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Current developments in (Malaria) mosquito protective methods: A review paper

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Abstract
The mosquito vector spread a variety of diseases. It is responsible for several million deaths and hundreds of millions of cases every year and has an adverse effect on public health. There are different types of mosquitoes which bite at different times of the day and spread different viruses. The paper highlights the causes of malaria and their prevention methods in detail. Malaria is a major health problem for children and pregnant women. It has been highlighted as a major cause of death for children below age of five years. More than two-thirds of all malaria deaths occurs in children below age of five years. In India, malaria has been a problem for centuries. India has the highest number of morbidity and mortality rates of malaria after Africa. A number of protective and preventive methods/techniques are adopted against this vector. A common method of preventing mosquito bite(s) is the use of repellents of synthetic and natural origin. The merits and demerits of synthetic and the natural mosquito repellents have been critically assessed. Malaria is preventable and not supposed to be a deadly disease if treatment is available, which is not the case for many of the underdeveloped areas. These regions bear a disproportionate burden of the disease, mainly due to non-adoption of prevention measures. Microencapsulation is one of the techniques to extend the longevity of the repellents used for prevention of mosquito bites. The review briefly assess the various aspects of microencapsulation technique in the mosquito-repellent fabric domain. There is a need for increased research and development of (natural and synthetic) mosquito-repellents.

Keywords: malaria, WHO, underdeveloped countries, natural repellents, synthetic repellents

1. Introduction

Mosquitoes bite during day or night. They live indoors and outdoors and begin to search for warm places as temperatures drop. Some of them hibernate in enclosed spaces to survive the cold temperatures. The season for the mosquitoes generally starts in summer and continues till fall. Bite(s) from a mosquito can be more than just annoying or itchy. It can make one sick and in rare cases can cause death [1]. Deforestation in the Amazon basin has resulted in an increase of 48% in the malaria incidences [2]. Globally, there are about 2.5 billion people who live in malaria endemic zones [3]. According to WHO (2016), about 50% of world's population is at risk of malaria. Malaria, however is a preventable and curable disease. Increased efforts have resulted in reducing the malaria burden in many areas. From 2010 to 2015, malaria incidence among populations at risk has reduced by 21% globally. Malaria mortality rates among populations at risk has also reduced by 29% globally among all age groups, and by 35% among children under 5 years of age [4]. As of 2015 there were 91 countries in which the transmission of this disease was going on. More than 200 million people were infected and half a million died from the disease. More than 90% of such cases were from Africa [5].

There are different types of mosquitoes which bite at different times of the day and spread different viruses. The intensity of transmission will also depend upon the vector, the human host, the environment [5]. For example, *Aedes aegypti*, *Aedes albopictus* spread chikungunya, dengue and zika viruses. Primarily they bite during daytime, but they can also bite at night time. Likewise, Culex species spread the West Nile virus and bite between evening to morning. Diseases transmitted by mosquitoes include, malaria, West Nile virus, dengue, chikungunya, filariasis, yellow fever, epidemic polyarthritis, Rift Valley fever, tularemia, dirofilariasis, Japanese encephalitis, Saint Louis encephalitis, Western equine encephalitis, Eastern equine encephalitis, Venezuelan equine encephalitis, Ross River fever, Barmah Forest fever, La Crosse encephalitis, and Zika fever [6]. Viruses like Eastern equine encephalitis (EEE) and Western equine encephalitis (WEE) have been identified in USA. Wikipedia mentions about occurrence of myiasis in humans or other mammals where mosquitoes can be the intermediate vector agents. Some species of mosquito can carry the filariasis worm. The viral diseases dengue fever, yellow fever, zika fever and chikungunya are transmitted mostly by *Aedes aegypti* mosquitoes. Other species of *Aedes* as well as *Culex* and *Culiseta* are also involved in the transmission of disease [7].

Malaria parasite is carried by the female mosquito of the genus Anopheles. Four different species of protozoa that cause malaria are *Plasmodium falciparum*, *Plasmodium malariae*, *Plasmodium ovale* and *Plasmodium vivax*. It is considered a major health problem in 106 countries. Estimating the exact number of deaths for malaria have been a difficult task because of the limitations in the available diagnostic resources in the developing countries, especially in the rural areas [8]. Malaria is a leading cause of premature mortality, particularly in children under age of five years. In 2012 the estimated cases of malaria stood at 207 million with more than half a million deaths [9]. More than two thirds of all malaria deaths occurs in children below 5 years of age [5]. According to CDC, many countries with malaria are among the poorer nations, thus the disease brings the vicious cycle of poverty and the disease occurrence.

