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BEYOND CHEMICALS: A HOLISTIC REVIEW OF NATURAL MOSQUITO REPELLENTS FOR HEALTHIER LIVING

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Abstract

Worldwide increases in the prevalence of diseases transmitted by mosquitoes such as malaria, dengue, Zika, chikungunya, yellow fever, and yellow fever have raised demand for insect repellents. Because the vital oils of plants include active ingredients including limonene, 1,8-cineole, geraniol, eugenol, and citronellal, there is a growing interest in using plants as a natural mosquito repellant. While emulsions and aerosols are frequently utilized in patents, natural repellent compositions such as aerosols and lotions are readily accessible in the market. For natural repellents, microparticles are the ideal extended-release technique; the most often used kind is citronella essential oil. Further research ought to concentrate on extended-release methods based on nanotechnology and materials that decompose. There are dangers to people and the environment associated with synthetic pesticides used to manage insects and other arthropods. As an alternative, natural solutions like plant-derived essential oils are being investigated. Monoterpenes and sesquiterpenes, which have repelling qualities, are found in essential oils. A few of the oils' constituents may combine to increase efficacy. The oils extracted from Cymbopogon spp., Ocimum spp., and Eucalyptus spp. show potential when used as repellents. Certain compounds have strong repellant properties, such as limonene, thymol, and alpha-pinene. Natural items could be less harmful to the environment and humane repellents.

Keywords: **Essential Oils, Citronella, Eucalyptus, Neem, Repellent Formulation, Natural mosquito repellent.**

Introduction

Insects are everywhere, and while some may be harmless, others can pose serious threats to our health and comfort. Mosquitoes, ticks, flies, and other biting insects are not just annoying; they can also transmit diseases like malaria, dengue fever, Zika virus, Lyme disease, and more. To protect ourselves from these tiny but mighty creatures, insect repellents have become a necessity in many parts of the world.[1]

Insect repellents are substances designed to deter insects from landing or biting. They come in various forms, including sprays, lotions, creams, and candles. The primary goal of insect repellents is to prevent insect bites, which can cause discomfort, itching, and in some cases, serious illnesses. By keeping insects at bay, repellents help reduce the risk of insect-borne diseases and contribute to overall public health.[2]

Traditionally, synthetic chemicals such as DEET (N, N-diethyl-meta-toluamide) have been the go-to option for insect repellents. While effective, these chemicals have raised concerns about their safety and environmental impact. Some people may experience skin irritation or other adverse reactions to synthetic repellents, and there are questions about their long-term effects on human health and the ecosystem.[3]

Given the drawbacks associated with synthetic repellents, there has been growing interest in exploring natural alternatives. Natural insect repellents are derived from plant-based ingredients such as essential oils, extracts, and herbs. These substances have been used for centuries by various cultures around the world to repel insects and pests. Unlike synthetic chemicals, natural repellents are often perceived as safer and more environmentally friendly.[4]

In summary, insect repellents play a crucial role in protecting humans from insect bites and the diseases they may carry. While synthetic repellents have been widely used, concerns about their safety and environmental impact have led to increased interest in natural alternatives. By exploring the efficacy, safety, and practicality of natural insect repellents, we can better understand their potential role in insect bite prevention and public health efforts.[5]

Natural Insect Repellents: Types and Sources

In this section, we will explore the various types and sources of natural insect repellents, focusing on plant-based ingredients and other natural substances known for their repellent properties. Understanding the different types and sources of natural repellents is essential for evaluating their efficacy, safety, and practicality in insect bite prevention.[6]

Plant-based Repellents

Plant-based repellents are derived from botanical sources such as leaves, stems, flowers, and seeds. These repellents contain active compounds that repel or deter insects from landing or biting. One of the most common types of plant-based repellents is essential oils, which are concentrated extracts obtained from aromatic plants through steam distillation or cold pressing.[7]

Essential Oils:- Essential oils are highly concentrated liquids containing volatile aromatic compounds extracted from plants. These oils often possess strong fragrances and characteristic scents, which can repel insects. Some of the most commonly used essential oils for insect-repellent purposes include.[8]

i. **Citronella Oil**:- Citronella oil is derived from the leaves and stems of various Cymbopogon species, particularly Cymbopogon nardus and Cymbopogon winterianus. It is known for its strong lemon-like scent and is effective against mosquitoes and other biting insects.[9]

ii. **Lemon Eucalyptus Oil:-** Lemon eucalyptus oil is obtained from the leaves of the Eucalyptus citriodora tree. It contains a compound called p-menthane-3,8-diol (PMD), which has been found to be effective against mosquitoes, ticks, and other insects.

iii. **Lavender Oil:-** Lavender oil is extracted from the flowers of the Lavandula angustifolia plant. It has a pleasant floral aroma and is known for its calming and insect-repellent properties.

iv. **Peppermint Oil:-** Peppermint oil is derived from the leaves of the Mentha piperita plant. It has a refreshing minty scent and is believed to repel mosquitoes, ants, and spiders.

v. **Tea Tree Oil:-** Melaleuca alternifolia leaves are used to make tea tree oil, sometimes referred to as melaleuca oil.It has antiseptic, antimicrobial, and insect-repellent properties, making it useful for treating insect bites and preventing infections.

