



Synthesis and Uses of various essential oil based derivatives in biomedicine

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Abstract

Essential oils are naturally occurring compounds. Essential oils are, usually, impulsive as well as odoriferous oils separated from different plants, commonly called as the soul of the plants. The essential oils of citrus species are the by-product of peels of the citrus fruits. The essential oils are sweet scented oils. Essential oils are utilized to flavor the food. These are liquid hydro-carbons as well as pale yellow in color. These are useful due to their charming fragrance. There will be a lot of sources of aroma oils like peels, bark, stem, leaves, as well as seeds, woods and etc. Essential oils of all plants showed bioactivities such as antifungal, antimicrobial, as well as antibacterial, antioxidant. There are different kinds of parameters which are utilized to perform biological-activities. Essential oils Derivatives enhanced the activities of essential oils. In the present review, different bioactivities of essential oils derivatives are reviewed extensively. Main constituents of the essential oils or their derivatives are utilized for the treatment of different infections. These are useful in different medicines.

Key words: Essential oils, Bioactivities, Limonene, Antioxidant, Menthol

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1. Introduction

Demand of essential oils has been increased during the past few years. Essential oils are extracted from fragrant plants which are spread in Mediterranean as well as in tropical areas. Main components of essential oils are used in medicine [1]. Essential oils are extracted from different parts of plants as flowers, bud peels, leaves, fruits, seeds as well as stem and roots of plants. Essential oils are found in cavities as well as in secretory cells and also in epidermic cells [2]. Lamiaceae herb family consists richest essential oil containing plant family, includes 252 genera and seven thousand species[3]. Species of Lamiaceae family show medicinal properties and numerous species are widespread in Mediterranean area. Some species of Lamiaceae are utilized in food preparation, flavors and in traditional medicine. In fact, rosemary, oregano, sage as well as thyme are mostly present in the mediterranean cuisine. Essential oils extracted from Lamiaceae varieties have been utilized against several diseases such as intestinal-disorder as well as bronchitis [4]. An essential oil is an intense hydrophobic liquor containing impulsive fragrance compounds extracted from different plants. Essential oils are also recognized as aromatic oils, or simply as the oil extracted from a plant,

as grapefruit peel oil and clove oil as well as oil of pine, oil extracted from leaves of eucalyptus etc. An oil is "essential" in the way that it includes the "essence of" the plant's odor, the distinctive smell of the plant through which it is extracted. Distillation technique is utilized to separate the aroma oil. Essential oils contain terpenic compounds (hydrocarbons) as well as oxygenated derivatives as ketones, aldehydes, alcohols, and organic acids as well as esters. The impulsive components of oils are sweet-smelling that produce in plants as a result of glycerides degradation through the action of an enzyme. Since these are not glycerides esters, so they are chemically different from edible oil [5]. But the composition of essential oils depends on different seasons [6]. Essential oils are terpenes and also contain fragrant poly-propanoid components separated through acid (acetate mevalonic acid) and also shikimic acid. Different methods usually used for the separation of essential oils such as hydrodistillation, liquid CO₂ extraction, steam distillation method as well as solvent extraction method etc. The composition of separated oil is different from one method to another. Mostly GC-MS analysis is used for the analysis of essential oils [7-9].

Essential oils are utilized as fragrance, flavor or

taste in a lot of foodstuffs, such as alcoholic as well as non-alcoholic beverages, toffee (candy) and gelatins. In pharmaceutical fields, these are used to provide flavor to cover unlikable tastes of the drugs. In cosmetic as well as perfumery, essential oils are utilized in numerous preparations [10-11]. Essential oils are also utilized widely in aromatherapy and in different medicines [12-13]. Different essential oils are used for the treatment of different diseases [6] such as asthma, cancer, as well as HIV, heart strokes and bronchitis, etc. Herbalists mix some essential oils with other essential oils in order of smell or function, to make a huge repertoire combination of the essential oils.

2. Bioactivities

Essential oils displayed biological activities such as antibacterial, antimicrobial, antifungal, and antiviral, insecticidal as well as antioxidant activities [8-14-15]. Out of 3000 essential oils, only 300 essential oils are important on commercial scale such as in the pharmaceutical, food items, agronomic as well as perfume, sanitary and in the cosmetic industries. Essential oils are, commercially, utilized in four main ways: 1) as pharmaceuticals, 2) to give flavor in many food items, 3) as odorants or fragrant, and 4) as an insecticide. These showed antibacterial, antiviral, antifungal, antimite, antitermite and also insecticidal activities [16].