In India, malaria has been a problem for centuries. At the time of independence about 23% of the population was found to be infected with malaria [10]. To combat this menace the National Malaria Control Programme was launched in 1953. Encouraged by the success of this programme it was changed to a more ambitious Programme (National Malaria Eradication Programme) in 1958. After 1961 the programme suffered repeated setbacks and the malaria cases started to rise again. In 1976 the highest number of malaria cases (6.45 million cases) since resurgence were recorded. Then came the Urban Malaria Scheme (UMS) in 1971-72 and the Modified Plan of Operation (MPO) in 1977 which improved the situation for the coming 6 years. The *P. falciparum* Containment Programme (PfCP) launched in 1977 helped in reducing falciparum caused malaria in the areas where this programme was operated but its general spread could not be contained. In the 1990s malaria returned with new features which were not witnessed earlier like, the vector resistance to insecticide(s); extensive vector breeding grounds created principally by the water resource development projects, urbanization and industrialization; resistance developed by the *P. falciparum* to chloroquine and other anti-malarial drugs; human resistance to chemical control of vectors etc. [10]. According to the WHO, World Malaria Report 2017, in 2016, more than half of the population was at risk of malaria. India accounted for 6% of malaria cases, 6% of the deaths, and 51% of the global *P. vivax* cases. The Report estimates the total cases in India at 1.31 million (0.94-1.83 million) and deaths at an average figure of 23990 (1600-46500). The data produced by the NVBDCP till September 2017 shows a decline in the overall endemicity of malaria in the country.

2. Protective methods

The breeding of mosquitoes can occur in the smallest of the water body. They can breed in puddles by the roadside, in water that accumulates in furrows/ gardens/ fields, in street and house gutters, in the holes in rocks, in hollows of trees, in pitcher plants, anywhere which permits a gill of water to stand. For doing away with mosquitoes permanently in the artificial water bodies, there is a need for a modern closed system inaccessible to mosquitoes. Other than eliminating the breeding places for the mosquitoes or using preventive medicine against malaria, some biologists have suggested ideas like eradicating the disease causing mosquitoes, but there is no strong evidence to support the same [11]. The other important methods of protection are discussed in the following sections.

1) Destruction of larvae/pupa/egg or the winged insect

The destruction of the mosquito can be classified into 2 stages, those directed against the egg, larva or pupa and those directed against the winged insect. For the extermination of the mosquitoes the best method is to destroy their breeding places so that they do not get to multiply. Both individual and community level efforts are required to achieve this. It is important to know breeding places and the breeding habits of the mosquitoes to suppress them successfully [12].

However the above way to eliminate the breeding places of the mosquitoes cannot be that successful in the developing world because of water supply and replacing water becomes a difficult task. There are some techniques which could be helpful like, Open Water Marsh Management (OWMM) is a technique which involves the use of shallow ditches to create network of water within the marshes and connecting the marsh to a canals. This drains the mosquito habitat and lets in fish which feeds on the mosquito larvae. Simply predators access to mosquito larvae can result in long-term mosquito control. It reduces the need for other mosquito control methods like pesticides. OWMM is used in eastern and western coasts of the USA [13]. Rational Impoundment Movement (RIM) is another mosquito management technique which involves the use of large pumps and culverts with gates to control the water level in an impounded marsh. Water is pumped into the marsh in late spring or summer to prevent mosquitoes from laying eggs on the soil. The marsh is allowed to drain in fall, winter and early spring. Gates in the culverts are used for the purpose of entry and exit of the fish, crustaceans, etc. RIM is used in great extent in the east coast of Florida [11].

The use of natural enemies to manage mosquito population is known as “biocontrol” or biological control. The use of biological control to control the mosquito population have shown promising results, however, this approach needs elaborate research [14]. Research has also been reported based on experiments conducted for biological control of mosquitoes using genetic methods. Integrated Pest Management (IPM) is the use of the environmentally appropriate method(s) to control pest population. Typical mosquito-control programs using IPM first conduct surveys, in order to determine the species composition, relative abundance, seasonal distribution of adult and larval mosquitoes, and then a control strategy is defined [11].

