage test

The cage test might assess the viability (Fig. 1) of repelling substance against mosquitoes for lotions, cream including impregnated material done fast and effective approach. It is designed to observe the mosquito landing on the untreated and treated fabric in the cage. The advantages of this method is it provided the real situation of the probing and biting of the mosquito to the human besides it can directly provide the observation of the mosquitoes behaviour towards the treated materials. The drawbacks of cage test involve the human participation, it takes a lot of preparation either in term of paper works such as needed to apply ethical approval, the human and mosquito preparation. In term of human participation, the consent form and incentives must be

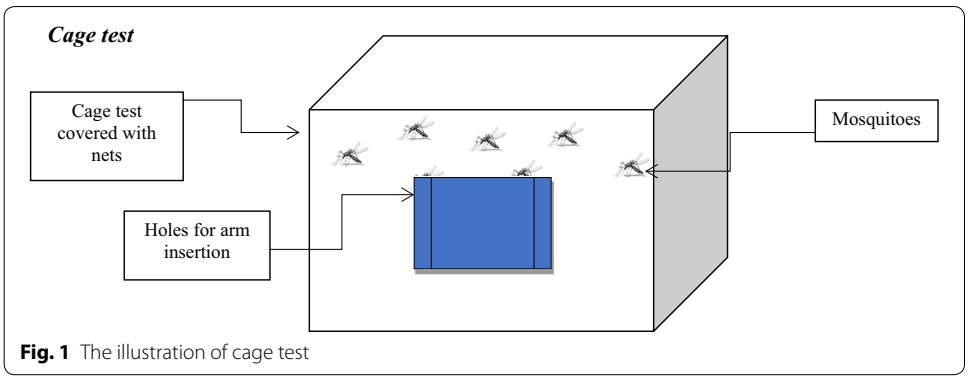


Fig. 1 The illustration of cage test

prepared as an appreciation to the volunteer. The mosquitoes used in the test need to be free from pathogen as the human subject involved in the test must have the assurance that the test will not harm them. The cage measurement is according to WHO guideline for efficacy testing of mosquito repellents for human skin (WHO 1996) the range of 35–40 cm per side. Some studies reported in modification of the cage dimension; Bano et al. used a cage 18 × 18 × 18 cm dimension(Bano 2014), Phasomkusolsil et al. used cage 30 × 30 × 30 cm dimension (Phasomkusolsil and Soonwera 2011), Anitha et al. used 34 × 32 × 32 cm cage dimension (Anitha et al. 2011) and Chang et al. used the 35 × 35 × 35 cm cage dimension (Chang et al. 2006). Two other studies reported the used of bigger cage dimension, measuring 40 × 30 × 30 cm by Fei and Xin (2007) and 45 × 45 × 45 cm by (Vigneshkumar and Vijaykumar Vediappan 2012).

The cage concealed with transparent mosquito nets for easy observation and also to keep mosquito remain inside the cage. It has holes which also covered with nets for arm accessing purpose. According to WHO (WHO 1996) conventional standards, the cage needs to be filled with 200 mosquitoes that have been starved overnight and only were supplied with sucrose solution. Updated standards the use of lesser number of mosquitoes in the cage (as low as 30 mosquitoes), as lower density provides more accuracy which better reflect the typical biting environment encountered during most indoor and outdoor activities and also to give a comfortable condition to volunteer. Volunteers should be preferable not to be tobacco users and should avoid using fragrance or repellent products for 12 h ad during testing. This factor may alter the person attractiveness to the mosquitoes and will affect to the outcome repellency assay. In preparation of the volunteer, their hand must be washed with unscented soap and rinsed with water and placed separated from each other by ≥20 m away. The arm covered with gloves or treated materials of the volunteers will be inserted into the cages. The left arm served as control while the right arm use as treated samples. Both forearms with untreated and treated materials will be exposed to the population of mosquitoes simultaneously for a period of 3 min. At least two mosquitoes landed or bite within the 3 min, the test will continue. If there is no mosquito landed within 3 min, the hand will withdraw from the cage. The number of mosquito landing will be counted independently using the digital camera for an accurate result. The exposition is done every 30 min up to 8 h or until the repellency fails. Each test samples done in triplicates at 28 ± 2 °C and 80 ± 5 % RH with 5 min waiting period between replicates. The time between applications of the treated

materials recorded as the protection time. The percentage of repellency or protection time was calculated using the formula.