2.1. Antioxidant activity

Antioxidants are frequently utilized in food items since they slow down the adverse changes because of the oxidation [17]. Essential oils (EOs) are liquor combination of impulsive compounds gained through fragrant plants. Numerous essential oils have shown anti-oxidant properties. The use of essential oil as a natural anti-oxidant is increasing the attention since some synthetic antioxidants like butylated hydroxyanisole (BHA) as well as butylated hydroxytoluene (BHT) is now assumed to be potentially dangerous for the health of human. Essential oils are added to other edible products to prevent the auto-oxidation and extend the shelf life [18]. The main source of the bioactive compounds is citrus fruit peels as the major anti-oxidants present in this EOs are phenolic compounds, ascorbic acid, flavonoids and pectins. There are three types of flavonoids (flavanones, flavonols, and flavones) that are present in the citrus fruits. naringin, hesperidine, narirutin and eriocitrin are the main flavonoids that are present in various citrus varieties. Citrus flavonoids show strong antioxidant, anti-carcinogenic and anti-inflammatory properties and reduced the risk of coronary heart disease. Citrus peels contain a high concentration of flavonoids [19]. Antioxidants stop oxidation. Sometimes these are added to foodstuff to stop or slow the oxidative degradation of the fats. Agents of antioxidant are efficient due to several methods as free radical scavenging, and chelating of pro-oxidant metal ions as well as quenching- singlet-oxygen development [20]. Antioxidants in essential oils are essential for stabilization

of the free-fatty acids. Essential oils are mixtures of important terpenoids such as monoterpenes C₁₀, diterpene C₂₀, sesquiterpenes C₁₅ and hydrocarbons with low molecular weight acids, alcohol, phenolic components, aldehydes, acyclic esters and lactones.

2.2. Antimicrobial activity

The essential oils are separated from aromatic plants by using hydrodistillation technique, frequently used in tradition medicine because they show strong antimicrobial, antibacterial and antifungal activities. They show antimicrobial activity against dermatophyte, bacteria, aspergillus strains, yeast etc. Phenolic compounds such as terpenoids and phenylpropanoids are major components of essential oils which show the antimicrobial as well as antioxidant properties. The composition, as well as the structure and functional groups of essential oils, plays a vital role in their antimicrobial activity. It is found that hydrophobicity is present in the toxicity of essential oils [21].

2.3. Insect control

Essential oils, in nature, play a significant role in the plant defense system because of their anti-bacterial, antimicrobial, anti-viral, antifungals, and insecticides activities and also protect the plants from herbivores by dropping their desire for such plants. They may repel or attract several insects for spreading of pollens as well as seeds. Defense of safe products usually involves a combination of grains along with protectants made up of the plant components [22]. Because of their fungicidal as well as bactericidal activities, essential oils are utilized to defend the natural equilibrium. Essential oils are antiseptic and are used in pharmaceutical and in traditional medicines, as well as embalmment and as antimicrobial, anti-microbial, analgesic, and sedative, spasmolytic, anti-inflammatory and the anaesthetic medicines [23]. Plants contain insect control agents since they hold several biologically active chemicals, which are not harmful for organisms as well as for environment. Phyto-chemicals are probable resource of mosquito-control-agents [24]. Hence, essential oils are used for different purposes such as flavoring agents, to give flavor in food, food preservation and protection [25].

2.4. Pathogen inhibition effect

Essential oil are not only utilized in the food items but also generally documented as safe as well as have inhibitory effect against the gram positive and gram negative bacteria. Natural anti-microbes are included in that group. Several anti-microbial constituents are liable for their usage in the foodstuff. Terpenoid components of essential oil are mixed simultaneously and liable for the pathogen fungus- inhibition. Gram-negative bacteria are less responsive to essential oil than the gram-positive bacteria. The oil separated from plant species has a great pathogen inhibitory result [26].

3. Essential oil based derivatives

3.1. Synthesis of ether derivative of limonene

The limonene sodium salt is made by mixing the limonene (7.71g, or 0.05M) in 10% solution of NaOH 40mL, 0.05M alkyl halide NaCl is then added. Reaction mixture is refluxed for 2-3 h and then cooled and the oily product is separated with the help of benzene (4 x 30mL). The extract is washed by using saturated solution of sodium bicarbonate (2 x 40 mL) and with water (2 x 40mL) then it dried over by using sodium sulphate. Benzene is removed to attain the derivatives of crude ether in 85 to 89% yields [27].