Other Plant-based Repellents:

In addition to essential oils, various other plant-based ingredients have been explored for their insect-repellent properties. These include:- [10]

i. **Neem Oil:-** The seeds of the neem tree (Azadirachta indica) are used to extract neem oil. It includes substances that are insecticidal and repellant to flies, mosquitoes, and other insects, such as azadirachtin.[11]

ii. **Catnip Oil:-** Catnip oil is derived from the Nepeta cataria plant, a member of the mint family. It contains a compound called nepetalactone, which is known to repel mosquitoes, cockroaches, and other insects.[12]

iii. **Garlic Extract:-** Garlic (Allium sativum) contains sulfur compounds that produce a strong odor repulsive to mosquitoes and other insects. Garlic extract can be used as a natural insect repellent when applied to the skin or diffused in the air.

iv. **Cinnamon Oil:-** Cinnamon oil is extracted from the bark of the cinnamon tree (Cinnamomum verum or Cinnamomum cassia). It has a warm, spicy aroma and is believed to repel mosquitoes and other insects.

Most Frequent Insect Repellents[13, 14]

There exist several insect repellants derived from plants and utilized for this purpose. One notes that numerous plants are examined as potential insect repellents in both local and laboratory settings. In the conducted studies, the duration of efficacy of the extracts or essential oils derived from multiple endemic plants, based on their concentration, against insects as well as their ability to repel insects were assessed. The plants predominantly employed as insect repellents up until the year 2020 are succinctly outlined in Table 1.

Table no. 1: most frequent insect repellents

Plant	Chemical Constituents	Quantity	Uses
Citronella	Citroellal, citronellol, geraniol	Varied	Citronella oil: insect repellent, flavoring, antimicrobial.
Neem	Azadirachtin, Nimbin, nimbidin	Varied	Neem: traditional medicine, antifungal, antibacterial, insecticidal, natural pesticide.
Rosemary	Rosmarinic acid, carnosic acid, rosmaridiphenol	Varied	Rosemary: cooking, cosmetics, herbal medicine, antioxidant, anti-inflammatory, antimicrobial.
Clove	Eugenol, eugenol acetate, β-caryophyllene	Varied	Clove: cooking, dental care, traditional medicine, analgesic, antimicrobial, antifungal.
Turmeric	Curcumin, demethoxycurcumin,bisdemethoxycurcumin	Varied	Turmeric: spice, food coloring, traditional medi-

			cine, anti-inflammatory, antioxidant, antimicrobial..
Eucalyptus	Eucalyptol (1,8-cineole), α-pinene, limonene	Varied	Eucalyptus: pharmaceuticals, cosmetics, aromatherapy, decongestant, antimicrobial, insect repellent.

Citronella *(Cymbopogon nardus)*

Citronella, derived from various types of lemongrass is a vital essential oil used in natural repellent products. It typically comprises α-pinene, citronellal, β-citronellol, and other compounds. Lemongrass itself contains addi tional constituents like nerol, geraniol, and linalool. While citronella is effective against mosquitoes like Anopheles culicifacies for 11 hours higher concentrations may cause skin sensitivity. confirm its efficacy.[15]

Figure no. 1: citronella (*cymbopogon nardus*)

Peppermint (*Mentha piperita*)

Peppermint, a hybrid of spearmint and water mint, contains potent biological compounds like menthone and menthol. Originally from Europe and the Middle East, it's now grown globally. Farnad and Aslanipour identified various components in peppermint through HPLC, including ascorbic acid, rutin, and gallic acid. In a study found that undiluted peppermint oil repelled Anopheles mosquitoes with 100% efficacy for 11 hours.[16]

Figure no. 2: peppermint (*mentha piperita*)

Eucalyptus (*Eucalyptus teriticornis*)

Eucalyptus, particularly lemon eucalyptus (Corymbia citriodora), contains para-menthane-3,8-diol (PMD), a potent insect repellent as effective as DEET. PMD's lower vapor pressure compared to other plant oils ensures longer-lasting protection. Lemon eucalyptus essential oil repels mosquitoes for about an hour, but hydro-distillation produces a distillate with superior repellency. Different eucalyptus subspecies vary in repellency rates; lemon-scented eucalyptus offers the highest protection, followed by narrow-leaved and broad-leaved eucalyptus, against An. stephensi for up to 8 hours. Eucalyptus globulus essential oil provides complete protection against An. virus for 1.7 to 3.4 hours, depending on concentration.[17]

Figure no. 3: eucalyptus (*eucalyptus teriticornis*)

Neem (*Azadirachta indica*) Neem, a tropical tree native to the Indian subcontinent and much of Africa serves as a natural alternative to DEET for repelling insects. Despite not being confirmed by the EPA for topical use, neem has low cutaneous toxicity but may cause skin irritation if undiluted. Its primary active ingredient, azadirachtin, along with other compounds like Nimbin and quercetin, contribute to its repellent properties. Neem leaves contain various constituents, including polyphenolic flavonoids with antibacterial and antifungal qualities. Asadollahi et al. noted that a 20% dilution of neem and chinaberry oils achieved a 71% repellency rate against An. arabiensis. Additionally, Mishra et al. found that neem extract is more effective at repelling female Anopheles mosquitoes compared to Culex species.[18]

