REVIEW ARTICLE e-ISSN: 2349-0659 p-ISSN; 2350-0964

Insect Repellents: A Review on Available Options and Current Formulation Trends

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Abstract

A total of 164,103 dengue cases were recorded in 2021, compared to 205,243 cases in 2019. Since 2008, the case fatality rate has been fewer than 1%. The administration had reviewed the country's worrisome dengue condition. Dengue cases have all surged dramatically around the world. One among the best way to avoid the bite of mosquito is to use repellents. The previous papers have primarily relied on herbal repellents or synthetic, formulation methods and thud has been unable to compile it in single paper with global forecast and recent products available in market. So, I tried to compile all this matter in this paper. In this review, a survey plants that have a repelling effect, synthetic agents (chemicals with insect repellent), a review of formulation trends, and a global forecast market and products available in the market were conducted.

Keywords: Extended release, Formulations, Global market, Insect repellent, Products

Asian Pac. J. Health Sci., (2022); DOI: 10.21276/apjhs.2022.9.4S.37

Background

Mosquito-borne illnesses continue to be a major cause of sickness and death.[1] Mosquito administration is getting highly challenging as various species have developed physiological resistance to numerous common bug sprays. Intestinal sickness remains a serious worldwide open well-being concern in spite of decades of endeavors to control it, with 3.3 billion individuals at chance in 106 subtropical and tropical countries and regions.[2] There is currently no effective prophylactic antimalarial vaccination available, and no acceptable preventative intervention other than vector control.[3] As a result, avoiding mosquito bites are effective ways to limit the occurrence of illness. Because mosquitoes such as *Culex* and *Aedes aegypti* sp. have adapted to the urban environment, diseases caused by mosquito bites have proliferated throughout the world. As a result, climate alter, the world's hot, and muggy districts are developing. The world's hot, humid climate, combined with a large number of urban breeders, creates an ideal habitat for mosquito reproduction and the creation of new vector-borne viral illnesses. The key preventive approach for mosquito eradication and the spread of arboviruses are to limit mosquito breeding areas. The distress of an unfavorably susceptible response, the potential for infection transmission, comes with mosquito chomps. Thus, employing a safe and efficient topical repellent formulation at home, at work, or in open areas throughout the time duration might reduce biting activity.[4]

Repellents

The repellents are oily volatile compounds that must be administered through the skin in a physiologically suitable carrier. The repellent's direct application to skin may increase cutaneous toxicity and create systemic side effects. A few aspects must be considered while selecting the optimal repellent formulation, such as the active repellent, formulation, user, action time length, and environment.[4] Because of the high vapor pressure, repellents are greasy and volatile compounds. The strategy of activity of repellents, whether characteristic or engineered, is associated to layer formation of vapor on the skin with an unsavory odor that diverts the insect's course and avoids contact with the have.[5]

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How to cite this article: Pawar SA, Kapadnis M, Dhikale R, Jadhav A. Insect Repellents: A Review on Available Options and Current Formulation Trends. Asian Pac. J. Health Sci., 2022;9(4S):184-193.

Source of support: Nil

Conflicts of interest: None.

Received: 09/03/2022 **Revised:** 14/03/2022 **Accepted:** 05/05/2022

Distinctive Features of Insect Repulsive Agents

- Repelling the biggest number of species at a time
- Eight hours effective
- Harmless
- Water and scraped spot resistance, low cost, and odorless to humans and unbearable to mosquitoes.

They ought to not: Influence clothing by recoloring it, fading it or puncturing it; take off sleek buildup on the skin or saturate the skin, maintaining a strategic distance from passage into the circulation system.[6]

Chemical components such as allethrin, mandelic corrosive amide, and dimethyl phthalate, N, N-diethyl-meta-toluamide (DEET) are used in commercial repellents.[7] Chemical repellents have been decided to be dangerous to open well-being and ought to be utilized with caution due to their negative impacts on manufactured texture and plastic, as well as harmful responses such as hypersensitivities, dermatitis, cardiovascular, and neurological side effects, which have been detailed regularly taking after their abuse. The broad utilization of chemically determined synthetic repulsive agents for mosquito control has disturbed normal ecosystems, driving to the improvement of pesticide resistance, a resurgence in mosquito populaces, and negative impacts on

non-target creatures. As a result, employing natural mosquito repellent products as a substitute for developing new eco-friendly repellents could be a win-win option for reducing the negative impacts on environment with human well-being. The field of repellent advancements from plants is amazingly prolific due to the riches of insecticidal compounds found in plants as guards against creepy crawlies.[8] The majority of plants have chemicals that protect them from phytophagous (plant eating) insects.

The chemical classes: Development controller, nitrogen compounds (primarily alkaloids), phenolics and terpenoids, and proteinase inhibitors. In spite of the fact that the major work of these compounds is protection against phytophagous insects, numerous of them, especially the unstable components produced as output of herb ivory, are too proficient against mosquitoes and gnawing Diptera.[9] The truth that several of these chemicals discourage hematophagous creepy crawlies may be developmental holdover from a plant feeding precursor, as a few of these compounds created as phytophagous creepy crawly repellents. Many plant volatiles, on the other hand, are most likely deterrents or repellents due to their more vapor harmfulness to creepy crawlies.[10]

Mode of Action

a. Arthropods such as mosquitoes utilize chemical signal green crest to discover a have and feed topical repellents red plume acts as near run or on contact by disturbing fascination behavior. Spatial repellent shows their impact at much longer remove
b. Compounds such as DEET connected with different bunches of tactile receptors (odorant receptors OR gustatory receptors GR and ionotropic receptors IR) dispersed on different arthropod members. Future repellents may connect with receptor potential channel, receptors of pickpocket, and G protein-coupled receptors [Figure 1].

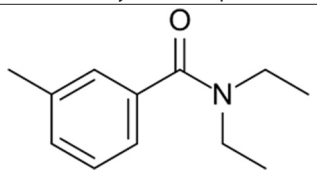
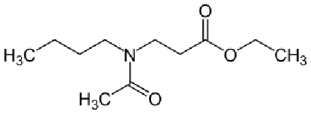
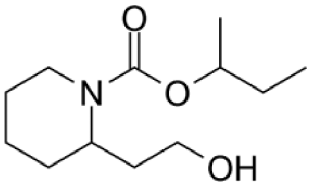
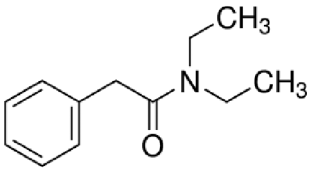
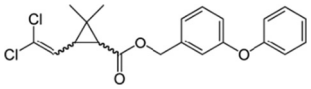
Discussion

Customers have started to move their inclinations toward herbal-based mosquito repellents as the number of well-being dangers related with chemical-based products has expanded. Plants have, moreover, been utilized for ages as rough fumigants, in which plants were burned to drive absent annoying creepy crawlies, and afterword as oil definitions connected to the skin, clothing, which was to begin with recorded in antiquated Greek, Roman, and Indian sources.[11] Herbal repellents are broadly utilized within the conventional country communities within the tropics, as sometimes they are as it were source security from mosquito nibbles accessible to the poorest bunches.