3.1.1. Uses

Monoterpenoids are generally considered to be involved in the self-defense mechanism against plant pathogen. Monoterpenoids have a relatively wide spectrum of biological activities against agricultural and public health insect pests. Biological activities of monoterpenoids against insects, nematodes, phytopathogenic fungi and other plant species are well documented. Limonene is a phenolic terpenoid obtained from the essential oil of grapefruit peels. In a research biological activities were improved through structural modifications of the natural monoterpenoids. Ether and ester derivatives of limonene were synthesized and anti-fungal activity was checked. The antifungal potency of synthesized derivatives was compared with the parent compound, limonene; to study and establish structure-activity relationships and it was observed that the newly formed show good antifungal activity as compare to that of parent molecule [27].

This derivative helps to;

- Lessen heart-burn as well as Gastro-esophageal reflux.
- Also used as anti-inflammatory as well as anti-oxidants for the digestive tract.
- Aids to soften the gall-stones.
- Facilitates the metabolic-disorders.
- Helps to reduce weight.
- Lessen the inflammation of the skin.
- Helps to lessen the anxiety as well as tension.

3.2. Synthesis of ester derivative of limonene

Ester derivative of limonene was prepared by some researcher in order to improve the biological activities of limonene. For this purpose, sodium salt of the limonene was made by adding limonene (7.71g, 0.05M) in the 10% solution of NaOH 40mL and then acid chloride (HCl, 0.06M) was mixed. Reaction mixture was refluxed for two to three h and cooled the product. The oily product was separated by using benzene (4 x 30mL). The separated mixture was washed along with the saturated solution of sodium bicarbonate (2 x 40 mL) and also with water (2 x 40mL). After that the product was dried over by using sodium sulphate. Benzene was removed to attain derivatives of the crude ester with 85 to 89% yields [27].

3.2.1. Uses

It is utilized to compose medicine. Derivative of

limonene is utilized to encourage weight loss, stop cancer, treat cancer, as well as treat bronchitis. In foodstuff, drink, along with chewing gum, it is utilized as a taste.

3.3. Acyl and aryl derivatives of L-menthol

Acyl as well as aryl derivatives of the L-menthol, such as trifluoroacetate, dichloroacetate and menthyl acetate, chloroacetate, as well as propionate, pivalate, chloropropionate, and benzoate, are prepared through the reaction along with acid anhydrides and with acid halides by using pyridine and/or triethylamine as a catalyst at the room temperature. The acyl derivatives of L-menthol by using an acid moiety may be lactic acid and/or cinnamic acid (like menthyl lactate as well as cinnamate) prepared through the reaction with di-cyclohexyl and carbo-di-imide as well as with 4-dimethylaminopyridine in the presence of dichloromethane catalyst [28].

3.3.1. Uses

It was confirmed by Mehrparvar et al [29] that many of eleven tested plant essential oils possessed in vitro antifungal activity against *Lecanicillium fungicola* var. *fungicola* and *Agaricus bisporus*. In former papers, this antifungal activity was strongly associated with the presence of monoterpenic phenols, especially thymol and carvacrol, in the essential oils. Paeonol, a major phenolic component of *Paeonia suffruticosa* and *P. lactiflora*, also has various biological activities. However, the molecules of EOs are generally volatile, unstable to light or heat and difficult to extract, having the disadvantages of short-term fungicidal efficacy and slow action, which restrict their possible practical application.

On the other hand, the methoxyacrylate unit is an important pharmacophore from natural plants, and many natural molecules with this unit have been discovered (such as the strobilurins A and B). These methoxyacrylate derivatives have been demonstrated to exhibit good fungicidal activities, and many such compounds have been developed as commercial fungicides (such as kresoxim-methyl, azoxystrobin, pyraclostrobin, trifloxystrobin, picoxystrobin, fluoxastrobin, oryastrobin, dimoxystrobin, coumoxystrobin, etc.). Currently, methoxyacrylate class is an important kind of broad-spectrum fungicides, which have a unique fungicidal mechanism, belonging to mitochondrial respiration inhibitors. Kresoxim-methyl, which has good fungicidal activity, was the first commercial fungicide of this class. However, following the commercial introduction of the strobilurin fungicides in 1996 resistant isolates were quickly detected in several plant pathogens. For example, *Erysiphe graminis* showed obvious resistance to strobilurins in Germany in 1998, and, by 1999, resistant wheat isolates were found in other countries, including France, Belgium, UK and Denmark. After this other resistant strains were also found successively.