Figure no. 4 neem (*azadirachta indica*)

Rosemary (*Rosmarinus officinalis*)
Rosemary, a fragrant evergreen shrub belonging to the Lamiaceae (Labiatae) family and native to the Mediterranean region, demonstrates effectiveness as a mosquito repellent. Amer et al. utilized a 20% oil solution of rosemary (R. officinalis) to repel Anopheles stephensi mosquitoes, providing complete protection for eight hours. Additionally, Banupriya and Maheshwari conducted tests on cotton plain-woven fabrics treated with rosemary extract, which showed mosquito-repellent rates of 92% for treated fabrics compared to 0% for untreated ones.[19]

Figure no. 5: rosemary (*salvia rosmarinus*)

Turmeric (*Curcuma longa*)
Turmeric, a member of the Zingiberaceae family, is not only a culinary spice but also possesses medicinal properties. According to Auysawasdi et al., turmeric essential oil demonstrates significant repellent efficacy against Anopheles dirus, with varying durations of protection at different concentrations. Additionally, Tawatsin et al. reported a 100% repellency effect for six hours using 3 ml of volatile turmeric oil.[20]

Figure no. 6: turmeric (*curcuma longa*)

Chrysanthemum (*Dendranthema grandiflora*)

Chrysanthemum, belonging to the Asteraceae family, is native to China, Northeastern Europe, and East Asia, with various horticultural variations and cultivars. Bhatt and Kale discovered that applying chrysanthemum oil nanoemulsion using layer-by-layer (LBL) finishing on nylon 66 net textiles resulted in repellency rates of 55%, 75-80%, and 95% at concentrations of 50 g/l, 75 g/l, and 100 g/l, respectively Pyrethroids, synthetic compounds mimicking chrysanthemum flower extracts, are commonly used as insecticides. Permethrin, a well-known synthetic pesticide, falls under the pyrethroid category.[21]

Figure no. 7: chrysanthemum (*dendranthema grandiflora)*

Castor Oil Plant (*Ricinus communis*)

Castor oil plant, belonging to the genus Ricinus in the Euphorbiaceous spurge family, has mosquito and fly-repelling properties, and its mature trees are incompatible with moles and garden insects. Castor oil, derived from its seeds, is utilized in medicinal formulations for combating various dangerous fungi and insects. Meghan researched applying 2% castor oil to cotton fabrics, resulting in reduced mosquito contact compared to untreated fabrics. The optimal outcome was achieved with 2% castor oil and 6% binder using the pad-batch-dry process, although the mosquito-repellent finish showed low washing resistance.[22]

Figure no. 8: castor oil plant (*ricinus communis*)

Oleander (*Nerium oleander*)

Nerium oleander, a plant known for its toxicity, acts as a natural insect repellent due to its compounds such as flavonoids, sterols, terpenes, and coumarins, which protect against diseases and insects, inhibit insect reproductive functions, and cause cell denaturation and transitions in insects.[23]

Figure no. 9: oleander (*nerium oleander*)

Table no. 2: common natural insect repellents, the parts used for oil extraction, and the methods of extraction

Repellents	Parts Used for Extraction	Extraction Method
Citronella	Cymbopogon nardus Leaves	Steam Distillation
Lavender	Lavandula angustifolia flowers	Steam Distillation
Tea Tree	Melaleuca alternifolia leaves	Steam Distillation
Neem	Azadirachta indica seeds	Cold Expeller Pressing, Rolling, Centrifugation
Eucalyptus	Corymbia citriodora leaves	Steam Distillation
Peppermint	Menthe Piperita leaves	Steam Distillation
Lemongrass	Cymbopogon citratus leaves	Steam Distillation

Comparison of Efficacy:

Studies have evaluated the efficacy of various natural insect repellents against different insect species, comparing them to synthetic repellents like DEET.[24] While natural repellents may offer protection against certain insects, their efficacy can vary depending on factors such as concentration, formulation, and application method.[25] Some natural repellents, such as citronella oil and lemon eucalyptus oil, have been found to be comparable to DEET in terms of efficacy against mosquitoes. However, their duration of protection may be shorter, requiring more frequent reapplication. It's important to note that the efficacy of natural repellents may also be influenced by individual factors such as body chemistry, sweat production, and attractiveness to insects. What works well for one person may not be as effective for another.

Natural insect repellents derived from plant-based sources offer a promising alternative to synthetic chemicals for insect bite prevention. Essential oils, neem oil, catnip oil, garlic extract, and cinnamon oil are among the many plant-based ingredients known for their repellent properties.[26] These natural repellents can be used individually or in combination to create effective formulations against mosquitoes, ticks, flies, and other biting insects. While their efficacy may vary, especially compared to synthetic repellents like DEET, natural repellents are generally considered safer for human health and the environment.

