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NATURAL VS. SYNTHETIC REPELLENTS ON TREATED CLOTHING: ADVANTAGES, CHALLENGES AND THEIR EFFICACY

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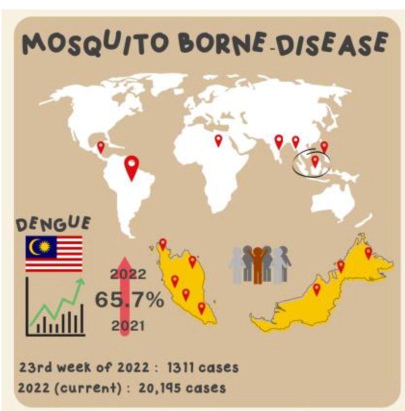
Graphical abstract



Abstract

Arthropod-borne viruses have become a major threat to human health worldwide. The implementation of personal protection through clothing is necessary to avoid insect bites, especially for military operations and public health emergencies. Development of synthetic repellents in clothing impregnation has been well-established whilst, numerous studies regarding the application of essential oils on textile substrates have been carried out to develop their use as an alternative to synthetic repellents. The present review attempts to give a general overview and summarize the current technology used in treated clothing, as well as the advantages, challenges, limitations, and factors that may affect the performance of synthetic repellents and essential oils in textiles. Current research trends in developing more effective repellents from essential oils are also summarized.

Keywords: Essential oils, DEET, mosquito repellent, Permethrin, textile

Abstrak

Virus bawaan arthropod merupakan ancaman utama kepada kesihatan manusia sejagat. Implementasi perlindungan peribadi melalui pakaian adalah perlu bagi menghindar gigitan serangga, terutamanya melibatkan operasi ketenteraan dan kesihatan awam. Kemajuan penggunaan penghalau sintetik pada pakaian telahpun mencapai tahap mapan sementara, beberapa kajian tentang aplikasi minyak pati ke atas substrat tekstil telah dijalankan untuk membangunkan penggunaan minyak pati sebagai pengganti kepada penghalau sintetik. Artikel ini merumus dan meringkaskan secara umum tentang teknologi terkini yang digunakan dalam rawatan pakaian dan kelebihan, cabaran, limitasi serta faktor-faktor yang memberi kesan kepada prestasi penghalau sintetik dan minyak pati terhadap tektil. Ringkasan tentang aliran penyelidikan terkini dalam membangunkan penghalau daripada minyak pati yang lebih efektif juga diringkaskan.

Kata kunci: Minyak pati, DEET, penghalau nyamuk, Permethrin, tektil

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1.0 INTRODUCTION

There is a growing research interest in developing repellents either from synthetic or natural-based product for the protection against the arthropods-borne viruses (arboviruses) due to the alarming substantial rise in the number of cases associated with the infection. Arboviruses such as yellow fever, dengue, Zika and West Nile viruses are disseminated by the blood-feeding arthropod vectors to humans and become global incidence that millions of people have been infected by mosquito-borne and tick-borne viruses [1]. Therefore, research in development of effective methods for the humans to help avoid insect bites and the safe medicinal to be used against the arboviruses are intensified since neither efficient vaccines nor specific drugs against these viruses has been developed to obstruct their dissemination.

Clothing is one of several methods that can be used to help avoid noxious insect bites where fabrics can operate as a physical barrier between human skin and the arthropods however, it provides only a short-term protection. A recent progress in clothing with improvised function have been develop where the textile materials such as cotton, polyester and mixed fabrics are treated with an insect repellent. By utilizing these materials, an effective textile with mosquito repellent compound may be demonstrated to have numerous beneficial features. The practicality of insecticide-treated clothing is viable and could easily integrate into daily life routine; this can be observed by the increasing numbers of treated-clothing users which consist of agricultural and wildlife groups, commercial companies, militaries and even school children [2]. Simulation data amongst the school children in Thailand depicted that the dengue cases may potentially be reduced by up to 50%, which also emphasizing the prospect of insecticide-treated clothing in preventing dengue transmission [2].