Citronella (*Cymbopogon nardus*)

Essential oils from plants of the genus Citronella belonging to family Poaceae are extensively utilized as ingredients in plant-based mosquito repellents, particularly this is sold in the United States. Commercial preparations from North America: Citronella. Many commercial preparations contain it. Because of its nature, it is more useful. It was first employed to repulse mosquitoes in Indian Armed Force,[12] and it was afterword enrolled for commercial utilized within the United States in 1948.[13] Citronella is fundamental oil derived from the takes off and stems of lemongrass plants (*Cymbopogon* spp.). Citronella today is used

Table 1: Synthetic repellents structures

1		DEET
2		IR3535
3		Icaridin
4		DEPA
5		Permethrin

at 5–10% in concentration as a natural repellent. Limonene, citral, citronellal, geraniol, pinene, and citronellol found initially in citronella.[14] The active chemicals in citronella for mosquito repelling are linalool, citronellal, citral, eugenol, camphor, and eucalyptol.[15] These constituents meddled with olfactory receptors of mosquitoes.[16] *An. gambiae* can distinguish citronellal compounds through neurons, that is, olfactory within the antenna controlled by the gene TRPA1, which are enacted specifically by the chemical with potency.[17,18] Citronellal straightforwardly actuates cation channels, which is comparable to the excite-repellent impact of pyrethrin, another plant-based terpene. Furthermore, citronella grass fundamental oil 100 ml and citronella grass basic oil 0.1 ml given 2.16 and 0.8 h of add up to protection against *Anopheles minimus*[19] and *Anopheles dirus*,[20] respectively.[16]

Catnip (*Nepeta cataria*)

Catnip is a perpetual plant that has a place to Labiatae family, this plant can be found from Europe, Asia, Iranian plateaus.[21] This oil is extracted from *Nepeta cataria*. Catnip has the capacity to influence feline behavior. The active ingredient is nepetalactone, a terpene: Two isoprene units. Catnip has been scientifically proven as a repellent and is certified by Environmental Protection Agency. Catnip had repellency activity against species with 5% concentration.[22] Catnip and its dynamic fixing nepetalactone activate the aggravation receptor TRPA1, an old pain receptor found in creatures as assorted as flatworms, natural product flies, and people. The aggravation receptor TRPA1 intervenes the mosquito repellent impact of catnip.

Neem (*Azadirachta indica*)

Neem is widely planted in India's tropical regions. Neem is widely promoted as a natural DEET substitute.[23] Several Indian field investigations have found that neem-based treatments have a very high efficacy, in contrast to other researchers' findings of moderate repellency.[24] Neem plays a key part in growth and reproduction in mosquitoes due to its relevant action in inducing toxicity through inhibition and demonstrating repellency against Anopheles mosquitoes.[25] These incongruities can be inferable to diverse procedures and the solvents utilized to transport the repellents. Neem has not been granted by the Natural Assurance Office for utilize as a tropical creepy crawly repellent. It has less dermal harmfulness, but when applied undiluted, it may cause dermatitis.[26] The repellent components in neem are azadirachtin saponins.

Clove (*Syzygium aromaticum*)

Clove may be a normally happening zest which has been appeared to possess antioxidant, antipyretic, anti-candidal, antibacterial, and aphrodisiac activities. Clove, lavang, and Cravinhoda-india are all synonyms for this Myrtaceae family member. Initially, clove contains volatile oil, 15-20% containing eugenol, and vanillin, caryophyllene, and acetyl eugenol, tannin, resin, chromone, eugenin, and esters, alcohols and ketones in small quantities. Eugenol, carvacrol, thymol, and cinnamon aldehyde are the components which have effective repellent properties. Clove indicated a dose-dependent trend. Anti-An. virus repellency was 92% and 98%, respectively.[27] Clove is a moderately effective repellant.

Thyme (*Thymus vulgaris*)

Thyme or garden thyme is a blossoming plant with Lamiaceae family, native to southern Europe. Carvacrol, p-cymene, linalool, terpinene, and thymol, all produced from thyme essential oil, were tested for their ability to repulse the mosquito *Culex pipiens pallens* L. Based on a test, all five monoterpenes effectively repelled mosquitoes.[28] When 100% thymus vulgaris oil is connected to clothing, mosquito *Aedes aegypti* is repulse for at slightest 30 min.[29]

Basil (*Ocimum basilicum*)

Basil is herb in the Lamiaceae family, Ocimum genus and is utilized as traditional medicine in the world.[30] Basil is an effective repellant against different *Anopheles* species. P-cymene, estragole, linalool, linoleic acid, eucalyptol, eugenol, camphor, citral, thujone, limonene, and ocimene are the repellent constituents found in basil. When the basil leaves are rubbed, a typical scent is released due to estragole, which helps with insect repellent activity. Basil essential oil in 20% had a 100% repellent effect which is 3.5 h against *An. stephensi*, with a 66.7%.[31]

Lantana (*Lantana camara*)

Lantana is shrub verbena, blooming plant family of Verbenaceae. It contains -phellandrene, linalool, limonene, camphor, -humulene, -caryophyllene, -germacrene B D, cadinene, and others. Caryophyllene, germacrene, eucalyptol, and humulene are the constituents that are found as insect repellents. Caryophyllene[32] presents a repellent action against *Anopheles gambiae*. Eucalyptol, -humulene, and germacrene are toxic to adult mosquitos.[33] Lantana camara leaves release volatile compounds, including -pinene, that have repellent action.[34]

Peppermint (*Mentha spicata and Mentha aquatica*)

Peppermint is a cross-breed mint made by water mint and spearmint, that is *Mentha aquatica* and *Mentha spicata*, which contains naturally active constituents and with high menthone, menthol, and methyl esters. A 1 ml undiluted peppermint oil totally repels *Anopheles annularis* and *Anopheles culicifacies* for 11 and 9.6, respectively, with percentage repellency of 100% and 92.3.[35]

Lippia (*Lippia javanica*)

Lippie species are pubescent or glabrous shrubs or undershrub belonging to the family Verbenaceae, commonly found in South Africa. Strong lemon smell leaves repel insect.[36] Linalool, myrcene, ipsdienone, p-cymene, and caryophyllene are chemical components responsible for repulsive activity from *Lippia javanica*. When *Lippia javanica* dried leaves alcoholic extract was on the skin, it provided 100% protection against *Aedes aegypti* for 2 h.[37]

Stone root (*Collinsonia canadensis*)

It also known as horseweed, richweed, hardhack, and heal-all, perennial herb with Lamiaceae family, stone root is being used since hundreds of years for medicinal characteristics also has a strong unpleasant smell. By crushing and boiling, the plant root extract is made for mosquito repellents.