Further research is needed to better understand the efficacy, safety, and practicality of natural insect repellents, including their long-term effects and optimal formulations. By exploring the types and sources of natural repellents, we can harness the power of nature to protect ourselves from insect-borne diseases while minimizing our impact on the environment.[27]

Efficacy of Natural Insect Repellents[28]

Natural insect repellents offer a promising alternative to synthetic chemicals for protecting against insect bites.[29]In this section, we will explore the efficacy of natural repellents against various insect species, the factors influencing their effectiveness, and comparisons with synthetic repellents.

Studies Evaluating Repellent Efficacy Against Specific Insect Species:

Numerous studies have investigated the efficacy of natural insect repellents against specific insect species.[29] These studies typically involve laboratory experiments and field trials to assess the effectiveness of different repellent formulations.[30]

Table no. 3: repellent efficacy against specific insect species[31]

Insect Species	Natural Repellent	Study Findings
Mosquitoes	Citronella oil	Effective in repelling mosquitoes
	Lemon eucalyptus oil	Comparable to DEET in repelling mosquitoes
Ticks	Neem oil	Repellent activity against tick vectors
		Potential for tick bite prevention
Flies	Catnip oil	Repellent activity against various fly species
	Eucalyptus oil	Effective against biting flies

Factors Influencing Efficacy:

The efficacy of natural insect repellents can be influenced by various factors:-

i. **Concentration of Active Ingredients:** Higher concentrations of active ingredients may provide longer-lasting protection, but excessive concentrations can increase the risk of skin irritation. Finding the right balance is crucial for maximizing efficacy while minimizing adverse effects.[32]

ii. **Formulation**: The formulation of repellents, such as creams, sprays, or lotions, can affect their efficacy and ease of application. Different formulations may be suitable for different use cases or target insects.

iii. **Application Method**: Proper application techniques, such as thorough coverage of exposed skin, can enhance repellent efficacy. Reapplication may be necessary, especially in humid or high-activity environments.[33]

iv. **Environmental Conditions**: Factors such as temperature, humidity, wind, and vegetation can influence the effectiveness of natural repellents. Strong winds or heavy rainfall may reduce repellent potency.

v. **Individual Factors**: Body chemistry, sweat production, and attractiveness to insects vary among individuals and can affect repellent efficacy. Some people may require higher concentrations or more frequent applications for adequate protection.[34]

Comparison of Efficacy with Synthetic Repellents:

Comparative studies have evaluated the efficacy of natural and synthetic insect repellents against various species:-

- **Mosquitoes**: Some natural repellents, such as lemon eucalyptus oil, have been found to be comparable to DEET in repelling mosquitoes. However, efficacy may vary depending on the specific repellent and concentration used.

- **Ticks**: While natural repellents like neem oil and rosemary oil have shown promise in repelling ticks, synthetic chemicals like permethrin are often more reliable for tick bite prevention. Further research is needed to identify the most effective natural repellents for tick control.[35]

Natural repellents containing ingredients such as catnip oil and eucalyptus oil have demonstrated repellent activity against various fly species. However, their efficacy may not be as consistent or long-lasting as synthetic repellents in some cases.[36]
Natural insect repellents show promise as effective alternatives to synthetic chemicals for insect bite prevention. Studies have demonstrated their efficacy against mosquitoes, ticks, flies, and other biting insects. However, efficacy can be influenced by factors such as concentration, formulation, application method, environmental conditions, and individual factors. Comparative studies have found some natural repellents to be comparable to synthetic repellents like DEET, but further research is needed to identify the most effective formulations for different insect species and conditions.[37]

Properties of Ideal Insect Repellents:
An ideal insect repellent should be effective against a broad range of arthropods[38]

- Safe to apply on the skin without adverse effects,
- Not damage clothing or plastics,
- Have no odor or a pleasing odor,
- Leave no oily residues on the skin,
- Be difficult to remove by washing or sweating,
- Chemically stable,
- Reasonably priced,
- Nontoxic

Test Methods for Determining Effectiveness of Insect Repellents:
There are several methods for evaluating the effectiveness of insect repellents and repellent-treated textiles. The most used techniques are cage test, cone test, and excito chamber test.[39]

Cage Test
The cage test is one of the most used techniques for applying insect repellents. This technique works well for testing impregnated textiles and topical repellents (creams, lotions, and spray formulations). This approach involves watching mosquito behavior inside of a cage. Mosquitoes are shown descending on the subject after they wear treated and conventional cloth separately. One benefit of this technique is that it allows one to witness mosquito landings and bites on humans while also allowing one to see mosquito movement right up against the fabric coated with repellent. The cage test's drawback is that it uses human participants.[40]
When it comes to human engagement, it is best to get the volunteers' permission and an authority's ethical approval. The test mosquitoes need to be pathogen-free. As a result, participants may be sure the test won't hurt them.[41]

Figure no. 10: cage test for measuring the effectiveness of *mosquito repellent* in a laboratory