An oil drip or oil drip barrel has been used as a common non-toxic mosquito control measure [15]. Control of larvae can be accomplished through use of contact poisons, growth regulators, stomach poisons (including bacterial agents), and biological agents such as fish, fungi etc. [16]. Sogan et.al. (2018), talks about castor oil (Ricinus communis) based nano-emulsion developed for large field breeding mosquitoes like

Anopheles culicifacies [17]. Abebe *et al*. (2018), have documented the use of Oreochromis niloticus and Tilapia Zilli fishes for control of mosquito larvae in Ethiopia and have reported a significant reduction of about 92% in their field experiment [18].
Spraying insecticides is a common method of killing adult mosquitoes. Formerly DDT was commonly used insecticide throughout the world. It has now been banned in most of the developed countries [19].

2) Preventing mosquito bites
When the coverage of vector control interventions in a specific area is high enough, then a measure of protection will be conferred across the community [5].The world has seen a re-emergence of mosquito borne viruses caused by the *Aedes aegypti* mosquito like, zika virus, chikungunya virus, dengue fever and yellow fever. This re-emergence have been at a faster rate and over a wider geographical area. This could be due to expanding global areas, mosquito's ability to adapt to the urban atmosphere, disruption of traditional land use and the inability to control expanding mosquito populations [20].
Prevention strategies for protection against mosquitoes involves vaccination to improve the immunity of the hosts. Some of the diseases caused by a mosquito do not have a vaccine. The other methods of prevention focuses on,

- Reducing the adult mosquito populations,
- Controlling mosquito larvae, and
- Protecting individuals from mosquito bites.

The first two points have been covered in the earlier section. This section revolves around the third point. The protection method is decided based on the affected area and the type of the mosquito vector. One of the common ways of preventing mosquito bite is using a repellent. The EPA registered insect repellents are generally proven to be safe and effective. It is important to use these repellents as directed. WHO recommends protection for all people at risk of malaria with effective vector control. It also recommends ITNs and IRS to be effective for a wide range of circumstances [5]. Some of the commonly used mosquito prevention methods are discussed below. Here we have concentrated on methods which are not in direct contact with human body, therefore antimalarial drugs and the development of vaccines against malaria have not been focused.

i. Untreated nets and ITNs (Insecticide treated mosquito-nets)
ITNs have become popular in the last decade for protection against the malaria vector. Field use of pyrethroids at concentrations recommended for treatment of mosquito nets (taking care of precautions) poses little or no hazard to people treating the nets or to the users of treated nets. Many domestic users of pyrethroid 'home treatment kits' or ITNs may not be fully literate, therefore it is essential that 'instructions for use' should be portrayed via pictograms with supporting text in appropriate local language(s) [21]. Along with health education messages, net distribution also needs to be accompanied with a community participation programme. ITNs are at the forefront of preventing mosquito bites causing malaria. Their prevalence in the sub-Saharan Africa has grown for use against the mosquito vectors Anopheles gambiae and Anopheles funestus which carry malaria. As Anopheles gambiae feeds indoors and rests indoors after feeding, ITNs have been successful in interrupting their feeding pattern. WHO recommends ITNs treated with pyrethroid class of insecticides. There has been some concern about the ITNs with respect to the mosquitoes developing resistance against them. About 27 sub-Saharan African countries have reported Anopheles vector resistance to the pyrethroid insecticides [22]. The ITN becomes ineffective after a certain number of washes, therefore re-impregnation is important. It is in this context that the Long-lasting Insecticides Treated Nets (LLINS) could be helpful. Many of the populations at risk of malaria are extremely poor and thus there is also a need for ITN's being provided free of charge. This will also ensure equal access.
The use of bed-nets or mosquito nets have been a common practice of protection against the mosquitoes. They provide a barrier to the mosquitoes. It is used by about 65% of the West-African countries for protection against mosquitoes [23]. A study done by Bradley *et al* (1986) in Gambian children show that bed-nets have strong protective effect against malaria [24]. The paper suggested further investigation of bed-nets as malaria control means in Africa. The problem that comes with untreated nets is that the person sleeping under the net is only protected unlike the treated ones, which is beneficial for the nearby person also.