$$\% \text{ Mosquito protection} : (U - T)/U \times 100$$

where U corresponds to the number of mosquitoes on untreated samples or control samples and T represents the number of mosquitoes on treated samples. This is the regularly utilized formulas as stated by Lupi et al. (2013) although the percentage of repellency was sometimes calculated with other formulas, but it will not be discussed further in this review. The results will be collected and performed in ANOVA software for further analysis. Six studies (Chang et al. 2006; Fei and Xin 2007; Fradin and Day 2002; Masetti and Maini 2006; Vigneshkumar and Vijaykumar Vediappan 2012; Yang and Ma 2005) demonstrated the use of cage tests in their study for mosquito repellent.

Cone test

The cone test is formerly the custom to (Fig. 2) evaluate the toxicity of insecticide-treated bed nets against malaria, which also able investigate the toxicity of other impregnated (textile) surfaces. The fabric treated, evaluated using the WHO cone test following the standard procedure described in the WHO 1998: test procedures for insecticide resistance monitoring in malaria vectors, bioefficacy and persistance of insecticdes on treated surfaces (WHO 1996). This test does not involve human participants as the bait to lure the mosquitoes come to fabric and this in one of advantages of this method. Due to this factor, this method is less chosen by the researcher to conduct the mosquito repellency test on clothing. The use of artificial blood or animal blood as bait in order to attract host seeking mosquitoes, which in this cone test could help future studies to better assess of the efficacy on the treated clothing. In the cone test, the mosquitoes might spend more time resting on the cone than on the treated surface during the 3 min exposition. The 3-min exposure test was carried out under the temperature of 27 °C. The standard WHO plastic cone was placed on top of the treated surface of the sample and secured using a masking tape. Five to ten female mosquitoes were blown into the cone using aspirator and mosquitoes were exposed to the treated surface. The low density mosquito number used for this method made it easy observation for the mosquito behaviour. The numbers of mosquitoes resting on the treated samples were counted within 3-min exposure.

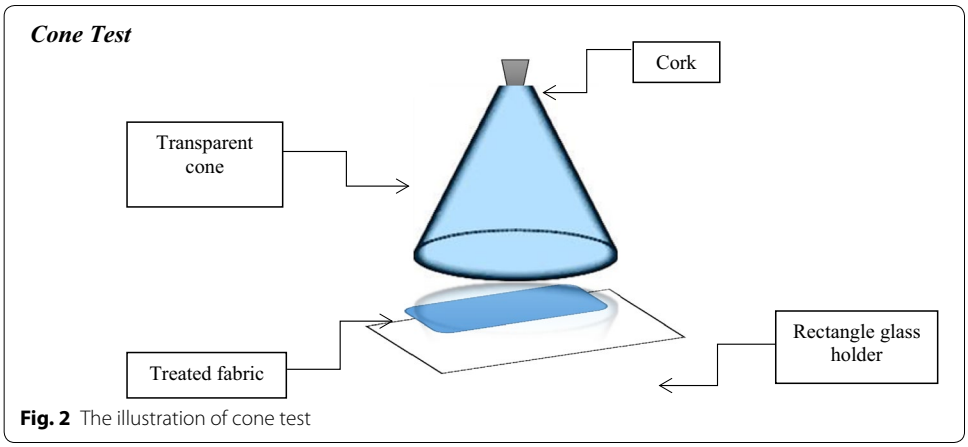


Fig. 2 The illustration of cone test

At the end of the exposition, the mosquitoes were transferred to the plastic cones for further observation. The plastic cup kept in an insecticide-free air and supplied with 10 % sucrose solution. The number of immobilized, knocked down test mosquitoes was determined 1 h after the exposition and the mortality rate was determined after 24 h. The percent mosquito repellency was calculated using the following formula:

$$\%\ \text{Mosquito mortality}: \ (\text{MR} - \text{MC})/(100 - \text{C}) \times 100$$

where MR represents the mosquitoes mortality in test replicate while the MC corresponds to the mosquitoes mortality in control samples. The natural mortality rate is determined with an untreated fabric as reported by (Lalit Jajpura 2015).The results will be collected and performed in ANOVA software for further analysis. Only one study by Farag et al. (2011) demonstrated cone test for their mosquito repellency test.