The L-menthol utilized for the cure of pain and allergic-dermatitis. Derivatives of L-menthol are used to

treat the digestive-dis-orders, e.g., irritable bowel infection, and also utilized in an oral cavity because of antiseptic as well as the properties of anesthetic.

3.4. Methoxy and glyceryl acetal derivative of the L-menthol

Methoxy derivative of the L-menthol such as menthyl-methyl ether is prepared through the reaction of dimethyl sulfate with the anhydrous potassium carbonate and then refluxed it in the dry acetone. The derivative of glyceryl acetal of the L-menthol is prepared through the reaction of glycerol with *p*-toluene sulfonic acid. After that, it reflux in the presence of toluene [29].

3.4.1. Uses

This derivative is used to treat cough, plaque, sore throat, oral discomfort as well as minor pains and aches, irritated skin as well as lips and relieve pain of muscles. When menthol applied to skin and some other tissues like tongue and inside the cheeks, it gives cooling sensation.

3.5. Synthesis of 2-Acetoxyethyl-N-benzoylindoline

Another essential oils base derivative i.e., 2-Acetoxyethyl-N-benzoylindoline was successfully prepared by some researchers. For this purpose, phenyliodine-(III)-bis-(trifluoroacetate) (PIFA) solution 5.16 g, 12.00 mmol was mixed with trifluoro ethanol (TFEA 120mL). After that benzamide solution (1.58 g, 6.66 mmol) was added in the 66 mL of the same solvent. Reaction mixture was stirred at the room temperature and then Na₂CO₃ solution (aqueous 10 percent, 50 mL) was added. The aqueous part was separated by using CH₂Cl₂ (3 × 30 mL) and extract was dried over sodium sulphate. After that solution was filtered and solvent was disappeared at the reduced pressure. Furthermore, the residue was cleaned with the help of column chromatography (hexanes or EtOAc 1:1) and indoline (71%) [30].

3.5.1. Uses

Aside from the role of the indole ring as the key substructure in all molecules containing the amino acid tryptophan, the indole and indoline frameworks are embedded in a wide range of natural products and designed compounds with varied biological activities. On the basis of their promising pharmacological applications, intensive research has been directed to develop new and efficient protocols for the synthesis of both types of hetero-cycles. However, the employment of substantial quantities of either toxic or expensive metal salts, and the high sensitivity of some of the required complexes to air and moisture limits the generality of most of the related reported protocols. Thus, the development of a new metal free strategy for the

synthesis of the target heterocycles remains a challenge in synthetic organic chemistry. This derivative is useful in cancer prevention, treat systemic lupus erythematosus disease, and tumors in respiratory tract and also helpful in a lot of other circumstances.

4. Applications and health benefit of various EOs

Essential oil shows a lot of applications in different fields. The grapefruit peel oil is a disinfectant, diuretic as well as stimulant, antiseptic, antidepressant and lymphatic, aperitif and also a tonic. In different places, grapefruit peel oil is utilized to stimulate the urination, as fight infections. It also reduces the depression. It defends the wounds from different diseases and removes toxic substances. Orange essential oil is an anti-inflammatory, anti-septic, anti-depressant and antispasmodic, diuretic, aphrodisiac, sedative, carminative as well as tonic and also a cholagogue. The orange essential oil has been usually utilized to calm inflammation, protect from the sepsis, fight depression. Orange essential oil also provides release from a gas, enhances the urination and eliminates the toxins. Lemon EOs is used as an antiviral, antiseptic, bactericidal, astringent, febrifuge, aperitif, as well as disinfectant and tonic, haemostatic and also restorative. This oil has various health benefits such as it is used to prevent from the septic injuries, used to slow down the bacterial as well as viral growth, used in the strengthening gums, and also utilized to stop the hair fall. Lime Eos shows strong properties of antiviral, bactericidal, antiseptic, astringent, as well as disinfectant, aperitif, febrifuge and hemostatic, tonic and also restorative. This oil is also utilized to prevent the septic wounds, it also protects from the infection of viral, increase hunger as well as utilized to kill the bacteria, the fight infections, lessen the fever and stop the hemorrhage and also generally improve physical condition. Jasmine essential oil is showed strong properties of antiseptic, antidepressant, aphrodisiac, expectorant, antispasmodic as well as cicatrisant, uterine and the galactagogue, sedative, emenagogue, and also parturient. This oil has great ability to fight against depression. This oil prevents wounds. It also lessens the spasms, cures different diseases such as coughs. Lavender EOs is utilized as calming, analgesic, sleep-inducing, antiseptic as well as anti-inflammatory, disinfectant and also used for antifungal activity. Lavender essential oil is best for treatment of problems with the nervous system, insomnia. It is best to relief pain, for urine flow, protect skin, treat respiratory disorder. Lavender oil is beneficial for hair growth, indigestion, circulation of blood, indigestion, as well as immune system strength.