Synthetic repellents

The chemical industry produces synthetic repellents on a huge scale. Permethrin, DEET, Icaridin, IR3535 (Ethyl Butylacetylaminopropionate), DEPA (N, N-diethylphenylacetamide), and are the most common synthetic repellents.

DEET (N, N-diethyl-3-methylbenzamide)

DEET is somewhat yellowish at normal temperature, volatile liquid, and oily in nature and has been most efficient repellent against hematophagous arthropods since the 1950s.[38] It is high solubility in alcohol, moderate solubility with petroleum ether, water insoluble [Table 1]. Clothing, plastics, and acrylics of synthetic fibers may be harmed. The method of action is based on DEET attaching to mosquito olfactory receptors, which repels them from host while they are still in flight, as well as chemoreceptors, which restrict biting behavior following mosquito contact with skin.[39] DEET is the least expensive repellent on the market, but it is also the most hazardous. DEET, which is included in topical formulations, has a long-lasting repellent effect on mosquitos of several species, including *Aedes aegypti*. Direct application to skin is not suggested since it lacks good sensory characteristics, such as an acute oiliness sensation, and because of its low molecular weight, it may cause cutaneous absorption. Avoid in pregnancy. Despite its toxicity, DEET is World Health Organization's (WHO) reference repellent since it is long-lasting and effective repellent. It is most recommended in dosages ranging 7–10% repellent as a short action (up to 2 h) and 20–30% for longer-term repellent

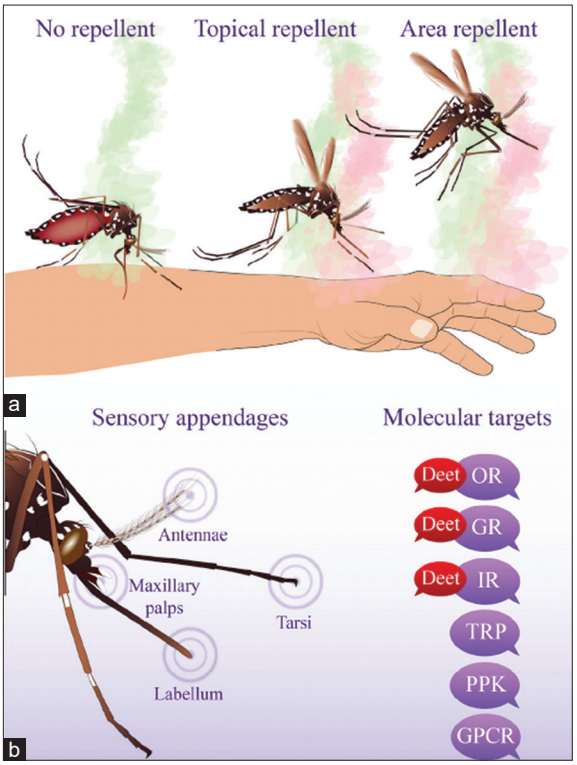


Figure 1: Mode of action of insect repellent

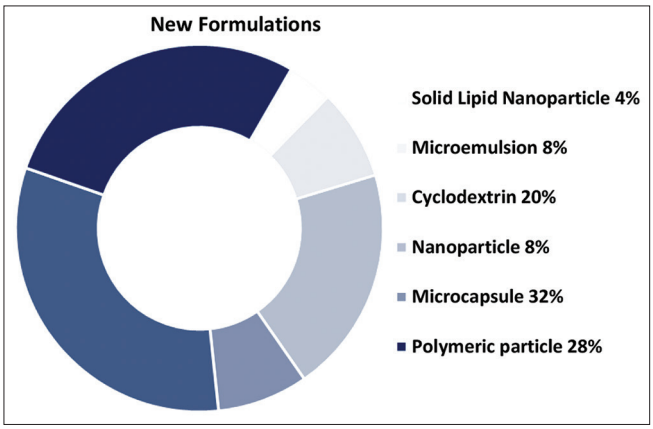


Figure 2: Pie graph showing % of formulations used

action (up to 6 h). DEET is more effective against *Culex* and *Aedes* mosquitos, but less effective against *Anopheles*.[40]

IR3535

IR3535 is liquid having oily nature that is volatile at room temperature and under normal pressure. It is mildly soluble in water but has higher solubility with organic solvents, odourless and colourless. As per INCI, the repellent's name is Ethyl Butylacetylaminopropionate (EB). Chemical structure of IR3535 based on beta-alanine, a naturally occurring amino acid [Table 1]. Mosquitoes, flies, ticks, lice, wasps, and bees are all attracted to it. It has a lower repellent efficiency than DEET, odorless, less harmfulness, and biocompatible. IR3535 is viable against some species of mosquito's wasps (*Polistes galliens*), and bees (*P. galliens*). The IR3535 is unstable and creates a vapor

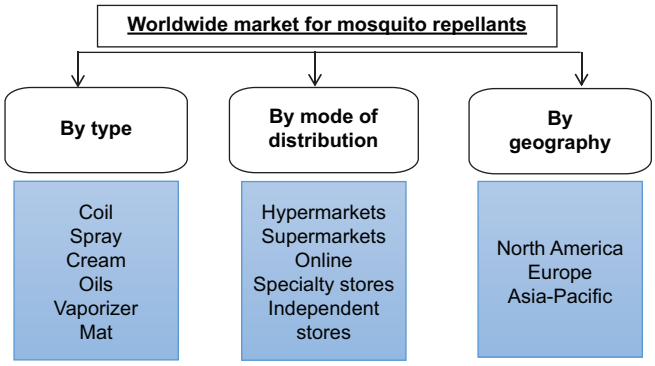


Figure 3: Mosquito repellent market segmentation flowchart

obstruction that prevents creepy crawlies from host contact due to the unsavory odor to mosquito.[41]

Icaridin

Bayer developed Icaridin (Picaridin) or KBR 023 as a long range mosquito repellent.[43] Chemically, it is 2-(2-hydroxyethyl)-1-methylpropylstyrene 1-piperidine carboxylate [Table 1]. Picaridin does not leave an oily or sticky buildup on the skin, is less prone to irritating the skin, and will not toxic to plastics, fabrics. It is having insolubility in water with volatile nature. Furthermore, it is odorless. It evaporates gradually from the skin compared to DEET, therefore, Icaridin repellent effect is longer duration. This repellent has a broad appearance with effective activity against mosquitos, flies, bees, ticks, and fleas. It is more efficient than DEET against *Aedes* and comparable to mosquitos of the genera Culex and Anopheles.[44] Icaridin can irritate sensitive people's eyes and skin, yet it's less toxic with good tolerability compared to DEET.