Excito chamber test

The excito chamber method is a modified custom method to observe the mosquito behaviour change in the form (Fig. 3) of moving away from the treated to untreated fabric. This method and Cone test method does not involve the human subject to lure the mosquito. However, both methods can determine the behaviour of the mosquitoes towards the treated materials. The box is made with one front and exit panel occupied with single escape portal. It builds up with screened inner chamber, glass holding frame and door cover. The mosquito was starved overnight or least minimum 4 h before the test. The behaviour of mosquito was observed in term of number of escaped mosquitoes to another space and remain mosquitoes inside the chamber which filled with treated product. The observation is recorded after 10 and 30 min exposure. The test was conducted in daylight and repeated for four times. The percentage of mosquito repellency was calculated using the formula:

$$\%\ \text{Mosquito repellency}: \ (\text{NES} + \text{NDE})/(\text{NEX}) \times 100$$

where NES corresponds to the number of mosquitoes escaped, while the NDE refer to the number of mosquitoes dead and last is NEX represents the number of mosquitoes exposed. The results will be collected and performed in ANOVA software for further analysis. Three studies (Alipour et al. 2015; Anitha et al. 2011; Chareonviriyaphap et al.

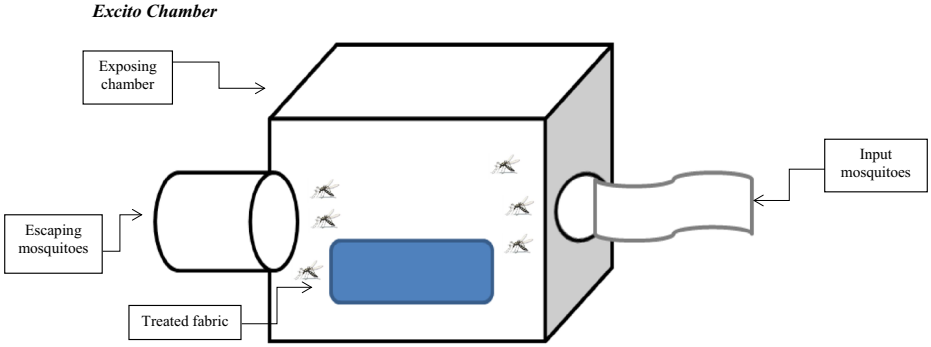


Fig. 3 The illustration of excito chamber

2002; Maheshwari and Ramya 2014; Roberts et al. 1997; Sumithra and Vasugi Raja 2012) conducted this method of mosquito repellency in their studies.

In general comparison, the suitability of the three methods reviewed according to different intended test objectives or situation. For example cone test is more suitable for a study that is conducted to investigate the toxicity of other impregnated surfaces. The excito chamber also can be evaluated to observe the comparison of mosquito behaviour on treated and untreated textile. Both methods do not involve human participation. However, the cage test involved human subject as volunteer to test the material may imitate the real situation of mosquito biting and may give the accurate results.

Conclusion

Vector borne disease from mosquitoes are one of the major problem arises. In order to avoid the transmission of diseases to other human, fabrics can act as a physical barrier between human skin and the blood sucking mosquito. This review outlines that most commonly used textile materials to impart the mosquito repellent comes from cotton, polyester and blended fabrics. By using these fabrics, an efficient textile material to treat with the mosquito repellent agent has been proven to demonstrate the good properties. It also showed that there are various techniques of imparting the repellent into the textile substrate which most used methods is a pad dry cure method with microencapsulation of repellents. In this review, it summarized the type of mosquito repellency assessment to conduct the efficacy of the impregnated textile. Differences in the findings of the included studies could be attributed to many factors such as type of textile materials used or type of technique used to impart repellent. Therefore, it suggested that the suitable fabrics with a suitable repellent agent with proper methods of mosquito repellency test is hoped to develop a new knowledge to other future study.

Competing interests

The authors declare that they have no competing interests.