Ideally, the features of a treated-clothing must be safe, effective and possess long-lasting effect that could withstand several cycle of regular washing at a reasonable price [2]. Differences in the outcomes could be owing to many factors and by identifying these factors such as appropriate textiles, repellence substance and the best method for treating permethrin materials will result in achieving the desired product while remain as environmentally safe. The objective of this article is to review and summarize the advantages, differences and limitations encountered using chemical-based and herbal-based repellents, specifically as mosquito repellent. In addition, several current trends in developing more effective mosquito repellent from plant-based essential oils are also described. The articles used for this review were obtained by searching until April 2022 on major databases such as Scopus, PubMed and Web of Science, with "synthetic repellent", "essential oils", "repellent/repellency", "treated clothing" as keywords.

2.0 TREATED CLOTHING USING SYNTHETIC COMPOUNDS: METHODS OF APPLICATIONS, DURABILITY AND PARAMETERS INVOLVED

Malaria is a serious health concern amongst the military personnel and their family members, especially in tropical area and literatures reported that most of the soldiers died due to the disease rather than the military wars [3]. Poor hygiene and vulnerable to arthropods areas are one of the contribution to the infection, which then the infected soldiers may potentially cause new outbreaks once they return to their own country [3]. Development of an effective and long-lasting mosquito repellent has become necessary since the World War II to help the military avoid the bites. Dimethyl phthalate was among the first reported synthetic repellent to be effective against the house and stable flies [3], followed by the discovery of dimethyl carbate. Later in 1954, one of the best quality of synthetic repellent in mosquito control, diethyltoluamide, DEET has been developed and widely used to protect the service personnel [4]. The most practical method to protect the military troops was by impregnated-clothes containing 75% DEET formulation, which was later replaced by permethrin [5] that was found in United Kingdom, 1970s by the National Research & Development Corporation. The use of clothing impregnation is recommended by the World Health Organization and the Centers for Disease Control and Prevention and, permethrin-treated military uniforms was preferably chosen due to its efficacy against wide range of arthropod and low toxicity [6 - 7] uniforms have been adopted as the standard clothing repellent since 1990 and with the concurrent used of permethrin-treated uniforms and DEET on skin, proper wearing of the uniform may provide almost 100% personal protection against vectors of disease [7 - 8].

Permethrin impregnated clothing are on the market and commercially available; interest in developing techniques of impregnated fabrics technology using synthetic compounds are increasing and currently, the recognized treatment techniques are: i) absorption method i.e. immersion method using hand dipped in permethrin water emulsion and shade-dried at room temperature, ii) pressurized spray method where the emulsion were sprayed directly towards the exterior surface of clothing with different permethrin formulations, iii) microencapsulation techniques and iv) polymer-coated i.e. factory impregnated using proprietary chemical and treatment process. The idea of treating the exterior surface of clothing was initiated from the absorption technique, whilst other methods were developed to improvise the residual efficacy of synthetic repellent under conditions like washings, wearing and heat exposure as these are amongst the parameters which commonly contribute to the elimination of insecticides from clothes and consequently affect the efficacy of treated clothing. Many literatures reported on their effectiveness and withstands against repeated launderings however, there are also articles suggesting that the treated clothing may provide only short-term protection due to effect of the factors mentioned. In this section, we will discuss on the performance of different impregnation fabric treatment techniques against several parameters that may affect the durability of treated clothing using synthetic insect repellent.

2.1 Washings and Methods of Treated Clothing

Different durability of insecticide-treated clothing depends on the methods of washing. Sukumaran *et al.*, 2014 reported that by using immersion method, the repellency of mosquitoes towards impregnated sleeves and the mortality rate of landed mosquitoes were reduced. After first washing, the percentage of mosquitoes landed was 34% and remained similar at ~ 51% of mosquitoes landed on the sleeves, even after 55 cycles of washings. Whereas for control sleeves, the percentage of mosquitoes landed for control sleeves was lower, ~ 32%. Laboratory studies on permethrin-treated fabric samples of Indian army uniforms indicated that more than half of the initial permethrin residue was lost after 5 washings, which also portrayed less efficacy against mosquitoes [6]. It was also reported to suggest scheduled retreatment of permethrin after the fifth washings to ensure that the treated uniforms are constantly effective against mosquitoes [9]. Similar results were reported by Ghamari *et al*., 2019 that for fabrics treated by permethrin emulsion exhibited more than 80% permethrin loss after 5 cycle of washings, and after 50 launderings, 100% of permethrin loss was observed [10].