DEPA (N, N-Diethyl Phenylacetamide)

DEPA having long-lasting repellency action, manufactured by the Research Development Establishment of Defense, Gwalior, India [Table 1]. Because the use of synthetic DEPA-based repellents is a cost-effective option, many endeavors have been undertaken to develop superior and more secure repellent formulations against mosquito bites and arbovirus transmission.[44] DEPA is secure for human utilize as per toxicological ponders.[45] A study was done in India to identify an effective, secure, and elective insect repellent due to a scarcity of components required for DEET manufacture, which led to the discovery of a new repellent: DEPA.[45] It has an action time of more than 8 h. DEPA has been utilized by Indian armed personnel to secure them from a variety of deadly arboviruses spread by hematophagous arthropods such as mosquitoes, blackflies, and land leeches.[46]

Permethrin

When compared to the chrysanthemum, naturally occurring insecticide, a viscous liquid from pyrethroid pesticides with a photo stable component, rather than a real repulsive agent having ability to protect crop.[47] It was first proposed in the 1970s to treat military gear by immersing it in a water emulsion containing 0.6 percent permethrin to keep flying insects at bay.[48] Pyrethroids are absorbed in humans fast after inhalation exposure, and they are gradually released in blood. Permethrin is a chemical treats

garments and outdoor gear [Table 1]. Because it is bonded to the fabric, it is resistant to washing.

Insect Repellent Formulation Trends

Polymeric micro- and nanocapsules, lipid solid micro- and nanoparticles, nano-emulsions/micro-emulsions, liposomes, micellar hydrogels, and cyclodextrin (CD) are among the latest insect repellent compositions. Polymers and lipids are used in the novel formulations. These materials can tolerate the release of repellent actives, giving them a longer duration of effect.

Nano Emulsion/Micro Emulsion

Natural as well as synthetic repulsive compounds having slight solubility and oily in nature in the concentrations required for repellent action. The majority of repellents are effective at concentrations greater than 10%. As a result, they need vehicles that are physiologically suitable for cutaneous administration. Most products available in the market as solutions and lotions form [Figure 2]. Spray solutions contain alcohol and propylene glycol, which help in the solubilization of repellent but cause dryness and skin irritation when applied to skin. They also have undesired skin permeation because of the alcohol. Nanostructured formulations developed using nanoemulsion as a result of problems with standard formulations. Over traditional emulsions, nanoemulsions have a low viscosity and may be utilize with variety of applications. It is easy to distribute on the skin, has a great sensory and esthetic appearance, and does not leave the skin white.[49]

Solid-lipid Nanocapsules

Because they are made with solid-lipid matrix, lipid nanoparticles differ from other lipid carrier systems. Other colloidal systems, such as emulsions, liposomes, and polymer nanoparticles, have limitations. SLNs have a round shape with an estimate size of 40–1000 nm. Solid fat accounts for about 0.1–30% of the weight of SLNs, which is disseminated in an aqueous phase. SLNs made to overcome these limitations [Figure 2]. Because it has advantages such as delayed release of active compounds on the skin, a simple manufacturing approach based on biocompatible lipids, and excellent cutaneous biocompatibility, as well as excellent physical stability.[50] Surfactants are employed in concentrations of 0.5–5% to improve stability. Polymeric microcapsules, microparticles create a layer of the compound on the skin, gradually releasing the chief constituent by volatilization. They are competent of extending the release of product by volatilization whereas decreasing skin saturation.[51,52] The NanoRepellent® product was developed by Nanovectors Company using medicinal nanotechnology. NanoRepellent® is a lipid nanoparticle combination of andiroba with citronella oils are encapsulated in oleic acid, stearic acid, and stearyl alcohol.

Polymeric Microcapsules

The microcapsule comprises as natural or synthetic polymers. Microencapsulation is the procedure of storing an essential oil in a core that has a covering substance on the outside. Because of their capacity to disintegrate under the influence of the environment, leaving only non-toxic waste, biopolymers are great coating materials. The polymeric microcapsules show a cavity able of putting away unstable substances having volatility as insect repellent. The microcapsules act as a reservoir for the product which we apply on the skin, releasing it slowly and gradually, limiting skin permeation.[53,54] Embodiment in polymeric microcapsules can reduce active substance absorption, making the repellent composition safer as of its water solubility, biodegradability, and film-forming capability. Gelatin; poly (vinyl alcohol) has been employed. Formulation comprising these CRSs slowly releases the active to the environment by volatilization, extending the duration of repellent activity while reducing the active's exposure to the skin and, as a result, skin permeation after application on skin.[55]

Polymeric Nanocapsules

Polymeric nanocapsules are nanostructures that differ from other polymeric nanoparticles in terms of form and architecture. Nanocapsules are made of a core that contains pharmaceuticals and is encompassed by a polymeric membrane, comparable to a vesicular system. Because the encircling layer protects the medicine from the surrounding environment, active substances that are destroyed, degraded, or metabolized after administration are suitable candidates for encapsulation into nanocapsules. Drugs come in a various form, including solid, liquid, and molecular dispersion.[56]

Micro/Nanofiber

Nanofibers emerged as an exciting one-dimensional nanomaterial because of their unique physicochemical properties with differentia. It is nanomaterial class with cross-diameters 10–100 nm. The ratio of superficial area and volume about nanofibers is extraordinarily high. Moreover, they can create very porous mesh nets with excellence interconnectedness between their pores. Nanofibers are made from a variety of materials, including natural polymers, synthetic polymers, carbon-based materials, and others.[57] Advanced techniques incorporating active repellent chemicals into polymer fibers developed in recent years. Electrospinning is widely used nanofiber processing processes. An electric field is supplied to a viscous polymer solution when electrospinning is in progress, generating a charge inside the polymer. A jet is formed when the charge repulsion force is more than surface tension, resulting in extremely thin and elongated droplets with a large surface area. The evaporated solvent attracts them to an oppositely charged manifold where mat is produced. This versatile technology for the formation in micro, nano scale of continuous polymeric strands under the application of a high-voltage electric field, and it can readily manufacture nanofibers. The electrospinning technique was used to create functional micro/nanofibrous matrix mechanisms as controlled release systems of mosquito repellent citronella oil from mono and multiple layer electro-functional untreated matrices, using biopolymers such as PVP, that is, polyvinylpyrrolidone cellulose acetate (CA) incorporating citronella oil, to determine citronella oil release profile from micro/nanofabricated nets and evaluate its repellency against *Aedes albopictus* mosquitoes.

CDs

CDs are cyclic oligomers that are water soluble formed by the degradation, or cyclization of starch, enzymatic conversion, and other-1,4-glucans and partially by amylases as well as by CD glucosyltransferase which are made up of 6–8 units glucopyranose connected by (1,4) linkages. Three varieties of CDs were identified from D-glucopyranose units: (a) CD (six units), (b) CD (seven

units), and (c) CD (eight units) (eight units). Because the cavity size is acceptable for popular pharmaceuticals with molecular weights between 200 and 800 g mol-1 and because they are reasonably priced, the -CD (which contains 7 glucopyranose units) is frequently used among the CDs.[58] Because insect repellents are tiny, hydrophobic molecules, they are perfect candidates for complexation with CDs. CDs can form complexes with repellents, lowering volatilization, and so boosting repellent efficiency and persistence. Coprecipitation, extrusion, paste complexation, wet mixing and heating, slurry complexation, and dry mixing are all examples of complexation procedures.[59] The ability of CDs creating inclusion complexes with volatile essential oils, which have ideal qualities for complexation due to their tiny size and hydrophobic nature, has piqued people's curiosity in their use. The formation of the inclusion complex protects the essential oil from oxidation and enhances chemical stability. Protection and controlled release are the major advantages because they allow for controlled release under the desired conditions, which improves the efficacy and essential oil's onset of action.[60] Songkro[61] has created citronella, citronellal, and inclusion compounds of citronellol essential oil using CD. The complexes were made using the kneading process with a ratio of 1:1 and 1:2 essential oil to CD. Incorporating the inclusion complexes into oil and water lotions resulted in some formulations.