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References

Abou-Donia, M. B. (1996). Neurotoxicity resulting from coexposure to pyridostigmine bromide, DEET, and permethrin: implications of Gulf war chemical exposures. *Journal of Toxicology and Environmental Health Part A, 48*(1), 35–56.

Agency, U. S. P. E. P. (2007). Reregistration eligibility decision (red) for permethrin.

Alipour, H., Mahdian, S. M. A., Rami, A., Abad, M. O. K., Amin, M., & Dinparast, N. (2015). Excito-repellency effects of Pelargonium roseum wild (Geraniaceae) essential oil-treated bed nets on the malaria mosquito, Anopheles stephensi Liston, 1901 (Diptera: Culicidae)

Amer, A., & Mehlhorn, H. (2006). Larvicidal effects of various essential oils against Aedes, Anopheles, and Culex larvae (Diptera, Culicidae). *Parasitology Research, 99*(4), 466–472.

Anitha, R., Ramachandran, T., Rajendran, R., & Mahalakshmi, M. (2011). Microencapsulation of lemon grass oil for mosquito repellent finishes in polyester textiles. *Elixir Bio Phys, 40*, 5196–5200.

Anuar, A. A. , & Yusof, N. A. (2016). Potential of geranium from *Pelargonium Graveolens As* natural mosquito repellent agent in fabric softener. Paper presented at the Fifth International conference on advances in applied science and environmental engineering—ASEE. Kuala Lumpur.

Appel, K. E., Gundert-Remy, U., Fischer, H., Faulde, M., Mross, K. G., Letzel, S., & Rossbach, B. (2008). Risk assessment of Bundeswehr (German Federal Armed Forces) permethrin-impregnated battle dress uniforms (BDU). *International Journal of Hygiene and Environmental Health, 211*(1), 88–104.

Ariffin, Z., Muhammad, N. A., Yusof, R., & Masdar, N. D. (2012). Formulation of an aromatic cream: the study on the geranium oil properties for the mosquito repellents.

Banks, S. D., Murray, N., Wilder-Smith, A., & Logan, J. G. (2014). Insecticide-treated clothes for the control of vector-borne diseases: a review on effectiveness and safety. *Medical and Veterinary Entomology, 28*, 14–25. doi:10.1111/mve.12068.