Microencapsulation technique is a method that penetrates individual fibres of the clothing which give the effect of longer lasting release of insecticide over time. Its average knockdown performance reported was lower than hand dipped method however, by comparing results in knockdown and mortality rate of mosquitoes against number of washing cycles, microcapsule-treated fabrics exhibited higher knockdown percentage due to great depreciation of permethrin residual showed by hand dipped method [2]. Microencapsulation may leave less insecticide effect on the surface of clothing which clarify the lower repellency and knockdown rate observed however, in the longer term, the efficacy of repellent may be maintained even better than the factory dipped clothing. Reports have shown that after 50 cycles of launderings, the knockdown rate at 60 min was reported similar with factory impregnated method ~ 40%, whilst no knockdown was observed for hand dipped method [2, 10]. Potentially, microencapsulated-treated clothing may offer effective treated clothing after the factory impregnated clothing type.

Of all the methods in treated clothing, factory impregnated clothing using polymer coating give the best protection and durability against number of washings, and environment condition. Treatment evaluation showed that factory impregnated polymer coated uniforms produced a knockdown of 96.5% after 1h exposure whilst repellency evaluation of bite and landing protections at 79.9% and 40.9%, respectively [2]. Ghamari *et al*. (2019) reported that the technique exhibited higher mortality rate compared to other methods and similar observation has been carried out by Faudel and Undelhoven (2003) [11] where high persistency of permethrin effect on *Ae*. *aegypti* and *Ixodes ricinus* observed after several launderings. Sukumaran *et al*. (2014) reported that the knockdown and mortality rate of mosquitoes was reported 100% even after 100 cycles of washings compared to immersion method at only up to 25 cycles. Similarly, the 6 months' worn-out uniform impregnated using factory polymer-coated permethrin technique which was supplied to Afghanistan army showed no significant difference in efficacy even after 50 washings [11]; higher residue of permethrin was found on polymer coating method even after 100 washings compared to commercial dip-treatment kit i.e. Peripel 10 and IDA Kit which gave similar quantity of residue after 3 and 6 launderings, respectively.

Repellency evaluation using arm-in-cage test for 1h knockdown depicted that hand dipped permethrin clothing provides good protection at 91.5% compared to microcapsule formulation and commercial factory treatment techniques at 65.5% and 79.9%, respectively [2]. However, considering the necessity of consistent performance with environmental conditions, hand dipped clothing is less appropriate to be used as a long-term intervention which may attributed to non-uniform insecticide coating, unpleasant odour and the change of clothing texture which may affect the performance of the treated clothing as well as on user compliance. Moreover, the method is most convenient to be used by individual users due to regular re-application coverage [2]. Due to this factor, factory impregnated clothing have been reported to possess excellent properties using polymer coating technique due to its sophisticated binding method involving heat and pressure application within the cross-linkage bound between polymer molecules, permethrin molecules and the fabric fibres [10]. Conversely, the lower permethrin persistence in microencapsulation-treated clothing is perhaps due to ineffective binding method of penetration into the individual fibers of clothing which may leave less insecticide available on the surface of the fabrics however, still the longevity of insecticide on fabrics is better and maintained longer than hand dipped or immersion method [2]. Nonetheless, manufacturing of microencapsulation-treated textile was reported to be discontinued due to further investigation on better properties of protection, durability and effectiveness are in progress. Table 1 shows the knockdown rate for all methods of treated clothing.