Nanostructured Hydrogel

Pluronic F127-based hydrogels are Micellar gels with nanostructures that have been employed as repellent vehicles. Pluronic F127 is surfactant which is polymeric that can form a micellar gel, allowing lipophilic actives like natural and synthetic repulsive agents to be included. They've been used to extend the duration of repellent activity by forming a film on the skin that slows active evaporation. Furthermore, when compared to traditional solution formulations in which free form repellent is there, skin permeation rate reduces when the release of repellent extended. According to cytotoxicity testing, the gel exhibits low cytotoxicity and is usable safely. Permeation trials revealed the formulation of the control encouraged skin penetration, whereas the gel promoted repellent retention in outer layer and permeation prevented. The findings indicate that 12.5% EB nanostructured gel is effective. As a result of its safe profile for cytotoxicity and penetration experiments, it can be deemed an insect repellent with the potential to be effective.[4] *Ex vivo* skin penetration investigations on pig ear skin were utilized to investigate safety of a 15% Pluronic F127 micellar gel containing 10% DEET (Formulation IV).[62]

Liposomes

Liposomes are vesicle having a lipophilic phospholipid bilayer and a hydrophilic aqueous core. Because of the way they're made, they are biocompatible and suitable for giving medications to the skin. They produce an extended-release reservoir system after application on the skin. Liposomes are good for repelling encapsulation because they have the following benefits: Lower volatilization rates, longer release times, longer action times, less skin permeation, and lower toxicity. Under the brand name ULTRA 30TM, Sawyer sells liposome-encapsulated DEET. The product contains 30% DEET liposomes and has an appearance, both sensory and esthetic.[63]

Polymeric Micelles

Spherical particles having hydrophilic outer layer and hydrophobic core are known as polymeric micelles. When the concentration of copolymer is greater than the micellar critical concentration, micelles form in the aqueous solution. Block copolymer hydrophobic segments are linked together in the CMC to reduce interaction with water molecules, resulting in the creation of a vesicle or core-shell micelle structure. The creation of micelles is supposedly triggered by a decrease in free energy. Hydrophobic pieces are removed from the aquatic environment, and hydrogen bonds in the water reduce the system's free energy are re-established, resulting in the formation of micelles. The surface of the micelles can be functionalized, allowing them to react to environmental stimuli. Poly (histidine), poly (aspartic acid), poly (isopropyl acrylamide), poly (2-ethyl-2-oxazoline), poly (2-dimethylaminoethyl), poly (ethylene imine), poly (dimethylamine methacrylate), and PEOs are polymers and copolymers utilized in the creation of micelles.[64] DEPA is contained in a polymeric nano micelle, resulting in the nano DEPA formulation.[64] Balaji measured the resistance to washing index by impregnating alginate cross-linked free active (DEPA) plain cotton fabrics and nano DEPA.[64]

Global Forecast

Because of rising greenhouse gases levels in atmosphere, the earth's global temperature has continued to rise in recent years and is predicted to continue to climb in the future. Mosquitoes thrive in hot weather because it allows them to spawn more easily and enhances their activity. It also produces a damp and wet environment in some areas, which aids in the population growth of those areas. As an output, impact of increased global warming would have a direct impact on the expansion of mosquito populations, leading to rise mosquito repellent products penetration. This would result in a boost in revenue for the mosquito repellant sector. Consumers in well-off nations have started to utilize plant-based substances neem-based sprays, citronella oil, lotions, and oils also birch tree bark and other (rep. mosquito allied marker research).

The global market for mosquito repellent was worth USD 6.9 billion in 2021, and is expected to grow at a CAGR of 5.6 percent to USD 9.0 billion by 2026. Mosquitoes have moved locations and adapted to their changing environment as the population of world has grown, as has migration to city and the transformation of villages to suburban areas (www.marketsandmarkets.com).

Landscape of Competition in the Insect Repellent Market

Available competitors of insect repellent market are Avon Products Inc., Coghlans Ltd., Dabur India Limited, Entomol Products, LLC., Enesis Group, ExOfficio LLC, Godrej Consumer Products Ltd, Homs LLC, Jyothy Labs Ltd., PIC Corporation, Quantum Health, Reckitt Benckiser Group PLC, Spectrum Brands Holdings Inc., Inc. Coghlan's Ltd., Dabur International Ltd., Godrej Consumer Products Limited, Jay Laboratories Ltd. (JLL), Himalaya Herbals, Reckitt Benckiser Group plc. (allied).

Insect Repellent by Type

Spray, vaporizer, cream and oil, coil, mat, and others include candles, incense sticks, cards, roll-ons, wet wipes, and patches [Figure 3].

Mosquito Net

It is a type in which mesh curtain that is spread circumferentially over a bed otherwise sleeping space to provide a barrier for mosquito bites and stings, as well as diseases that mosquitos may transmit. A mosquito net's mesh must fine to keep such insects out while not obstructing visibility or limiting ventilation. Pretreating a mosquito net with an adequate insecticide can significantly improve its efficiency. Mosquito nets have been established to be a very successful method of malaria control, avoiding roughly 663 million cases in 2000– 2015 (Bhatt S, Weiss).[63] It is made of polypropylene, polyethylene, cotton, polyester, and nylon.[66] (WHO, September 16, 2009) Mosquitoes are inhibited with 1.2 mm mesh size (0.047) and 0.6 mm as a smaller mesh inhibits other biting insects, including biting midges and no-see-ums (netting criteria).[67] Mosquito nets that have been treated with insecticides, called insecticide-treated nets (ITNs) also bed nets, for malaria prevention. When compared to no net, ITNs are expected to be double as efficient as nets that have not been treated, providing more than 70% protection (Swales Jay. Bouchou).[68] These mosquito nets are coated with synthetic insecticide like deltamethrin or permethrin, which provides twice the protection of mosquito net that has not been treated. For best efficiency, every 6 months, ITNs should be retreated with insecticide.