Cone Test
One technique for assessing a mosquito repellent's efficiency is the cone test. There are no human subjects involved, in contrast to the cage test. Instead, five female mosquitoes are placed within a cone that is set on a fabric surface that has been coated with repellant. The mosquitoes are removed and their death is observed after three minutes of exposure.[42] For precision, this step is performed several times. To ascertain natural death rates, a control group of mosquitoes exposed to untreated cloth is also employed. A formula is used to determine the percentage of mosquito fatalities attributable to repellent exposure. With this approach, the effectiveness of repellents is rigorously tested without involving humans.[43]

Figure no. 11: apparatus for WHO cone bioassay test

Excito chamber test

To differentiate between materials treated with insect repellant and untreated materials, the procedure entails studying mosquito behavior. There are no human volunteers in this. Prior to the test, the mosquitoes are not fed, and they are exposed for ten to thirty minutes. Using a formula based on the total number of exposed mosquitoes, escaped mosquitoes, and dead mosquitoes, the percentage of insect repellent is determined.[44] When evaluating items with and without insect repellent, this technique is helpful. It's also said that there isn't a trustworthy way to assess worn textile items' insect repellent performance at this time. Rather, controlled environment testing such as knock tests and bioassays are frequently employed.[45]

Figure no. 12: measurement of repellency by Excite-chamber test

World Health Organization (WHO) Repellency Test Standards:

Researchers developing plant-based insect repellents should adhere to World Health Organization (WHO) testing guidelines. It's crucial to include a control group using DEET, a common synthetic repellent, in studies to accurately compare results and detect any potential errors. Following these guidelines ensures reliability and consistency across studies. Comparing plant-based repellents to DEET helps validate findings and provides a standard for evaluation. Considering potential errors in experimental design is vital for accurate interpretation of results. By following standardized protocols and incorporating appropriate controls, researchers can generate reliable data on plant-based repellent effectiveness, advancing our understanding of natural alternatives and enhancing public health strategies for preventing vector-borne diseases.[46]

Table no. 4: the WHOPES guidelines outline steps for testing repellents, including initial screening for adverse reactions and subsequent evaluations for efficacy and safety

WHOPES approved repellent testing methodology
Laboratory Testing
Use 20% DEET in ethanol as a positive comparison
Human subjects preferable to reflect the end user
Before the test, the test area of skin should be washed with unscented soap then rinsed with 70% ethanol / isopropyl alcohol
Mosquitoes should be reared under standard 27±2 °C temperature, ≥ 80±10% relative humidity, and a 12:12 (light:dark) photoperiod
Mosquitoes should be 3 to 5 days old, nulliparous females, starved for 12 hours preceding the test
Tests should be conducted with three or more species
40 x 40 x 40 cm cages with 50-100 mosquitoes for effective dose testing
40 x 40 x 40 cm cages with 200-250 mosquitoes for complete protection time testing
Control arms should be used to estimate mosquito readiness to feed
Treatment arms should be offered to mosquitoes after avidity has been measured
Field Testing
Use 20% DEET in ethanol as a positive comparison
Human subjects preferable to reflect the end user
Before the test, the test area of skin should be washed with unscented soap then rinsed with 70% ethanol / isopropyl alcohol
Volunteers should sit >20 meters apart
Design should be completely randomised
Trials should be conducted with medium biting pressures of representative vector species
All participants should be recruited on informed consent from the local area and be provided with malaria prophylaxis
In all testing monitoring of adverse effects should be carried out

Safety and Environmental Considerations:

In this section, we will explore the safety and environmental considerations associated with the use of natural insect repellents.[47] While natural repellents are often perceived as safer alternatives to synthetic chemicals, it's essential to evaluate their potential risks to human health and the environment.[48]

Human Health Safety

Skin Irritation and Sensitization: Natural repellents, particularly those containing concentrated essential oils, may cause skin irritation or sensitization in some individuals. This can manifest as redness, itching, or allergic reactions upon contact with the skin. It's important to perform patch tests and follow recommended dilution guidelines to minimize the risk of adverse reactions.

Inhalation Exposure: Inhalation of airborne repellent particles or vapors may occur during the application or use of natural repellents, especially in poorly ventilated areas. Certain essential oils can irritate the respiratory tract or trigger asthma symptoms in sensitive individuals. Using repellents in well-ventilated spaces and avoiding direct inhalation can help reduce the risk of respiratory irritation.

Oral Ingestion: Accidental ingestion of natural repellents, particularly by children or pets, can lead to gastrointestinal upset or poisoning. Some essential oils are toxic if ingested in large quantities and should be stored securely out of reach. Educating consumers about the potential dangers of ingestion and providing child-resistant packaging can help prevent accidental poisonings.

Environmental Impact:

- **Ecotoxicity**: Natural repellents may have unintended effects on non-target organisms and ecosystems due to their bioactive compounds. Runoff from repellent-treated surfaces or disposal of unused products into water bodies can contaminate aquatic environments and harm aquatic organisms. Assessing the ecotoxicity of natural repellents through laboratory and field studies can help mitigate potential environmental risks.[49]

- **Persistence and Bioaccumulation**: Some natural repellents may persist in the environment or bioaccumulate in organisms, posing long-term risks to ecosystem health. Essential oils with high persistence or bio-accumulative potential can accumulate in soil, water, and sediments, affecting microbial communities and aquatic food webs. Understanding the fate and behaviour of natural repellents in the environment is essential for assessing their environmental impact.