Of all, commercial factory treatments (polymer coated method) provides the most effective protection at 50 - 100 washings, followed by microencapsulation method at 20 launderings and dipping method at 10 launderings [10, 12]. In the case of worn-out or when the efficacy of uniform/clothing has dropped to the minimum acceptable level, there is no need to re-treat the polymer-coated clothing as the technique has been reported to provide residual protection against arthropods for the life of the uniform/clothing [13]. There was no minimum value of insecticides amount that has been defined for the polymer coated clothing to be re-treated or disposed since the effective dosage is dependent on the vector arthropod [13] plus, it was also reported to produce higher binding efficacy than that of factory-based dipping method. There are reports that confirmed their effectiveness at laboratory scale and field conditions even at a small amounts of insecticides [13]. As for factory-based dipping method, disposal of clothing after several washes or re-application of insecticide using home dipping insecticide kits can be considered as the solution to worn-out clothing. However, it is easier to re-apply insecticide at small scale rather than larger community level on a regular basis, as it requires more frequent reapplication that will consume additional energy and high cost in maintaining the clothing [2].

Table 1 Knockdown rate at different treatment methods

Methods / Parameters	Factory Impregnation	Micro-encapsulation	Dipped Permethrin
Knockdown rate ≥ 50 washing cycles	40 - 100 %	40 %	0 – 25 %
Knockdown rate using arm-in cage test	79.9 %	65.5%	91.5 %

2.2 Environmental Conditions and Ironing Effect

Another parameter that may affect the durability and performance of insecticide-treated clothing is the washing technique used. It is recommended by the WHO to hand wash the permethrin-treated uniforms so as to preserve the residual permethrin quantities of the uniforms and to avoid the mechanical disruption of permethrin polymer layers during machine launderings [10] which may prolong the duration of protection against arthropods vectors. It has been reported that the mortality rate of permethrin-treated swatches decreased from 94.2 – 100% to less than 28% after 2 cold water washes, and the knockdown rate was less than 20% after 3 washes [3] however, the protection rate varied considerably depending on the type of insecticide used. Repeated machine laundering may cause mechanical disruption of permethrin containing polymer layer on the surface of military clothing especially in the field condition [11]. The structure of treated clothing fibres against numbers of washings can be examined using scanning electron microscopy, SEM. The characterisation depicted that military uniform treated using immersion method contained chlorine, oxygen, and carbon in between the fibres and, after several washings, the chlorine content reduced as the number of washings increased which depicted the reduction of permethrin on the military uniforms [14]. The results were in agreement with Faulde *et al*. (2003), where the destruction and reduced amount of cross linkage fibres on the treated fabrics were detected after 100 cycles of repeated launderings. Therefore, hand washing is recommended to preserve permethrin coating and provide better protection in longer duration [3, 11]. Oppositely, DeRaedt Banks *et al*. (2015) discussed that the machine washing method may retain more of residual permethrin compared to hand washing method, with the use of scentless detergent and this has been recommended for hand washing method as well [2].

Ironing is another factor that may provide negative effect on the treated clothing which caused to the decrease in permethrin concentration. Studies reported that for unlaundered clothing, permethrin concentration decrease significantly from 0.119 mg/cm^2 at day 0 to 0.004 mg/cm^2 after 3 months simulated exposure whilst, simulated ironing with 10 cycle of washes resulted to the decreased of 0.001 mg/cm^2 due to the greater amount of permethrin left on the surface of fabric impacted from the harsh and larger volume of water used from the machine washing [2]. The exposure of UV light towards ironed and washed clothing may expedite the reduction of permethrin concentration significantly. Data for one day's simulated experiment showed the reduction of 31.5% and after three months, the permethrin concentration decreased further to 78.1%; the increased exposure of UV light however, gave no effect to the reduction in permethrin concentration, significantly [2].

2.3 Types of Fibres

Different types of fibres in the military uniforms may act differently upon the application of insecticide molecules in physical bonds and penetration DEET [15]. Efficacy of each fibres towards insecticides may vary; for example, Deltamethrin is more effective on cotton fibres, for jute fibres the application of Cyfluthrin is more effective than other insecticides whilst, efficacy of Lambdacyhalothrin on all types of fibres including nylon and polyester are constant [16]. Similarly, no difference detected against different types of fibres for permethrin insecticide. As discussed by Khoobdel *et al*. (2005), the application of permethrin on 6 different types of military uniforms showed no significant difference in protection percent regardless the difference in types of fibres, thickness, and other physical factors of uniforms therefore, the use of permethrin is perfect for any types of clothing materials [17]. Nevertheless, the choice of materials is important with the consideration of its suitability and effectiveness towards insecticide molecules for example for 100% cotton, and 50% cotton – 50% nylon clothing are inappropriate to be treated due to ineffective properties against mosquito biting however, both materials were reported to be effective against weather [18].