Mosquito Coil

It is mosquito repelling scented which frequently spiraled and formed from dried pyrethrum powder paste. To allow continuous burning, the coil is typically kept in the spiral's center, hanging in the air, or jammed between two fireproof pieces netting. The burning starts at the spirals outer end and slowly advances into the center, releasing mosquito repellent smoke (McKean, Erin). These neurotoxic chemical vapors paralyze their bodies, eventually causing them to die. A mosquito coil typically measures diameter 15 cm (6 inches) and 7–12 h lasts. In Asia, Africa, Australia, South America, Mexico, and Canada, mosquito coils are commonly utilized (Liu Weili, Zhang). Active ingredients may include pyrethrin, pyrethrum, allethrin, metofluthrin, meperfluthrin, dimefluthrin, esbiothrin, etc. However, the disadvantages are that can cause fire hazard and result in a harmful fire accident when left unattended (Trumbull, Charles).[69]

A Mosquito Trap

The utilization of traps providing artificial breeding places to lay eggs is a classic method of managing mosquito populations. While ovitraps just catch eggs, fatal ovitraps frequently have poison inside that kills adult mosquito, larvae trapped inside.[70] Laurentian University researchers published design for low-cost trap dubbed an Ovillanta in 2016, which uses attractant-laced water filled in segment of discarded rubber tire. For removing deposited eggs larvae, the water is filtered at regular interval. The water is then reused to attract new mosquitoes as it includes an "oviposition" pheromone (Gignac, Julien).[71] Newer mosquito traps or known mosquito attractants release other mosquito attractants such as sweet scents, lactic acid, octanol, warmth, water vapor, and sounds are combined in a cloud of carbon dioxide (Okumu FO; Killeen GF).[72] The trap attracts female mosquitoes by imitating a mammal's secretions as well as scent and they are often dragged in net by electric fan, where they are gathered.

Liquid Repellents

Mosquito repellents in liquid form are increasingly frequently utilized. A graphite rod is in the center of the Liquidator insect repellent container, which is loaded with the repellent. Heater coil is present in it. When the repellent chemical comes into touch with the heated rod, it produces fumes that target insect neurological systems. The liquid mixture in the refill is of (1) Insecticide: This causes the mosquito to flee. (2) Stabilizers/antioxidants: To keep the insecticide from oxidizing as an output of heat. (3) A perfume – human compliance. A liquid contains transfluthrin 0.888% w/w as insecticide, butylated hydroxytoluene 1% w/w as stabilizer/antioxidant, perfume Drakkar 1% w/w as perfume, and deodorized kerosene 97.120% w/w as solvent. Disadvantages include headaches, nausea, coughs, dizziness, sore throats, and long-term exposure can cause respiratory irritation, allergies, wheeze in children, and asthma.

Creams, Lotions, and Oils

These products interfere with the navigational systems of insects. Chemical receptors are present in the antennae of system. Lactic acid that evaporates naturally from warm-blooded animal's skin stimulates chemical receptors. DEET ingredient forms barrier on skin after application. Therefore, a mosquito is not able to discover a person. DEET comes in various forms. Picaridin is available various forms, including sprays, pumps, lotions, creams, and liquids. Permethrin is used as a spray only for clothes. Citronella oil is available in sprays, lotions, creams, and aerosols.

Ultrasonic Insect Repeller

These electronic devices use electronic or ultrasonic waves to repel roaches and insects. Electronic insect repellents are plug-in electronic repellents, electromagnetic lamps, and ultrasonic transmitters. The following components are used: 555 timer, preset resistors, variable resistors, speakers, and capacitors. Working of circuit is to emit a stream of predetermined frequency pulses. At the output speaker, there is a high-pitched sound (a buzz) that triggers the mosquitoes' auditory senses, thus scaring them away.

Mosquito Racket

This racket is a mosquito-killing gadget; when the user swings the racket about to trap a mosquito inside the metal grid, the circuit is shorted, and the insects are electrocuted. The handle of the mosquito racket has an activation button that must be turned on every time you decide to destroy an insect. The device is very popular in India, where mosquitos are an annoyance and are responsible for spreading diseases. There are many brands and variations of the racket available on the market. Size: 530 × 220 × 30 mm, weight: 310 g. The gadget comes in a transparent polypropylene bag of a printed label that includes information about the brand, device characteristics, usage guidelines, and safety precautions. This is an economical packaging that will last the whole product life.

Mosquito Killing Paper

The Fast Card of Good knight was created by the R & D at Godrej Consumer Products. Mosquito repellents based on paper are unique paper cards impregnated with mosquito repellent

chemicals that work by causing the paper to burn. It is a mosquito repellent made of paper that provides immediate relief and capable of 4 h of mosquito protection. Its spiral shaped known as the good knight Jumbo Fast Card. Fast action is triggered by the technology and an instant knockout impact on mosquitoes as soon as a giant fast card is lit. It also emits a pleasant scent that lingers in the space. In India, burning insect repellents account for about half of all mosquito repellents used. Almost a third of them are using unapproved and illegal mosquito repellent incense sticks, which have negative health impacts because they include toxic chemicals as active ingredients. For users of such formats, the Jumbo Fat Card is a high-quality standard that is both affordable and safe. Advanced TFT-dot technology provides instant relief from mosquitoes.

A Mosquito Mat

A mosquito repellent machine needs a liquid repellent that has to be inserted. Mosquito repellents that plug in come in the vaporizers and mats forms. Products like the Good Knight Mat act instantly. It is capable of 10-night action. First, tear the wrapping paper off the mat. Then, by taking it out, insert it into the electric mosquito coil in the incense device. Then, plug it to the power source. Therefore, the iron in the middle of the mosquito is a ceramic chip, which gets hot and starts heating after the electricity is on. The mat also contains a dye that gradually changes color to show when the mat is exhausted.

Future Prospects

The market for insect repellents was worth USD 4150.91 million in 2020 and is likely to increase at a 6.85% CAGR between 2021 and 2026. The use of repellent can boost the pleasure and comfort of tourists in nations like Kenya, tourism is noteworthy source of revenue national wealth. They may lower the incidence of disease and discomfort among military troops, allowing them to fulfill their missions more quickly. As a result, repellents can be thought of as a tool that plays a specialized role in protecting people against insect-borne sickness. More traditional pest management techniques must be combined with repellent technology. Because it is considered a home hygiene and home care product, the COVID-19 epidemic has had a beneficial impact on the market for insect repellents all over the world. Furthermore, as consumers become better aware of the outbreak, demand for hygiene and household cleaning products is probable to rise in the coming days.

Conclusion

Most important interventions against mosquito-borne disease vectors are use of repellents, primarily topical formulations. Several alternative formulations have been tested to improve the safety and performance of these repellents. Trends in natural insect repellent formulas published in scientific literature, invention patents, and commercially accessible products were investigated. By analyzing data gathered from formulations of natural repellents in literature and patents, it is feasible to ensure that microcapsules are the technical trend among the extended-release systems.

Acknowledgments

We express our gratitude to our guide, Mrs. Rupali Dhikale who helped us throughout the complete process of review article. We would also like to thank all our professors and principal, Mr. Anil Jadhav during work.