Bano, R. (2014). Use of chitosan in mosquito repellent finishing for cotton textiles. *Journal of Textile Science & Engineering*, *4*, 1–3. doi:10.4172/2165-8064.1000162.
Brain, J., Bennett, S. W., Zhen, Y., Pluyter, J. G. L., Popplewell, L. M., & Lee, K. D. (2007). Encapsulated fragrance chemicals: google patents.
Brown, M., & Hebert, A. A. (1997). Insect repellents: an overview. *Journal of the American Academy of Dermatology, 36*(2), 243–249.
Chang, K. S., Tak, J. H., Kim, S. I., Lee, W. J., & Ahn, Y. J. (2006). Repellency of Cinnamomum cassia bark compounds and cream containing cassia oil to *Aedes aegypti* (Diptera: Culicidae) under laboratory and indoor conditions. *Pest Management Science, 62*(11), 1032–1038.
Chareonviriyaphap, T., Prabaripai, A., & Sungvornyothrin, S. (2002). An improved excito-repellency test chamber for mosquito behavioral tests. *Journal of Vector Ecology, 27*, 250–252.
Chen, Y. C., Chung, H. N., & Lin, S. M. (2006). Yarns and fabrics having long-lasting mosquito repellent or antibacterial effect and their preparation: google patents.
Division of Vector-Borne Disease. (2012). *Dengue and Aedes aegypti mosquito*. San Juan.
Farag, S. A., Osama, H., Mohamed, R., & Mohamed, H. (2011). Development of longer-lasting repellence cellulosic based curtain fabrics. *Material Sciences and Applications, 2*, 200–208. doi:10.4236/msa.2011.23025.
Faulde, M., & Uedelhoven, W. (2006). A new clothing impregnation method for personal protection against ticks and biting insects. *International Journal of Medical Microbiology, 296*, 225–229.
Fei, B., & Xin, J. H. (2007). N, N-diethyl-m-toluamide–containing microcapsules for bio-cloth finishing. *The American Journal of Tropical Medicine and Hygiene, 77*(1), 52–57.
Fradin, M. S., & Day, J. F. (2002). Comparative efficacy of insect repellents against mosquito bites. *New England Journal of Medicine, 347*(1), 13–18.
Frances, S. (1987). Effectiveness of deet and permethrin, alone, and in a soap formulation as skin and clothing protectants against mosquitoes in Australia. *Journal of the American Mosquito Control Association, 3*(4), 648–650.
Geethadevi, R., & Maheshwari, V. (2015). Long-lasting UV protection and mosquito repellent finish on bamboo/tencel blended fabric with microencapsulated essential oil. *Indian Journal of Fibre & Textile Research (IJFTR), 40*(2), 175–179.
Hall, A. J. (1966). *Textile finishing Finissage des textiles: American Elsevier*. New York: NYUSA.
Kongkaew, C., Sakunrag, I., Chaiyakunapruk, N., & Tawatsin, A. (2011). Effectiveness of citronella preparations in preventing mosquito bites: systematic review of controlled laboratory experimental studies. *Tropical Medicine and International Health, 16*(7), 802–810.
Koren, G., Matsui, D., & Bailey, B. (2003). DEET-based insect repellents: safety implications for children and pregnant and lactating women. *Canadian Medical Association Journal, 169*(3), 209–212.
Lalit Jajpura, M. S., Abhilasa Rangi, Kalpana Chhichhilia. (2015). A Review On Mosquito Repellent Finish For Textile Using Herbal Extracts. *International Journal of Engineering Sciences and Management Research, 2*(8).
Lupi, E., Hatz, C., & Schlagenhauf, P. (2013). The efficacy of repellents against *Aedes*, *Anopheles*, *Culex* and *Ixodes* spp.—a literature review. *Travel Medicine and Infectious Disease, 11*(6), 374–411. doi:10.1016/j.tmaid.2013.10.005.
Maheshwari, V., & Ramya, K. (2014). Development of eco friendly mosquito repellent fabric finished with *Andrographis Paniculata* plant extracts. *International Journal of Pharmaceutical Sciences, 6*(5), 115–117.
Masetti, A., & Maini, S. (2006). Arm in cage tests to compare skin repellents against bites of *Aedes albopictus*. *Bulletin of Insectology, 59*(2), 157.
McCamy, T., & Clark, W. H. (1996). Insecticidal carpet and pretreatment process for producing insecticidal carpet: google patents.
Mweresa, C. K., Mukabana, W. R., Omusula, P., Otieno, B., Gheysens, T., Takken, W., & van Loon, J. J. (2014). Evaluation of textile substrates for dispensing synthetic attractants for malaria mosquitoes. *Parasites and Vectors, 7*, 376. doi:10.1186/1756-3305-7-376.
N'Guessan, R., Knols, B. G., Pennetier, C., & Rowland, M. (2008). DEET microencapsulation: a slow-release formulation enhancing the residual efficacy of bed nets against malaria vectors. *Transactions of the Royal Society of Tropical Medicine and Hygiene, 102*(3), 259–262.
Patel, E., Gupta, A., & Oswal, R. (2012). A review on: mosquito repellent methods. *Int J Pharm Chem Biol Sci, 2*(3), 310–317.
Paya, J. G., Aracil, M. A. B., Aboy, P. M. R., & Perez, P. M. (2010). Insect Repellent Textile: google patents.
Pennetier, C., Chabi, J., Martin, T., Chandre, F., Rogier, C., Hougard, J.-M., & Pages, F. (2010). New protective battle-dress impregnated against mosquito vector bites. *Parasites and Vectors, 3*, 81. doi:10.1186/1756-3305-3-81.
Phasomkusolsil, S., & Soonwera, M. (2011). Comparative mosquito repellency of essential oils against *Aedes aegypti* (Linn.), *Anopheles dirus* (Peyton and Harrison) and *Culex quinquefasciatus* (Say). *Asian Pacific Journal of Tropical Biomedicine, 1*(1), S113–S118.
Rajkumar, S., & Jebanesan, A. (2007). Repellent activity of selected plant essential oils against the malarial fever mosquito *Anopheles stephensi*. *Tropical Biomedicine, 24*(2), 71–75.
Roberts, D. R., Chareonviriyaphap, T., Harlan, H. H., & Hshieh, P. (1997). Methods of testing and analyzing excito-repellency responses of malaria vectors to insecticides. *Journal of the American Mosquito Control Association, 13*(1), 13–17.
Rozendaal, J. A. (1997). Vector control: methods for use by individuals and communities. In W. H. Organization (Ed.), (pp. 59–87). Geneva: WHO. Retrieved from http://www.who.int/water_sanitation_health/resources/en/vector059to87.pdf.
Schoepke, A., Steffen, R., & Gratz, N. (1998). Effectiveness of personal protection measures against mosquito bites for malaria prophylaxis in travelers. *Journal of Travel Medicine, 5*(4), 188–192. doi:10.1111/j.1708-8305.1998.tb00505.x.
Shannon, K. (1988). Protective garment for protection against mosquitoes and other insects: google patents.
Sholdt, L., Schreck, C. E., Mwangelwa, M., Nondo, J., & Sianchji, V. J. (1989). Evaluations of permethrin-impregnated clothing and three topical repellent formulations of deet against tsetse flies in Zambia. *Medical and Veterinary Entomology, 3*(2), 153–158.
Snodgrass, H. L. (1992). Permethrin transfer from treated cloth to the skin surface: potential for exposure in humans. *Journal of Toxicology & Environmental Health Part A: Current Issues, 35*(2), 91–105.