Table 1. Properties and health benefits of essential oils

Essential oils	Composition	Properties	Health properties
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Citrus oil	Limonene (86.27%), α -thujene (0.15%), myrcene (6.28%), α -pinene (2.11%), α -pinene (1.26%), citronellol (0.50%) and caprinaldehyde (0.31%) [5].	Diuretic, disinfectant, stimulant, antidepressant, antiseptic, aperitif, lymphatic, and a tonic.	It is used to stimulate urination, fight infections, reduce depression and uplift mood. It also protects wounds from becoming septic while increasing the elimination of toxins.
Eucalyptus essential oil	Piperitone (40.5%), \pm -phellandrene (17.4%), p-cymene (8.5%) and terpin-4-ol (4.7%) 1,8-cineole (34.8%), neral (10.8%), geranial (10.8%), \pm - phellandrene (8.8%) and methyl geranate (5.2%) being the dominant ones [31].	Anti-inflammatory, antispasmodic, decongestant, deodorant, antiseptic, antibacterial, and stimulating.	Very useful in the treatment of respiratory problems, wounds, muscle pain, mental exhaustion, dental care, skin care, diabetes, fever, and intestinal germs.
Lavender essential oil	1,5-Dimethyl-1-vinyl-4-hexenyl but yrate as the most abundant component (43.73%), followed by 1,3,7-Octatriene, 3,7-dimethyl-(25.10%), Eucalyptol (7.32%), and Camphor (3.79%) [32].	Lavender essential oil can be calming, sleep-inducing, analgesic, disinfectant, anti-inflammatory, antiseptic, and antifungal.	This oil is beneficial for the treatment of issues with the nervous system, insomnia, pain relief, urine flow, respiratory disorders, skin care, hair care, blood circulation, indigestion, and immune system health.
Pine essential oil	The main components include α -terpineol (30.2%), linalool (24.47%), limonene (17.01%), anethole (14.57%), caryophyllene (3.14%), and eugenol (2.14%) [33].	An antibacterial, analgesic, diuretic, energizing, antiseptic, or aromatic substance.	It is employed to help in skin care, cosmetics, increase of metabolism, pain relief, stress disorders, mental fatigue, urinary tract infections, and various respiratory problems.
Clove Essential Oil	Eugenol (76.8%), followed by β -caryophyllene (17.4%), α -humulene (2.1%), and eugenyl acetate (1.2%) as the main components [34].	It is anti-microbial, anti-fungal, antiseptic, antiviral, aphrodisiac, and stimulating in nature.	It is used in treatments related to dental care, like toothaches and cavities. It is also used cure infections, skin conditions, stress, headaches, respiratory problems, earaches, indigestion, nausea, blood circulation issues, blood purification, diabetes, immune system weakness, premature ejaculation, cholera, and sties
Cumin Essential Oil	Cuminal (36.31%), cuminic alcohol (16.92%), γ -terpinene (11.14%), safranal (10.87%), p-cymene (9.85%) and β -pinene (7.75%) were the major components [35].	This essential oil is bactericidal, carminative, digestive, diuretic, antiseptic, antispasmodic, detoxifying, emenagogue, stimulant, nervine, and tonic in nature.	It has been known to kill bacteria and inhibits bacterial infection, while removing excess gas from the intestine, promoting digestion, increasing urination, and protecting wounds against becoming septic.
Frankincense Essential Oil	α -pinene (2.0–64.7%); α -thujene (0.3–52.4%); β -pinene (0.3–13.1%); myrcene (1.1–22.4%); sabinene (0.5–7.0%); limonene(1.3–20.4%); p-	Antiseptic, disinfectant, astringent, carminative, cicatrisant, cytophylactic, digestive, diuretic, emenagogue, expectorant,	It protects wounds from becoming septic, fights infections, induces contractions in gums, muscles, and blood vessels, and removes excess gas, heals scars, keeps cells healthy