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References

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1. Alayo M, Femi-Oyewo M, Bakre L, Fashina A. Larvicidal potential and Mos Quito repellent activity of *Cassia mimosoides* extracts. Southeast Asian J Trop Med Public Health 2015;46:596-601.
2. Karunamoorthi K, Girmay A, Hayleeyesus SF. Mosquito repellent activity of essential oil of Ethiopian ethnomedicinal plant against Afro-tropical malarial vector *Anopheles arabiensis*. J King Saud Univ Sci 2014;26:305-10.
3. Soonwera M. Efcacy of essential oil from *Cananga odorata* (Lamk.) Hook. f. and Thomson (Annonaceae) against three mosquito species *Aedes aegypti* (L.), *Anopheles dirus* (Peyton and Harrison), and *Culex quinquefasciatus* (Say). Parasitol Res 2015;114:4531-43.
4. Tavares M, Marcio R. Trends in insect repellent formulations: A review. Int J Pharm 2018;539:190-209.
5. Islam, J, Zaman, K, Duarah S, Raju PS, Chattopadhyay P. Mosquito repellents: An insight into the chronological perspectives and novel discoveries. Acta Trop 2017;167:216-230.
6. Katz T, Miller J, Hebert A. Insect repellents: Historical perspectives and new developments. J Am Acad Dermatol 2008;58:865-71.
7. Alayo M, Femi-Oyewo M, Bakre L, Fashina A. Larvicidal potential and Mos Quito repellent activity of *Cassia mimosoides* extracts. Southeast Asian J Trop Med Public Health 2015;46:596-601.
7. Harrewijn P, Minks AK, Mollema C. Evolution of plant volatile production in insect-plant relationships. Chemoecology 1995;5:55-73.
8. Pichersky E, Gershenzon J. The formation and function of plant volatiles: Perfumes for pollinator attraction and defense. Curr Opin Plant Biol 2002;5:237-43.
9. Gershenzon J, Dudareva N. The function of terpene natural products in the natural world. Nat Chem Biol 2007;3:408-14.
10. Herodotus H, Owen T. The Histories. Penguin. Geoponika: Agricultural Pursuits. London, England: Penguin Classics; 1996. p. 1805. Available from: http://www.ancientlibrary.com/geoponica/index.html [Last accessed on 2005 Oct 01].
11. Covell G. Anti-mosquito measures with special reference to India. Health Bull 1943;11:11202.
12. EPA. Registration Eligability Descision Document: Oil of Citronella. Washington, DC: United States Environmental Protection Agency; 1948.
13. Curtis CF, Lines JD, Ijumba J, Callaghan A, Hill N, Karimzad MA. The relative efficacy of repellents against mosquito vectors of disease. Med Vet Entomol 1987;1:109-19.
14. Moore S, Lenglet A, Hill N. Plant-based insect repellents. In: Debboun M, Frances SP, Strickman D, editors. Insect Repellents: Principles, Methods and Uses. 1st ed. Boca Raton: CRC Press; 2006. p. 275-304.
15. Pappenberger B, Geier M, Boeckh J. Responses of antennal olfactory receptors in the yellow fever mosquito *Aedes aegypti* to human body odours. Ciba Found Symp 1996;200:254-66.
16. Kwon Y, Kim SH, Ronderos DS, Lee Y, Akitake B, Woodward OM. Dros ophila TRPA1 channel is required to avoid the naturally occurring insect repellent citronellal. Curr Biol 2010;20:1672-8.
17. Kongkaew C, Sakunrag I, Chaiyakunapruk N, Tawatsin A. Efectiveness of citronella preparations in preventing mosquito bites: Systematic review of controlled laboratory experimental studies. Trop Med Int Health 2011;16:802-10.
18. Phasomkusolsil S, Soonwera M. Insect repellent activity of medicinal plant oils against *Aedes aegypti* (Linn.), *Anopheles minimus* (Theobald) and *Culex quinquefasciatus* say based on protection time and biting