3.0 SAFETY MEASURE IN USING SYNTHETIC REPELLENTS

Even though permethrin and DEET have been used for more than 50 years, there has been persistent safety concern on their uses which may result to several issues, and health effect is one of them. The use of synthetic repellent must be within the recommended doses; Novak & Gerberg (2005) reported that extremely high doses of DEET and permethrin application may produce effects that associate with neurological signs and in many instances, increase mortality, especially for individuals with low plasma enzyme activity [19]. Other associated problems which related to synthetic repellents are urticarial syndrome, toxic encephalopathy among children and skin eruption [20]. Therefore, the use of synthetic repellent must be applied within the suggested dose as lower doses have significantly lesser or no adverse effects. Another cause resulting from synthetic repellent is the environmental consequences due to the released of insecticide residual of washing the treated clothing into current and stagnant waters and thus, contamination may occur and endanger the aquatic organism.

Vector control strategies have improved the level of public health, globally however, it could expose to the threat of resistant populations to insecticides [21]. Insecticide resistance arises from mutations of genes that carry the genes resistance and they increase in numbers, with the increasing of generations. Literatures reported that resistance mechanisms from pyrethroid and organophosphate i.e. decreased sensitivity of the target protein and increased metabolic detoxification have been found in sub-Saharan Africa countries [21] which therefore, highlighting the necessity to find the replacements of synthetic insecticides [22 – 28]. Natural plant based essential oils with superior repellent properties have always been considered as the alternative to synthetic repellent. The next sections discuss further on the efficiency, challenges and limitations in realizing plant-based repellent as the best substitute to classical synthetic repellents.

4.0 ESSENTIAL OILS AS THE ALTERNATIVE TO SYNTHETIC REPELLENT: BENEFITS AND CHALLENGES

The use of plant-based repellent has been practiced since many years ago by burning or hanging dried plants or leaves within homes, and later as oil formulations applied on skin or clothes as reported by ancient Greek, Roman and Indian scholars [29]. Indeed, plant-based repellent is still widely used and preferred, and today the trend in using essential oils or natural product is increasing as they are safe, pleasant-to-use and offers environmentally sustainable methods of insect bite protection which can minimize the toxic insecticides residues. Several compounds that have been identified attributable to the repellent properties in essential oils are monoterpenoids, sesquiterpenes and alcohols [1] and in particular, citronellol, citronellal and limonene are the several constituents of many essential oil exhibiting repellent effect [1]; the list of essential oils with repellent properties can be obtained from Agnihotri *et al*. (2018) [20]. The efficacy of plant-based repellents has been extensively reported as well for example, Sukumaran *et al*. (2014) investigated the mosquito repellent effect of essential oils from selected plants i.e. *C. asiatica*, *I. cairica*, *M. charantia*, *P. guajava and T. procumbens* and of all, *I. cairica*, *M. charantia* and *T. procumbens* exhibited high repellency effect at 6% concentration which lasted for more than 5 hours, followed by *C. asiatica* and *P. guajava* lasted less than 2.5 hours; the high concentration of essential oils were reported to contribute to high repellent activity [30].

Despite benefits and advantages of natural repellent, there are several challenges and limitations that need to be reconciled so that their performance can be as good and important as the classical synthetic repellents. The efficacy of natural-based repellent is always debatable due to their short-lived effect of protection; their repellence trends do not last-long as it decays rapidly [31, 32]. However, through numerous researches and technology, the duration of protection can be prolonged. The following chapter reviews and summarizes the limitations/challenges, technology associated in improving their effectiveness and safety of essential oils as repellents.