- **Non-Target Effects**: Natural repellents may inadvertently affect non-target insects, including beneficial pollinators such as bees and butterflies. While repellents are intended to deter pests, they may also repel or harm beneficial insects, disrupting ecological balance and ecosystem services. Developing repellent formulations that selectively target pest species while minimizing harm to non-target organisms is a key consideration for environmental safety.

Regulatory Oversight and Labelling:

Labelling Requirements: Regulatory agencies such as the Environmental Protection Agency (EPA) in the United States and the European Chemicals Agency (ECHA) in Europe impose labelling requirements for insect repellents to inform consumers about potential hazards and proper use.[50] Labels should include information on active ingredients, application instructions, precautions, and first aid measures in case of exposure.

Registration and Approval: In many countries, insect repellents, including natural formulations, are subject to registration and approval by regulatory authorities before they can be marketed and sold to consumers.[51] This process involves **evaluating** product efficacy, safety, and environmental impact through laboratory testing and field trials. Registration requirements help ensure that repellents meet established standards for human health and environmental protection.

Public Education and Awareness: Educating the public about the safe and responsible use of natural insect repellents is essential for minimizing risks to human health and the environment. Providing clear instructions on product labels, disseminating information through public health campaigns, and promoting sustainable practices such as proper disposal can help raise awareness and promote the safer use of repellent products.

Safety and environmental considerations are essential aspects to consider when evaluating the use of natural insect repellents. Understanding potential risks to human health and the environment, regulatory oversight, and promoting public education and awareness can help ensure the safe and responsible use of these products while minimizing adverse effects on ecosystems.

Table no. 5: comparison of safety and environmental considerations

Aspect	Synthetic Repellents	Natural Repellents
Skin Irritation and Sensitization	Potential for skin irritation, allergies in sensitive individuals.	Essential oils: skin irritation, sensitization potential.
Inhalation Exposure	Inhalation of vapors may irritate the respiratory tract	Inhalation of airborne repellent particles can cause respiratory irritation
Oral Ingestion	Toxic if ingested in large quantities;child-resistant packaging recommended	Accidental ingestion can lead to gastrointestinal upset or poisoning
Ecotoxicity	May have adverse effects on aquatic organisms and ecosystems	Runoff and disposal can harm aquatic ecosystems; potential ecotoxicity
Persistence and Bioaccumulation	Some compounds may persist in the environment or bioaccumulate in organisms	Essential oils may persist in the environment or bioaccumulate in organisms

Non-Target Effects	May harm non-target insects, including beneficial species	May inadvertently affect beneficial pollinators
Regulatory Oversight and Labeling	Subject to regulatory approval and labeling requirements	Subject to registration and approval; labeling requirements for safety and proper use
Public Education and Awareness	Public education initiatives on proper use and disposal	Promotion of safe and responsible use practices

Safety-related to natural repellent:

Since ancient times, humans have relied on natural repellants like burning leaves or direct contact with certain plants to fend off pesky mosquito bites. These methods have been passed down through generations, with anecdotal evidence suggesting their effectiveness. However, despite their long history of use, there's a notable gap when it comes to safety evaluations regarding the concentrations at which these repellants are employed.[52]

Traditionally, people have used various plant materials, such as citronella, eucalyptus, and lemongrass, either by crushing and applying them directly to the skin or by burning them to release their aromatic compounds into the air. These methods are believed to work by masking the scent of humans or by producing odours that mosquitoes find unappealing, thus deterring them from landing and biting.

While these natural solutions may offer some protection against mosquitoes, concerns arise regarding their safety, particularly in terms of the concentrations used. Without proper evaluation, it's challenging to ascertain whether these repellants pose any risks, especially with prolonged or repeated exposure.[53]
In today's world, where safety standards are rigorously enforced, there's a growing need for scientific research to assess the efficacy and safety of these traditional repellants. This would involve studying the optimal concentrations needed for effectiveness while ensuring they do not cause harm to human health through skin irritation, allergic reactions, or other adverse effects.

In summary, while natural repellants like burning leaves or direct contact with plants have been utilized for centuries to ward off mosquitoes, their safety remains uncertain due to the lack of comprehensive evaluations on the concentrations used. As our understanding of mosquito control evolves, it's imperative to bridge this gap through thorough scientific research to ensure both efficacy and safety in mosquito bite prevention methods.

Table no. 6: safe concentrations of several ingredients which commonly exist in plant-based repellents

Ingredient	Safe Concentration Range
Citronella Oil	5-10%
Lemon Eucalyptus Oil	30-40%
Peppermint Oil	2-10%
Lavender Oil	5-10%
Tea Tree Oil	5-10%
Cedarwood Oil	10-20%

Commercial Availability and Practical Considerations:

In this section, we will explore the commercial availability and practical considerations associated with natural insect repellents. Understanding where to find these products and how to use them effectively is crucial for individuals seeking alternatives to synthetic repellents.