ii. IRS (Indoor Residual Spraying)
WHO recommends IRS as a strong method to rapidly reduce malaria [5]. IRS is another widely used mode of protection from the mosquito vectors. Residual insecticides are sprayed indoors to control mosquitoes. It helps in killing the mosquitoes when they are resting on walls and ceilings after feeding. It can be combined with spraying the exterior of the building to reduce the number of mosquito larvae and number of adult mosquitoes. It is effective for 3-6 months depending on the type of insecticide formulation used and the type of surface it has been sprayed on [5]. For some type of temporary shelter, ITN's might not be a suitable mode of protection, in such cases IRS becomes a preferred option. People who are avert to the use of chemicals might not prefer using IRS.

iii. Mosquito traps
Another mode of controlling mosquito populations is the use of ovitraps or lethal ovitraps, which provide artificial breeding spots for mosquitoes to lay their eggs and then trapping the eggs (and mosquitoes) [25]. Some of the newer traps uses carbon dioxide etc. to mimic human body smell. Efficiency of such traps is not well documented. One such trap (called the human decoy trap) developed by the University of Greenwich, the UK, reported about collecting more mosquitoes compared to the human landing catches. It uses the right shape and temperature to encourage mosquitoes to land on its surface. Such traps could also be used for keeping away the mosquitoes from the houses during night.

iv. Chemicals/natural agents which repel or kill mosquitoes
Repellents are substances that act locally or from a distance, deterring an arthropod from flying to, landing on or biting human or animal skin (or a surface in general) [26]. Vapor layer produced by repellants when applied on skin or clothing has either an offensive smell or taste which makes a person unattractive for feeding and therefore repels the mosquito [27]. Some of the effective synthetic repellents are, DEET,

Permethrin, Allethrin and Malathion [27]. IR3535 is a synthetic repellent available in the market. Picaridin is another synthetic compound which was made to resemble the natural compound piperine, found in group of plants used to produce black pepper [28].

Extracts from roots, stem, leaves, fruits, flowers and seeds of diverse species of plants can exhibit mosquito repellent properties [29]. Plant-based repellents are generally found to be less effective than DEET [30]. N,N-diethyl-3-methylbenzamide (DEET) is the most effective and studied insect repellent. DEET has a remarkable safety profile of 40 years of worldwide use, but it has been found to be toxic [30]. Among the plant based essential oils the most cited ones are, Cymbopogon (lemongrass) spp., Ocimum spp. (basil) and Eucalyptus spp. [31]. Trongtokit *et al*. have shown that undiluted oils of *Cymbopogon nardus* (citronella), *Pogostemon cablin* (patchuli), *Syzygium aromaticum* (clove) and *Zanthoxylum limonella* (Thai name: makaen) provided repellency of about 2 hours against *Aedes aegypti* mosquitoes [32]. Shukla *et al*. (2018) mentions about mosquito repellents derived from Basil (*Ocimum basilicum*), oils of Castor, Cedar, Clove, Fennel, Citronella , Eucalyptus, Neem, Rosemary and Catnip oil of Nepeta species having nepetalactone, Celery extract (*Apium graveolens*) and *Solanum villosum* berry juice [33]. These natural resources have the added benefit of smelling good. The natural mosquito repellents work by masking the human scent. Oils from the citronella group are the most tested ones to access their repellent activity [33]. Citronella, lemon and eucalyptus oils works as repelling agents for the insects and have been registered by EPA for use as skin treatment, these natural products have been frequently used for their low toxicity, customer approval, comparable efficacy, etc. [34]. Grieco *et al*., reported that the primary action of DDT is repellent, alphacypermethrin is irritant, and dieldrin is only toxic [35]. They have further proposed that the repellents can be classified according to these three characteristics. These repellents could be incorporated into a wide range of products. In the present market a variety of mosquito repellent products like cream, lotion, sprays, wipes, fabric roll on, bracelets, portable repellers, etc. could be spotted.

v. Mosquito protective garments/textiles

Mosquito repellent fabrics have been attempted by using fine mesh designs. Textile treated with the mosquito repellents is a revolutionary innovation for protecting humans from the bites of the mosquito and thus protecting them from mosquito-borne diseases. Textiles are treated with a mosquito repelling agent without destroying the characteristics of the fabric [27]. Fradin *et al*. (1998) have shown that DEET-based repellents can be applied in combination with permethrin-treated clothing to provide about 100% protection from mosquito bites [30].