Specos, M. M., Garcia, J., Tornesello, J., Marino, P., Della Vecchia, M., Tesoriero, M. D., & Hermida, L. (2010). Microencapsulated citronella oil for mosquito repellent finishing of cotton textiles. *Transactions of the Royal Society of Tropical Medicine and Hygiene, 104*(10), 653–658.
Sritabutra, D., Soonwera, M., Waltanachanobon, S., & Poungjai, S. (2011). Evaluation of herbal essential oil as repellents against Aedes aegypti (L.) and Anopheles dirus Peyton and Harrion. *Asian Pacific Journal of Tropical Biomedicine, 1*(1), S124–S128.
Stajković, N., & Milutinović, R. (2013). Insect repellents-transmissive disease vectors prevention. *Vojnosanitetski Pregled., 70*(9), 854–860.
Standards, A. (2006). Standard test methods for laboratory testing of non-commercial mosquito repellent formulations on the skin. *ASTM International,*. doi:10.1520/E0951-94R06.
Sumithra, M., & Vasugi Raja, N. (2012). Mosquito repellency finishes in blended denim fabrics. *International Journal of Pharmacy & Life Sciences, 3*(4), 1614–1616.
Tarbuk, A., Grancaric, A. M., & Leskovac, M. (2014). Novel cotton cellulose by cationisation during the mercerisation process—part 1: chemical and morphological changes. *Cellulose, 21*(3), 2167–2179.
Tawatsin, A., Wratten, S. D., Scott, R. R., Thavara, U., & Techadamrongsin, Y. (2001). Repellency of volatile oils from plants against three mosquito vectors. *Journal of Vector Ecology, 26*, 76–82.
Troutman, S. L. (2009). Laundry additive for the treatment and prevention of bed bugs: google patents.
Van Winkle, J. (2002). Addition of insect repellent during rinse cycle: google patents.
Van Winkle, J. (2004). In fabric softener: google patents.
Vigneshkumar, M., & Vijaykumar Vediappan, M. K. M. (2012). Repellence effect of microencapsulated citronella oil on treated textile fabrics against *Aedes aegypti* mosquitoes. *Hitek Journal of Bio Sci and Bioengg, 1*, 1–7.
WHO. (1996). Testing of insecticides.
Yang, P., & Ma, Y. (2005). Repellent effect of plant essential oils against aedes albopictus. *Journal of Vector Ecology, 30*(2), 231.
Yates, A., N'Guessan, R., Kaur, H., Akogbéto, M., & Rowland, M. (2005). Evaluation of KO-Tab 1-2-3®: a wash-resistant'dip-it-yourself'insecticide formulation for long-lasting treatment of mosquito nets. *Malaria Journal, 4*(1), 52.