4.1 Scarcity of Mass Production

While many essential oils have been demonstrated as biodegradable that naturally occur in native plant species, cost-effective and environmentally friendly, one of many issues and challenges that need to be encountered in the implementation and the use of essential oils on a large scale is mass production of uniform variety or crops [33] as typically, native plants are not grown in uniform variety. It has been reported that the composition of essential oil may not be consistent even in the same plant species, which identical chemical composition may hardly achieve [34] due to the obstruction of production at certain level of metabolism. The variable of composition can be the result of physiological development of the plant and degree of maturity, climatic, soil conditions, seasonal changes etc.

Essential oils are concentrated mixtures of volatile organic compounds from plants and due to their volatility, essential oils may be simply extracted using water vapors such as distillation [35] which requires biomass energy therefore, abundant and careful source of repellent plants is vital to avoid difficulties or insufficient unsustainable source of plants materials and cropping practices. However, appropriate system of planting may provide an important source of income for small scale farmers which also may beneficial environmental impact especially using intercropping system to inhibit soil pollution [1, 19]. Some countries like South America, India, Sri Lanka, Kenya, Congo and other malaria endemic countries have commercially grown the plants for essential oil production particularly from the genus Cymbopogon with high capacity of naturally occurring constituent para-methane-3, 8-diol (PMD) which primarily responsible for efficacy and protection insect repellent [36]. Locally planted and production of essential oil would reduce the cost of importation so that they shall be perceived as a consumer-friendly product at a reasonable price.

4.2 Short Duration of Repelling Activity

The most critical consideration for natural repellents is extending the longevity of these effective but volatile products. Generally, natural products provide significant repellent effect but relatively in short period of time due to their high volatility. Essential oils act in the vapor phase therefore, the effect has a tendency to dissipate rapidly, and reapplication is required frequently. For example, in the case of product contains citronella oil, reapplication of every 20 – 60 minutes is needed to sustain the repellency effect. In contrast with synthetic repellent, several DEET formulation provide up to 6 h of whole protection which no natural product can achieve the duration [37]. However, DEET–containing product is not recommended to be use topically and reapplied after the first application which in this case, is the advantage for essential oil that can be reapplied safely compensating the short protection activity [38].

The improved formulations are developed by retaining the active ingredients of essential oil on the skin through the combination with topical formulation of cream- or polymer mixture-based which resulted in long lasting protection [1]. It is important to understand that the topical formulation using cream-based act as the insect barrier, preventing the insect to land or penetrate the skin where barrier compounds are the skin lotions or cream [39]. These barriers, however, need to be field tested with appropriate volatile repellents to established product efficacy and safe with acceptable odour.

Other than that, the use of fixative agents such as vanillin, liquid paraffin and salicyluric acid may as well, prolong the duration of repellent effect; protection time of citronella oil and zanthoxylum pepiritum oil was reported increased to 4.8 h and 2.5 h, respectively when mixed with vanillin where the usual estimated duration of effectiveness for essential oil is estimated between 30 minutes and 2 hours [1]. Fixative agents when combine with microencapsulation produced improvement in the efficacy and longevity of repellents; literature reported that the achievement of geranium oil against *Culex pipiens* was attributed to the microencapsulation formulation based on non-ionic surfactants [29].

Essential oils are highly efficient when freshly applied however, due to their volatility, the shielding effects of repellent often dissipate instantly [40]. It is important to take into consideration that the use of natural repellent product is for general public purposes and not for military or public health emergencies due to entirely different routine and conditions applied [36]. Natural repellent products may not deliver consistent level of protection as they totally dependent on the user or individual parameters including the method of repellent application, frequency of application, the environment of exposure to mosquito bites, the use of personal product which may or may not affect the performance of repellents activity and ecological elements such as wind, temperature, humidity and mosquito species [4]. There are several research findings associated with essential oils summarized in the next section and these technologies are developed to improve the repellent activity of natural based essential oils which may illustrate the future trends of repellent research.