	cymene (2.7–16.9%) and β -caryophyllene (0.1–10.5%) [36].	sedative, tonic.	and promotes their regeneration.
Allspice Essential Oil	Eugenol (61.36%), β -caryophyllene (4.58%), α -humulene (1.90%) and 1,8-cineole (1.89%); minor components included δ -cadinene (1.08%), Germacrene D(0.86%) and β -elemene (0.69%) [37].	Good anesthetic, analgesic, antioxidant, antiseptic, carminative, relaxant, rubefacient, stimulant, and tonic.	It relieves pain, relax the body and mind, add color to the skin, and stimulate various other functions.
Basil Essential Oil	The essential oils consisted of linalool as the most abundant component (56.760.6%), followed by epi-a-cadinol (8.611.4%), a-bergamotene (7.49.2%) and c-cadinene (3.25.4%). Samples collected in winter were found to be richer in oxygenated monoterpenes (68.9%), while those of summer were higher in sesquiterpene hydrocarbons (24.3%) [38].	Carminative, anti-spasmodic, analgesic, anti-bacterial, and ophthalmic.	It is used for skin care, indigestion, respiratory problems, infections, stress disorders, blood circulation issues, pain, and vomiting.
Peppermint Essential Oil	Higher menthol and lower terpinen-4-ol [39]. The main constituents were menthol (40.7%) and menthone (23.4%). Further components were (\pm)-menthyl acetate, 1,8-cineole, limonene, beta-pinene and beta-caryophyllene.	Used as an analgesic, anesthetic, antiseptic, anti-galactagogue, antiphlogistic, antispasmodic, astringent, carminative, cephalic, cholagogue, cordial, decongestant, emenagogue, expectorant, febrifuge, hepatic, nervine, stimulant, stomachic, sudorific, vasoconstrictor and as a vermifuge.	It induces firmness in muscles, stops hemorrhaging, removes gas, is good for brain and memory health, promotes bile discharge, clears congestion and eases breathing.
Pistachio (Atlas pistachio) Essential Oil	The main constituents were Terpinen-4-ol (34.7-16.1%), α -pinene (64.8-15.4%), germacrene D (24.5-19.0%) and E-caryophyllene (23.1%) [40].	Used as antiseptic, stomachic, anti-bacterial, and ophthalmic.	The leaves are used in folk medicine as antidiarrheal and for Stomachache, cough, stress, tonic.

5. Conclusion

Essential oils are also known as volatile oils, ethereal oils, aetherolea, or simply as the oil of the plant from which they were extracted, such as oil of clove. An essential oil is "essential" in the sense that it contains the "essence of" the plant's fragrance—the characteristic fragrance of the plant from which it is derived. Aromatherapy is a form of alternative medicine in which healing effects are ascribed to the aromatic compounds in essential oils and other plant extracts. Aromatherapy may be useful to induce relaxation, but there is not sufficient evidence that essential oils can effectively treat any condition. Scientific research indicates that essential oils cannot treat or cure any chronic disease or other illnesses

[41]. Much of the research on the use of essential oils for health purposes has serious methodological errors. In a systemic review of 201 published studies on essential oils as alternative medicines, only 10 were found to be of acceptable methodological quality, and even these 10 were still weak in reference to scientific standards. Use of essential oils may cause harm including allergic reactions and skin irritation; there has been at least one case of death [42]. As such, the use of essential oils as an alternative medicine should be approached with caution. Research has shown that essential oils have potential as a natural pesticide. In case studies, certain oils have been shown to have a variety of deterring effects on pests, specifically insects and select arthropods. These effects may

include repelling, inhibiting digestion, stunting growth, decreasing rate of reproduction, or death of pests that consume the oil. However, the molecules within the oils that cause these effects are normally non-toxic for mammals. These specific actions of the molecules allow for widespread use of these green pesticides without harmful effects to anything other than pests. Essential oils that have been investigated include rose, lemon grass, lavender, thyme, peppermint, and eucalyptus [43].

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