Availability of Natural Insect Repellents:

- **Retail Stores**: Many retail stores, including supermarkets, pharmacies, and outdoor recreation stores, carry a variety of natural insect-repellent products. These products may be found in the personal care or outdoor sections, alongside synthetic repellents.[54]

- **Online Retailers**: Natural insect repellents are readily available for purchase from online retailers, including e-commerce platforms such as Amazon, Walmart, and specialty outdoor gear websites. Online shopping offers convenience and access to a wider range of product options.

- **Specialty Stores**: Some specialty stores focus exclusively on natural and eco-friendly products, including insect repellents. These stores may offer a curated selection of high-quality natural repellents sourced from sustainable and ethical sources.

Practical Considerations for Using Natural Insect Repellents:

- **Application Methods**: Natural insect repellents are available in various formulations, including sprays, lotions, creams, and wearable devices such as bracelets or patches. Choosing the right formulation depends on personal preference, intended use, and convenience.[55]

- **Frequency of Application**: Natural repellents may require more frequent reapplication compared to synthetic repellents, especially in hot and humid conditions or during outdoor activities such as hiking or camping. Following product instructions for reapplication intervals is essential for maintaining effectiveness.[56]

- **Compatibility with Clothing and Gear**: Some natural repellents may interact with certain fabrics or materials, potentially causing stains, discoloration, or damage. It's advisable to test repellents on a small, inconspicuous area of clothing or gear before widespread use to avoid unwanted effects.

- **Storage and Shelf Life**: Proper storage of natural insect repellents is essential for maintaining efficacy and prolonging shelf life. Store products in a cool, dry place away from direct sunlight and heat sources to prevent degradation of active ingredients. Check expiration dates and dispose of expired or deteriorated products responsibly.

- **Avoidance of Sensitive Areas**: When applying natural repellents, avoid contact with sensitive areas such as eyes, mouth, and open wounds to prevent irritation or adverse reactions. Use caution when applying repellents to children, pregnant women, or individuals with sensitive skin, and follow product-specific guidelines for safe use.[57]

Table no. 7: comparison of commercial availability and practical considerations

Aspect	Natural Insect Repellents	Synthetic Insect Repellents
Availability	Found in retail stores, online retailers, and specialty stores	Widely available in retail stores pharmacies, and outdoor retailers
Application Methods	Sprays, lotions, creams, wearable devices	Sprays, lotions, creams, aerosols, roll-ons
Application Methods	May require more frequent reapplication	Typically longer-lasting; reapplication less frequent
Compatibility with Clothing and Gear	Some formulations may interact with certain fabrics or materials	Generally compatible with most fabrics and materials
Storage and Shelf Life	Store in a cool, dry place away from sunlight; check the expiration	Store in a cool, dry place away from sunlight; check the expiration
Avoidance of Sensitive Areas	Avoid contact with eyes, mouth, and open wounds; use caution	Follow label instructions; avoid contact with sensitive areas

Commercially available natural insect repellents offer consumers a viable alternative to synthetic products, with options for purchase both in-store and online. Practical considerations such as application methods, frequency of use, compatibility with clothing and gear, storage, and avoidance of sensitive areas are important factors to consider when using natural repellents effectively and safely. By understanding these practical considerations, individuals can make informed choices about the selection and use of natural insect repellents for personal protection against insect bites.

Future Directions and Recommendations:

In this section, we will discuss potential future directions for research and provide recommendations for the use and development of natural insect repellents. By identifying areas for further investigation and offering guidance for practical application, we aim to contribute to the advancement of natural repellent technologies and their effective implementation in public health strategies.[58]

Advancements in Formulation and Delivery Systems

- **Nanotechnology**

  Explore the use of nanotechnology to enhance the efficacy and stability of natural-repellent compounds. Nanoformulations may improve the solubility, bioavailability, and targeted delivery of active ingredients, leading to longer-lasting and more effective repellent products.[59]

- **Microencapsulation**

  Investigate microencapsulation techniques to encapsulate natural repellents within protective matrices. Microencapsulated formulations can provide a controlled release of active ingredients, prolonging repellent efficacy and reducing the need for frequent reapplication.

- **Novel Delivery Systems**
  Develop innovative delivery systems such as transdermal patches, slow-release implants, or biodegradable polymers for sustained and localized delivery of natural repellents. These delivery systems offer convenience, flexibility, and extended protection against insect bites.[60]

Exploration of Novel Active Ingredients:

Plant-Derived Compounds: Screen diverse plant species for bioactive compounds with repellent properties. Explore traditional knowledge and ethnobotanical practices to identify novel plant sources and extract bioactive constituents for repellent formulations.[61]

Microbial-Based Repellents: Investigate the potential of microbial-derived compounds, such as bacterial metabolites or fungal extracts, as natural insect repellents. Microbial-based repellents offer sustainable and eco-friendly alternatives with unique modes of action against insect pests.