5.0 ESSENTIAL OILS & TECHNOLOGY ASSOCIATED

5.1 Nanotechnology and Patch Formulation

To increase the efficacy of natural repellent, nanotechnology has been widely used via inclusion of plant components as reducing and stabilizing agents in nanoparticle fabrication. The penetration of nanoparticles into the functional system of arthropods will produce disturbance in membrane permeability and the efficacy, size and shape of nanoparticles differ upon on the types of plant used [1] for example, silver nanoparticles using neem were mostly spherical in shape whilst nanoparticles from *Carissa spinarum* leaves were cubical. Involvement of nanotechnology in essential oils could simplify the development process and risks related with energy, temperature and pressure. Patch formulation of essential oil was also found to be efficient as mosquito repellent. Polymeric patch using essential oil based and embedded into ethylcellulose and polyvinylpyrrolidone polymers were found to be effective against *A. albopictus* and safe to be used into the surrounding environment, as well as consumer friendly and cost effective [1]. Future potential in natural repellent product using essential oil is a promising prospect as continuous studies in this field have been intensified for example, research using essential oils as the main component possess with antiviral properties extracted from *Cymbopogon citratus*, *Pelargonium graveolens* and *Vetiveria zizanioides* has been carried out and were evaluated against Ross River virus [1, 41].

5.2 Synergistic Reaction

Literatures reported that improvement of repellent activities of essential oils may be achieved using mixture of multiple essential oils from different plants which leads to a synergistic effect [1, 42]. Several blend oils from different plant sources have been reported to produce higher bioactivity than that of single isolated component. For example, blend oils from *L. cubeba*, *L. salicifolia* and *M. leucadendron* produced stronger repellent response against *Ae. Aegypti* [1, 42] and mixtures of sesquiterpenes and monoterpenes in different essential oils were reported to efficiently boost repellent effect compared to that of sum of individual oil [43]. However, detailed studies on compositional complexity containing major and minor components of the essential oils need to be carried out as not all mixture give rise to the repellent efficacies. Berenbaum, (1985) reported that low percentages of minor constituents in essential oils may function as stimulants that contribute to the repellent activity in which, they also reflect the significance of compositional complexity of the essential oils [44]. Therefore, repellent and toxicity properties of the blend oils might have resulted to the synergistic interactions within the compounds in the oils.

5.3 Microencapsulation of Essential Oils

The rise of repellent activity in essential oils may be achieved using microencapsulation technique via controlled release of the essential oils. Literatures reported that the technique may enhanced the efficacy of mosquito repellent, for example the successfully microencapsulated Zanthoxylum limonella oil in glutaraldehyde crosslinked gelatin enhanced the repellent effect against mosquito [45, 46]. Specos *et al*. (2010) reported that textiles treated with microencapsulated citronella exhibited higher repellent effect, < 90% with continuous protection from insects for three weeks, compared to the fabrics which were sprayed with ethanol solution of essential oil [46]. Geethadevi and Maheshwari (2015) reported for the microencapsules mixtures of a seaweed, sodium alginate, Acacia and an edible gum resin of *Moringa oleifera* as the wall materials with concentrated oils of thyme and grapefruit and they found that Moringa extraction was very effective against mosquito, with repellent potency increased by 60 % even after 30 cycle of washings [47,48].

However, there is a perception that natural based products are always 'safe' and unlikely to be harmed by the excessive usage of them and how far from the truth is this notion, will be summarized in the next section.

6.0 HOW SAFE IS ESSENTIAL OILS?

The term 'natural' is always recognized as safe however, it might cause side-effects due to the constituents present in essential oils. Moreover, the safety information on these natural products is often limited, vague and inconsistent [1, 49 – 51]. Many of the plants with promising repellent behavior, such as *Malaleuca bracteata* are inappropriate to be used on human due to the cause of adverse reactions. Some of the essential oils are registered with Environmental Protection Agency, EPA such as lemon and eucalyptus oils, whilst the other like lavender, peppermint and cedarwood oils have been exempted from the registration [1]. Even though parties like the US Food & Drugs Administration, FDA and the US EPA have recognized some of the essential oils as safe, the presence of methyl eugenol i.e. one of the trace components in several essential oils such as citronella and clove oil, have raised concerns from many other parties including International Agency for Research on Cancer, IARC, US National Toxicology Program, NTP and the US National Library of Medicine. The carcinogenicity of methyl eugenol in animals experimental is tangible even though no data available for humans. Due to the content of methyl eugenol in citronella, it cannot be used as insect repellent within Europe and Canada even though it exhibited poor duration of protection against mosquito bites [1, 49, 52] whilst for clove oil, it has been identified to cause side effects such as skin irritation, headache and increased bleeding due low blood clotting [1].