3. Problems with the synthetic repellents

Chemical repellents available in the market today have been formulated so that they maintain the safety profile, but their toxicity remain a concern. It can render rashes, eye irritation, swelling etc. Natural repellents are therefore preferred over the chemical repellents [33]. The plant based repellents are also safe and trusted mode of prevention [36]. They are generally recognized as safe by the FDA [32]. The extraction technique of these natural repellents is easy and therefore economically viable. A search of the SCOPUS database for articles published in between 1976 to April 2008, with terms relating to repellency of essential oils demonstrated an increase in the interest on finding natural alternatives against their synthetic counterparts, due to the rise in the number of publications every year (from 56 in 1976-2000 to 125 in April 2001-2008) [31]. For 2008 to 2017 with keywords “repellency of essential oils” SCOPUS gave a total of 424 search results, which is in line with the earlier findings of Quintana *et al*.

DEET was given a “Low toxicity” category for Acute Oral, Dermal, Primary Eye Irritation and Primary Skin Irritation and a “Very Low Toxicity” category for Inhalation [37]. Another quite common synthetic repellent permethrin has also been classified by the EPA as a likely human carcinogen, based on reproducible studies on mice [38]. It is highly toxic to fish and other aquatic animals. These toxic behaviour from the synthetic repellents also led to the growth in the demand of the natural repellents.

Another important problem with the synthetic repellents is the mosquitoes developing resistance to them. Resistance to insecticides among mosquitoes that act as vectors for malaria (*Anopheles gambiae*) and West Nile virus (*Culex pipiens*) emerged more than 25 years ago in Africa, America and Europe [39]. Ranson *et al*. (2011) have mentioned about pyrethroid resistance in African *Anophelene* mosquitoes [40]. Pyrethroids are the only class of compounds currently recommended for ITNs or LLINs. Mosquito resistance to pyrethroids has emerged in many countries, fortunately this has not reduced the efficacy of LLINs [5]. It is in this context that the value of natural mosquito repellents increases. The natural repellents will inherently bring with them variability depending on their variety, location etc. and thus it will take longer for the mosquitoes to develop resistance against them. There are a number of natural repellents which needs further research on their potential to repel mosquitoes. Simon and Akeju (2017) have shown that citrus peel and extracts could be used in malaria vector control strategies [41]. Read *et al*. (2009) have concluded that the linkage between agricultural applications and public health use of insecticides deteriorates their public health use aspect. The agricultural use is majorly responsible for the vectors developing resistance to the insecticides. Thus, developing separate health use vaccines would promote the pharmaceutical industry to invest more in malaria. The limited use of the insecticide would also make it easier to take it off the market in case of any negative side-effects popping up [42].

In the Indian subcontinent, initially some of the mosquitoes, including *An. culicifacies*, the major rural vector of malaria, developed resistance against DDT pesticide. Similar case happened with the pesticide malathion. Another cause of concern is populations of malaria vectors developing resistance to anti-malarial drugs [43].

4. Malaria in the underdeveloped areas

Malaria is not supposed to be a deadly disease if treatment is available, which is not the case for many of the underdeveloped areas. Packard (1997) has mentioned the below in his paper published under the Malaria and Development issue [44].

“Malaria eradication was a product of a postwar vision of economic and social development and needs to be examined in this context. Many of the problems that plagued eradication efforts flowed from this intense association between eradication and development."

Baeza *et al*. (2017) have shown that the increase in malaria transmission occurs because of the asymmetry between relatively fast ecological changes in the transformed landscapes and slower pace of investment in malaria protection. Economic development and revamping of the infrastructure can push malaria from its transition phase to the decay phase [43].

India has highest number of malaria deaths after Africa, with an estimated 200,000 deaths annually. The greatest burden of malaria in India is borne by the most backward, poor and remote areas of the country. The tribal communities account for 30% of all malaria cases, 60% of *P. falciprum*, and about 50% of mortality associated with malaria. This results in an economic burden of about Rs. 6000 crores per year [45]. The tribal group bear a disproportionate burden of the disease. These tribal areas often bring with them geographical and socio-economic barriers against the malaria control programs which degrades the availability of health facilities.