rate. Southeast Asian J Trop Med Public Health 2010;41:831.
20. Sritabutra D, Soonwera M, Waltanachanobon S, Poungjai S. Evaluation of herbal essential oil as repellents against *Aedes aegypti* (L.) and *Anopheles dirus* Peyton and Harrion. Asian Pac J Trop Biomed 2011;1:S124-8.
21. Grognet J. Catnip: Its uses and effects, past and present. Canadian Vet J 1990;31:455.
22. Webb CE, Russell RC. Is the extract from the plant catmint (*Nepeta cataria*) repellent to mosquitoes in Australia. J Am Mosq Control Assoc 2007;2:351-4.
23. Ava T: Neem oil: a safe alternative to Deet [http://trinityava.com/wpcontent/.../Neem-for-Outdoor-Protection-2009.07.pdf]. Book Neem oil: a safe alternative to Deet City; 2009 [http://trinityava.com/wp-content/ .../Neem-for-Outdoor-Protection-2009.07.pdf].
24. Barnard DR, Xue RD. Laboratory evaluation of mosquito repellents against *Aedes albopictus*, *Culex nigripalpus*, and *Ochierotatus triseriatus* (*Diptera*: *Culicidae*). J Med Entomol 2004;41:726-30.
25. Sukuma K, Perich MJ, Boobar LR. Botanical derivatives in mosquito control: A review. J Am Mosq Control Assoc 1991;7:210-37.
26. Reutemann P, Ehrlich A. Neem oil: An herbal therapy for alopecia causes dermatitis. Dermatitis 2008;19:E12-5.
27. Phasomkusolsil S, Soonwera M. Comparative mosquito repellency of essential oils against *Aedes aegypti* (Linn.), *Anopheles dirus* (Peyton and Harrison) and *Culex quinquefasciatus* (Say). Asian Pac J Trop Biomed 2011;1:S113-8.
28. Park BS, Choi WS. Monoterpens from thyme as potential mosquito repellents. J Am Mosq Control Assoc 2005;21:80-3.
29. USDA. Materials Evaluated as Insecticides, Repellents, and Chemosterilants at Orlando and Gainesville FLA 1952-64. Washington, DC: USDA; 1964.
30. Miele M, Dondero R, Ciarallo G, Mazzei M. Methyleugenol in *Ocimum basilicum* L. Cv Genovese Gigant. J Agric Food Chem 2001;49:517-21.
31. Amer A, Mehlhorn H. Repellency efect of forty-one essential oils against *Aedes*, *Anopheles*, and *Culex mosquitoes*. Parasitol Res 2006;99:478.
32. Ghisalberti EL. *Lantana camara* L. (Verbenaceae). Fitoterapia 2000;71:467-86.
33. Omolo MO, Okinyo D, Ndiege IO, Lwande W, Hassanali A. Fumigant toxicity of the essential oils of some African plants against *Anopheles gambiae* Sensu Stricto. Phytomedicine 2005;12:241-6.
34. Padhy PK, Varshney CK. Emission of volatile organic compounds (VOC) from tropical plant species in India. Chemosphere 2005;59:1643-53.
35. Ansari M, Vasudevan P, Tandon M, Razdan R. Larvicidal and mosquito repellent action of peppermint (*Mentha piperita*) oil. Bioresour Technol 2000;71:267-71.
36. Van Wyk BE, van Oudtshoorn B, Gericke N. Medicinal Plants of South Africa. Pretoria: Briza Publications; 1997.
37. Ukwa N. Do traditional mosquito repellent plants work as mosquito larvicides? Cent Afr J Med 1994;40:306-9.
38. Wylie BJ, Hauptman M, Woolf AD, Goldman RH. Insect repellants during pregnancy in the era of the Zika virus. Obstet Gynecol 2016;128:1111-5.
39. Degennaro M. The mysterious multi-modal repellency of DEET. Fly (Austin) 2015;9:45-51.
40. World Health Organization. Guidelines for Efficacy Testing of Mosquito Repellents for Human Skin. Geneva, Switzerland: WHO, HTM, NTD, WHOPES; 2009. p. 1-6.
41. Cilek JE, Petersen JL, Hallmon CE. Comparative efficacy of IR3535 and deet as repellents against adult *Aedes aegypti* and *Culex quinquefasciatus*. J Am Mosq Control Assoc 2004;20:299-304.
42. Merck. Technical Material. Interim Specification Who/Is/Tc/667/2001. Germany: Merck; 2001. p. 1-15.
43. Paumgartten FJ, Delgado IF. Mosquito repellents, effectiveness in preventing diseases and safety during pregnancy. Vigil Sanit Debate 2016;4:97-104.
44. Mendki JM, Singh AP, Tikar SN, Parashar BD, Shukla V, Prakash S. Repellent activity of N, N-diethylphenylacetamide (DEPA) with essential oils against *Aedes aegypti*, vector of dengue and chikungunya. Int J Mosq Res 2015;2:17-20.
45. Rao SS, Rao KM. Insect repellent N, N-diethylphenylacetamide: An update. J Med Entomol 1991;28:303-6.
46. Kalyanasundaram M. A preliminary report on the synthesis and testing of mosquito repellent. Ind J Med Res 1982;76:190-5.
47. Debboun M, Frances S, Strickman D. Insect Repellents Handbook. Boca Raton, FL: CRC Press; 2014.
48. Casida JE. Pyrethrum flowers and pyrethroid insecticides. Environ Health Perspect 1980;34:189-202.
49. Schreck CE, Posey K, Smith D. Durability of permethrin as a potential clothing treatment to protect against blood-feeding arthropods. J Econ Entomol 1978;71:397-400.
50. Sakulku U, Nuchuchua O, Uawongyart N, Puttipipatkhachorn S, Soottitantawat A, Ruktanonchai U. Characterization and mosquito repellent activity of citronella oil nanoemulsion. Int J Pharm 2009;372:105-11.
51. Naseri N, Valizadeh H, Zakeri-Milani P. Solid lipid nanoparticles and nanostructured lipid carriers: structure preparation and application. Adv Pharm Bull 2015;5:305-13.
51. Kasting GB, Bhatt VD, Speaker TJ. Microencapsulation decreases the skin absorption of N, N-diethyl-m-toluamide (DEET). Toxicol Vitr 2008;22:548-52.
52. Solomon B, Sahle FF, Gebre-Mariam T, Asres K, Neubert RH. Microencapsulation of citronella oil for mosquito-repellent application: Formulation and *in vitro* permeation studies. Eur J Pharm Biopharm 2012;80:61-6.
53. Kasting GB, Bhatt VD, Speaker TJ. Microencapsulation decreases the skin absorption of N, N-diethyl-m-toluamide (DEET). Toxicol Vitr 2008;22:548-52.
54. Pathak C, Vaidya FU, Pandey SM. Mechanism for Development of Nanobased Drug Delivery System. Netherlands: Elsevier Inc.; 2019.
55. Shi X, Zhou W, Ma D, Ma Q, Bridges D. Review article electrospinning of nanofibers and their applications for electrospinning of nanofibers and their applications. J Nanomater 2015;2015:140716.
56. Lis MJ, Carmona ÓG, Carmona CG, Bezerra FM. Inclusion complexes of citronella oil with β-cyclodextrin for controlled release in biofunctional textiles. Polymers (Basel) 2018;10:1-14.
57. Cal K, Centkowska K. Use of cyclodextrins in topical formulations: Practical aspects. Eur J Pharm Biopharm 2008;68:467-78.
58. Menezes PP, Serafini MR, Santana BV, Nunes RS, Quintans LJ, Silva GF, *et al*. Solid-state β-cyclodextrin complexes containing geraniol. Thermochim Acta 2012;548:45-50.
59. Songkro S, Hayook N, Jaisawang J, Maneenuan D, Chuchome T, Kaewnopparat N. Investigation of inclusion complexes of citronella oil, citronellal and citronellol with b-cyclodextrin for mosquito repellent. J Incl Phenom Macrocycl Chem 2012;72:339-55.
60. Sawyer, ultra 30 CRIR (Controlled Release Insect Repellent), Extended-Release Insect Repellent.2015.
61. Villanova JC, Oréfice RL, Cunha AS. Aplicações farma. Polímeros 2015;20:51-64.
62. Balaji AP, Mishra P, Kumar S, Mukherjee RS, Chandrasekaran N. Nanoformulation of poly (ethylene glycol) polymerized organic insect repellent by PIT emulsification method and its application for Japanese encephalitis vector control. Colloids Surfaces B Biointerfaces 2015;128:370-8.
65. Bhatt S, Weiss D, Cameron E, Bisanzio D, Mappin B, Dalrymple U. The effect of malaria control on Plasmodium falciparum in Africa between 2000 and 2015. Nature; 2015;526:207-11.
64. World Health Organization. Annex VII: Procedure for Treating Mosquito Nets and Curtains. Geneva: World Health Organization; 2012.
65. Mosquito Netting Criteria. Available from: https://en.wikipedia.org/wiki/Mosquito_net [Last accessed on 2009 Oct 27].
66. Swales J. Malaria: Fever Wars. United States: CDC; 2006.
67. Erin M, Mosquito Coil, the New Oxford American Dictionary. Oxford:

Oxford University Press; 2005. p. 1105.
68. Jamal H, Juliana J. Mosquito coil emission and health implications. Environ Health Perspect 2003;111:1454-60.
69. Trumbull CP. Disasters. Britannica Book of the Year. Chicago, Illinois: Encyclopædia Britannica, Inc.; 2000. p. 161.
70. Zeichner BC, Debboun M. The lethal ovitrap: A response to the resurgence of dengue and chikungunya. US Army Med Dep J 2011 (5);4-11. PMID: 21805450
71. Gignac J. Canadian Researcher's Mosquito Trap Offers Hope in Fight Against Zika Spread. 2016.
72. Okumu FO, Killeen GF, Ogoma S, Biswaro L, Smallegange RC, Mbeyela E, *et al*. Development and field evaluation of a synthetic mosquito lure that is more attractive than humans. PLoS One 2010;5:8951.