Other ingredient that can cause irritation to users is p-menthane-3,8-diol or PMD which can be found in lemon eucalyptus [1, 4]. Active repellent ingredients containing PMD, combined with isopulegol and citronella is an extremely effective with long hours of protection as mosquito repellent. It has been recognized by the Center for Disease Control and Prevention and registered as a biopesticide repellent by the EPA however, the pure essential oil of lemon eucalyptus, is not recommended due to eye irritation effect and lack of information on its safety and efficacy [1, 52]. Like citronella and clove oil, PMD is classified safe by the EPA and used in medicine and foods however, the FDA acclaimed that it should not be used in children under 3 years of age.

7.0 LEVEL OF DENGUE PREVENTION AND REPELLENT USAGE TREND AMONG MALAYSIAN

In general, knowledge and attitude towards dengue prevention among Malaysian is still low. Mashudi *et al*., (2022) in a study to determine the dengue preventive practices among residents in Taman Kota Masai, Johor, Malaysia reported that only half of the respondents, 50.2 % practiced good dengue preventive with the most common practice was the use of water container with a lid [53]. This is similar to that of results reported by Selvarajoo *et al*. (2020) that poor attitude and practice in reducing disease transmission among the respondents in Damansara Damai, Petaling district were observed, such as refusal in removing mosquito breeding sites within their premises and the belief of chemical fogging alone is adequate to reduce dengue transmission [54]. This poor attitude must be changed and more proactive measures or social mobilization are needed from all parties including the media, health authorities, management bodies of residential areas/apartments and religious bodies to educate, convey information and motivate the change in habit [53, 54].

Another important awareness that need to be raised among Malaysian is the use of mosquito repellent as the first line defense against mosquito bites. It has been reported to be the least common dengue prevention measures taken by the respondents in Taman Kota Masai, Johor with only 40.23 % of them that usually and always use mosquito repellent [53] whilst, in Damansara Damai, Petaling only 58.3 % respondents preferred to use mosquito repellents over bed nets and insecticides which score 49.7 % and 39.0 %, respectively [54]. There are many insecticide and natural repellent products in the market today such as MozAway, BioZ Natural and Mosiguard where all showed 100 % repellent effect against Cx. *Quinquefasciatus* [55] and campaign in using mosquito repellent as self-protection from dengue needs to be escalated.

Research and development related to mosquito-borne viral disease in Malaysia should be intensified as well, especially in treated clothing. As far as we concern, there is no scientific report has been published related to development of treated clothing or repellent test performed towards Malaysian clothing/uniform. It has been proven that treated clothing is one of the efficient method used in reducing the transmission of mosquito diseases to other human therefore, it is suggested that exploration in Malaysian impregnation clothing needs to be carried out, promptly so that our textile technology be at the same standard with other countries that already produced and implemented impregnation clothing such as Australia, France and the USA.

8.0 CONCLUSIONS

The wearing of insecticide-treated clothing may offer promising intervention in combating against arthropods diseases and it has been identified as the best protection for occupational health treat. Interests in progression treatment for treating textile with insecticide are increasing and using permethrin, factory impregnated clothing has been reported to provide the best protection of long-lasting effect that withstand several efficiency parameters like repeated washings, washings technique and heat exposure. Concerns on their safety issues, environmental effect and resistant populations to insecticides from synthetic repellents however, have stimulated the need and demand for plant-based repellent with better efficiency of protection as the alternative to classical repellents. With the advancement of biotechnology field through formulation technology and nanotechnology, the emergence of more effective and long-lasting repellency effect using essential oils can be accomplished. It is also essential to build specific regulatory standards for natural repellents so as to retain the quality and the most effective means of application and use. Extensive research on the modes of actions of repellent products is necessary in order to remedy the insecticide resistance in mosquito populations.

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