Many countries with high burden of malaria have weak surveillance systems and thus are not in a position to assess the disease distribution, trends etc. [5].

5. Disadvantages of plant extracts

The plant derived repellents have not been well studied compared to the synthetic ones. The major problem that arises with the natural repellents is their short life owing to their volatile nature [36]. Previous studies have shown that reduction in the repellent effect of these essential oils is attributed to their high volatility, thermal decomposition, biodegradability, and poor physiochemical stability which makes them unstable [46]. There exists a general perception that the materials which are plant based are safe for health, but their use is restricted in the cases where the active compound have been found to cause skin irritation [47].

A number of ways have been explored to increase the efficacy of the natural repellents. Tawatsin *et al*. (2001) have proved that the oils extracted from plant species of turmeric, kaffir lime and citronella grass with addition of 5% vanillin could repel three mosquito vectors for 8 hours, which is equivalent to the repellency provided by DEET [36]. Similar studies of vanillin increasing the efficiency of the natural oils were also done by Rehman *et al*. (2014) and Yang and Ma (2005) [48, 49]. Quintana *et al*. (2010) have suggested that the efficiency of essential oils could be increased by using fixative agents like liquid paraffin, vanillin, salicyluric acid, coconut oil and mustard [31]. Misni *et al*. (2017) suggested that though vanillin incraeses the repellency of pure oil, but its duration is yet to match with that of the synthetic repellent [50]. Likewise, another way to increase the effectivity of these oils could be to use them synergistically. Müller *et al*. (2009) have concluded that geraniol has better repellent activity than citronella and linalool, although both linalool and geraniol are constituents of citronella essential oil [51]. Shukla *et al*. (2018) have used the leaf extracts of lantana, lemongrass, tulsi, calotropis and neem in equal proportion and found that their repellency was enhanced to 5-6 hours from less than 2 hours [33]. Further screening of different blends of these natural essential oils can lead to more repellent combinations.

6. Microencapsulation of the natural oils

Ghayempour and Montazer (2016) have reported that the encapsulation technique plays an important role in finishing of plant extracts on textile substrates [52]. According to Banks *et al*. (2014) there are four main techniques for applying repellents on textiles, absorption, incorporation, polymer coating and microencapsulation [53]. Microencapsulation has come up as an important technique in increasing the efficacy of the natural (essential) oils. Effectiveness of the essential oils and their protection time can be increased by using formulation techniques like microencapsulation and nano-emulsion [48]. Microencapsulation is a widely used technique in the domain of encapsulation of essential oils [54]. It is a process in which small capsules of useful properties are made using tiny particles or droplets surrounded by a wall material. The material inside a microcapsule is known as the core material whereas the wall is called a shell, coating, or membrane. Usually, microcapsules have diameters between a few micrometers and a few millimeters. This technique is widely used in textile finishing. Encapsulation has made incorporation of therapeutic oils, moisturizers, and insecticides into fabrics easier. This technique has a vast application in various fields like Textile Finishes, Agro chemicals, Industrial chemicals, Food additives, Pesticides and Herbicides, Sealants, Cosmetics, Flavours and Essences, Nutraceuticals, Pharmaceuticals and Adhesives [55]. Functional properties can be imparted to the fabrics by microencapsulating the core material. This core material can be a substance having a special function to perform for the fabric. In herbal finishing of textiles, herbal extracts are used as "core material" along with the wall material to give a microencapsulated finish which is more durable compared to other finishing processes. The wall material can be a chemical compound like gelatin, sodium alginate, gum acacia etc. The microencapsulated herbal extracts were more effective when tested for anti-microbial activity and wash durability of up to 20 washes [56].

In the present context the core will be an essential oil, or a mixture of essential oils which is the repelling agent for the mosquitoes. The core will then be surrounded by the wall material and a coating agent (if required) will help in coating these microcapsules on the fabric. Misni *et al*. (2017) have shown that microencapsulated formulation show better repellency than non-microencapsulated formulations [50]. According to a study by Rehman *et al*. (2014) encapsulation of citronella essential oil increased its residual time [48]. A study by Ramya and Maheshwari (2014), have shown that microencapsulated extracts of *Andrographis paniculata*, when applied on fabric to impart mosquito repellency finish, gave good mosquito repellent activity of up to 30 washes [57]. A study by Specos, stated that textile treated with microencapsulated citronella provided higher and longer lasting protection against mosquitoes compared to fabric sprayed with ethanol solution of essential oil [58]. On similar lines, a study done by Anitha *et al*. (2011), have shown how microencapsulation increases the repellency of lemongrass oil coated polyester fabric [29].