Synthetic Analogues: Design and synthesize synthetic analogous of natural repellent compounds to enhance potency, stability, and selectivity. Structure-activity relationship studies can guide the optimization of chemical structures for improved repellent activity and safety profiles.[62]

Integrated Pest Management Strategies:

Combination Products: Develop integrated pest management (IPM) strategies that combine natural repellents with other control measures, such as insecticides, traps, and habitat modification. Synergistic interactions between repellents and other interventions can enhance overall effectiveness in reducing insect populations and disease transmission.[63]

Community-Based Approaches: Implement community-based approaches for the distribution and promotion of natural repellents in endemic areas. Engage local communities in the cultivation, processing, and distribution of repellent plants, empowering them to take ownership of vector control initiatives.[64]

Public Health Education: Strengthen public health education and awareness campaigns to promote the use of natural insect repellents as part of comprehensive vector-borne disease prevention strategies.

The future of natural insect repellents holds promise for innovative advancements in formulation, exploration of novel active ingredients, and integrated pest management strategies. By embracing interdisciplinary approaches and engaging stakeholders at all levels, we can harness the potential of natural repellents to mitigate the burden of vector-borne diseases and promote global health and well-being.

Table no. 8: future directions and recommendations for natural insect repellents

Area of Focus	Recommendations
Advancements in Formulation and Delivery Systems	Explore nanotechnology for enhanced stability. Develop microencapsulation techniques for controlled release Investigate novel delivery systems for sustained and localized protection
Exploration of Novel Active Ingredients	Screen diverse plant species for repellent compounds. Investigate microbial-derived repellents. Design synthetic analogs for improved efficacy.
Integrated Pest Management Strategies	Develop combination products for integrated pest management. Implement community-based approaches for distribution and promotion.

	Strengthen public health education and awareness

Procedure for Making Natural Insect Repellent Cream:[65]

- **Ingredients**
  1) Citronella oil
  2) Lemongrass oil
  3) Eucalyptus oil
  4) Lavender oil
  5) Tea Tree oil
  6) Beeswax
  7) Coconut oil
  8) Vitamin E oil
  9) Glass jars or containers for storage

Figure no.13: repellent cream ingredients

Table no. 9: essential oils, chemicals and glass wares

Essential Oils	Chemical	Glass wares & Apparatus
Citronella	Glycerine	China dish
Eucalyptus	Methyl Paraben	Glass rod
Lavender	Bees Wax	Measuring Cylinder
Lemongrass	Lanolin	Water bath
Tea Tree	-	Spatula
Sandal wood	-	Butter Paper
Rose	-	Weighing Machine
Rosemarry	-	-
Coconut	-	-

Table no. 10: formulation of mosquito repellent cream

Ingredients	Quantity (%)
Citronella oil	0.5 %
Beeswax	12 %
Tea Tree oil	0.5 %
Vitamin E	2 Capsule
Lemongrass oil	0.5 %
Eucalyptus oil	0.5 %
Lavender oil	0.5 %
Coconut oil	10 %
Lanolin	5 %
Methyl Paraben	Q. S

- **Procedure :**

Preparation

Ensure that the work area and all equipment are clean and sanitized before starting.

I. **Measure Ingredients:-** Measure 2 tablespoons of beeswax and 2 tablespoons of coconut oil. Measure 10 drops each of citronella oil, lemongrass oil, eucalyptus oil, and lavender oil. Measure 1 teaspoon of vitamin E oil.[66]

II. **Heat Ingredients:-** In a double boiler or a heat-safe bowl placed over a pot of boiling water, melt the beeswax, coconut oil together. Stir occasionally until all ingredients are fully melted and well combined.

III. **Add Essential Oils:-** Once the mixture is melted, remove it from the heat source. Carefully add the measured drops of citronella oil, lemongrass oil, eucalyptus oil, and lavender oil into the melted mixture. Stir the essential oils into the mixture until evenly distributed.[67]

IV. **Cooling and Mixing:-** Allow the mixture to cool slightly but not solidify completely. Add the vitamin E oil to the mixture and stir well to incorporate.

V. **Pour into Containers:-** Carefully pour the mixture into clean, dry glass jars or containers. Leave the jars open until the mixture has completely cooled and solidified.[68]

VI. **Labeling and Storage:-** Label the jars with the date of preparation and the ingredients used. Store the insect repellent cream in a cool, dry place away from direct sunlight. Use within 6 months for maximum effectiveness.

Figure no.14: Mosquito Repellent Cream

Usage

Apply a small amount of the insect repellent cream onto exposed skin before outdoor activities. Reapply as needed, especially after swimming or sweating.[69]

- Relief from Itching
- Soothing Irritated Skin
- Prevention of Insect Borne Diseaese

Table no. 11: evaluation parameters of [70] mosquito repellent cream

S. No.	Parameters	Result
1.	Description	Pale Yellow colored, smooth cream, having a characteristic odour.
2.	Spreadability	6.1g cm/sec
3.	Irritancy Test	Non-Irritant
4.	pH	7
5.	Thermal Stability	Stable at 45^0 c for 48 hours

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