Microencapsulation increases the stability of the encapsulated material(s) by providing it protection from the immediate environment. It also helps in the controlled release of active compounds. It thus have the potential to arrest the volatility of the essential oils by introducing slow release of oils. Recent studies (from 2007 onwards based on Google Scholar) on microencapsulated essential oils coated fabric (refer Table) are shown below.

Table 1: Summary table of the studies on microencapsulated essential oil coated fabric

Author(s) (year)	Core	Types of fabric	Application technique	Evaluation type and/or efficiency
Geethadevi and Maheshwari (2015) [60]	Microencapsulated thyme oil, cypress oil and grapefruit oils in 2:1:1 ratio 3 shell materials: sodium alginate, *Acacia arabica* and *Moringa oleifera* gum	bamboo/tencel 50:50 blended fabric	Exhaustion method	Durability of upto washes using *Moringa oleifera* gum
Ramya and Maheswari (2014) Tamil Nadu	Microencapsulated *AndrographisPaniculata*	Scoured, bleached and dyed 100% knitted cotton rib	Pad dry cure	Modified excito chamber
Vigneshkumar and Vijaykumar Vediappan (2012) [61] Tamil Nadu	Microencapsulated *Cymbopogon citrosa*/citronella	Scoured and bleached cotton fabric	Direct coating	Cage analysis field analysis
Sumithra and Vasugi (2012) [62] Tamil Nadu	*Ricinus communis, Senna auraculata, Euphorbia herita*	Blended denims	Pad-dry-cure	Modified excito chamber, good efficiency of finishes even after 30 industrial washes
Solomon *et al*. (2012) [63]	Microencapsulated citronella oil	Ointment bases		Encapsulation efficiency of 60% under optimized conditions
Anitha *et al*. (2011) Tamil Nadu	Microencasulated lemongrass oil with sodium alginate as the wall material	100% polyester	Pad-dry-cure	Modified excito chamber 92% (unwashed fabric) 84% (after 15 washes)
Specos *et al*. (2010)	Microencapsulated citronella oil for mosquito repellent finishing of cotton textiles	Cotton fabric	Pad-dry-cure method	>90% repellency for 3 weeks
N'Guessan *et al*. (2008) [59]	Microencapsulated DEET	Mosquito bed-nets		formulation repels, inhibits blood-feeding and kills mosquitoes for a period of at least 6 months under laboratory conditions

Selection of appropriate shell material is an important aspect of microencapsulation of essential oil(s). Geethadevi and Maheshwari (2015) compared three different wall materials for the same essential oil (core) combination. *Moringa oleifera* clearly stood out in comparison to sodium alginate and *Acacia arabica* [60]. The choice of wall material is important as it influences encapsulation efficiency and stability of microcapsules. An ideal wall material should not be reactive with the core material; should have the ability to seal and should maintain the core inside the capsule and should be able to provide protection to the core during adverse conditions [54]. Based on literature commonly used encapsulating material for essential oils are gelatin, sodium alginate, gum acacia etc.

In today's world of developing technologies, this technique of microencapsulation is applied in a number of fields. It has become a prominently effective technique enhancing the property imparted to the fabric and assuring its durability. There are certain modern microencapsulation techniques like fluidized bed technology using which the controlled release possibilities can be made considerably more versatile. These techniques require more study and research and are now in the beginning stage. Efforts in research and development could also help in developing new wall materials for improving and optimizing the existing methods of encapsulation.

7. Conclusion

Reducing the number of mosquitoes can help in prevention of malaria, but it is important to consider the cost, effectiveness and after effects of vector control strategies before implementing them. The earlier works suggests a need for regulatory standards for the natural repellents to ensure their quality and effective means of application. There is also a need for increased research and development of (natural and synthetic) repellents. Microencapsulated essential oil coated fabrics have come up well in laboratory studies, there is a need for more field testing of such fabrics.

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