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Properties and Applications of Essential Oils: A Review

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ABSTRACT

Essential oils are complex mixtures of volatile compounds obtained from plants where they play aromatic, communicative and defensive roles. They have been used for centuries in medicine, agriculture and industry due to their broad spectrum of biological activity. They exhibit antimicrobial, antiviral, anti-inflammatory, antioxidant and smooth muscle relaxant properties. Due to their lipophilicity and small molecular size, essential oil components easily penetrate biological membranes and exert therapeutic effects. Currently, research is underway on the use of essential oils for the treatment of viral infections, cancer prevention and inflammatory diseases. These agents may provide a valuable alternative to conventional therapies due to their natural origin and high tolerability. However, ensuring the appropriate quality and standardization of preparations is crucial to guarantee their efficacy and safe use. This paper provides an overview of the properties of essential oils, the methods used to obtain them, their composition, and their medical and therapeutic applications.

Keywords: essential oils, antimicrobial activity, antiviral activity, anti-inflammatory activity, toxicity, applications of essential oils

INTRODUCTION

Essential oils are very complex mixtures of volatile substances obtained from plant material. The composition of these plants depends on many factors, such as plant species, plant parts used for extraction, soil composition, harvest time, vegetative cycle phase, and extraction methods (Vigan 2010).

The primary function of essential oils is to provide scent and flavour to plants. They also play an important communicative role, attracting pollinators and repelling pests. Sometimes, they also act as signals for other plants of the same species (Gershenzon et al., 2007).

Aromatic plants and extracts prepared from them are known for their antiseptic, bactericidal, fungicidal, antiviral and medicinal properties (Swamy et al.,2016; Bassolé et al., 2012) for centuries, including for embalming, religious ceremonies, food preservation, insecticides and parasiticides in agriculture, and antimicrobial, antispasmodic, sedative, topical anaesthetic and anticancer agents (Kowalczyk et al., 2023; Mostafa et al., 2023). These properties are still relevant, and in recent years, some mechanisms of action of essential oils have been elucidated in more detail, especially at the antimicrobial level (Basile et al., 2000; Sienkiewicz et al., 2013).

In response to the growing interest in "natural" healing methods and the return to folk medicine, essential oils appear to be a promising source of a universal remedy for patients' basic ailments. Moreover, these findings could lead to the search for new antimicrobial, antiviral and anticancer drugs.

Table 1 presents the main compounds found in the essential oils. Table 2 presents example plant parts where essential oils mainly occur.

Table 1. The main compounds found in plant essential oils (Tongnuanchan et al., 2014)

Essential oil	Major compounds
Lavender	Linalool, linalyl acetate
Peppermint	Menthol, menthone
Eucalyptus	1,8-Cineole, limonene
Rosemary	1,8-Cineole, α-pinene
Tea tree	Terpinen-4-ol, γ-terpinene
Lemongrass	Geranial, neral
Ylang ylang	Linalool, geranyl acetate
Sandalwood	Santalol
Bergamot	Limonene, linalool
Chamomile	Bisabolol, matricin
Cedarwood	Cedrol, widdrol
Clove	Eugenol
Frankincense	α-Pinene, limonene
Ginger	Gingerol, zingiberene
Patchouli	Patchoulol
Vetiver	Vetivone, khusimol

Table 2. Plant parts containing essential oils (Tongnuanchan et al., 2014)

Part of plant	Example plants
Seeds	Anise, caraway, celery, coriander, cumin, dill, fennel
Woods	Camphor, cedarwood, rosewood, sandalwood
Barks	Cinnamon, sassafras
Berries	Juniper, pepper
Resins	Frankincense, myrrh
Flowers	Chamomile, lavender, rose
Peels	Lemon, lime, orange
Roots	Angelica, ginger, valerian
Herbs	Basil, oregano, thyme
Rhizomes	Ginger, turmeric
Leaves	Eucalyptus, patchouli, peppermint

METHODS OF OBTAINING AND COMPOSITION

There are several methods for obtaining essential oils from plant materials. The most popular methods are steam distillation, solvent extraction, supercritical CO_2 extraction, and cold pressing (Aziz et al., 2018). Steam distillation involves heating the plant material with water, which causes the volatile aromatic compounds to evaporate. The vapours then pass through a condenser, where condensation occurs – the oil collects in the liquid, while the water returns to the distillation kettle. This approach is the most commonly used method (Tongnuanchan et al., 2014), but its disadvantage is the risk of thermal decomposition of some oil components (Raut et al., 2014).

Solvent extraction involves passing an organic solvent through the plant material to dissolve the oil. The solvent is then evaporated, leaving the essential oil behind (Castro et al., 1999). This method does not require heating but involves the use of additional chemicals. Supercritical CO_2 extraction uses carbon dioxide in a supercritical state as a selective solvent (Wrona et al., 2017). This allows gentle extraction of the oil without high temperatures or other solvents. It is an expensive but very effective technique (Elsayed et al., 2023).

Cold pressing involves the mechanical expression of oil from plant material (Kitajima et al., 2004). It is used, for example, with citrus fruit peels. It is simple but low yielding. The choice of extraction method affects the composition and properties of the obtained essential oil. Table 3 presents the main methods of extracting essential oils. Essential oils are mixtures of tens or even hundreds of different chemical compounds (Bakkali et al., 2008). The main groups of substances are as follows:

- Terpenes and terpenoids (e.g., limonene, menthol);
- Aromatic compounds (e.g., cinnamaldehyde),
- Phenols (e.g., thymol, eugenol),
- Aliphatic alcohols (e.g., linalool, geraniol),
- Aliphatic ketones (e.g., camphor),
- Esters of aliphatic acids (acetates, propionates).

Often, 2–3 major components make up 20–70% of the oil, while the rest are present in trace amounts (Dhifi et al., 2016). The exact chemical profile of a given oil is determined by chromatographic techniques (Shellie et al., 2000). The diversity of essential oil compositions translates into a wide range of biological properties and applications (Edris et al., 2007).

POTENTIAL APPLICATIONS

Essential oils have been widely applied in folk medicine due to their various properties, such as anti-inflammatory, immunomodulatory, antibacterial, expectorant and sedative effects (Gironi et al., 2008). These diseases are characterized by several features that predispose patients to pharmaceutical and medical uses. These

Table 3. Essential oil extraction methods

Extraction method	Plants	Ref.
Hydrodistillation	Rose-scented geranium, germander, rosemary, lemon, oregano, marjoram, catnip, lavender, hyssop, anise hyssop, sage, cumin, clove, caraway, thyme, basil, garden mint	Vigan 2010; Gershenzon et al., 2007
Hydrodiffusion	Orange, rosemary leaves	Swamy et al.,2016; Bassolé et al., 2012
Steam distillation	Rose-scented geranium, thyme, germander, rosemary, fennel, anise, eucalyptus, basil, lavender, patchouli, clove, orange	Basile et al., 2000; Sienkiewicz et al., 2013
Subcritical water	Fructus amomi, marjoram, olive, coriander seeds	Aziz et al., 2018; Tongnuanchan et al., 2014
Supercritical CO_2	Rosemary, fennel, anise, cumin seed, sage, lemon, carrot fruit, marjoram, catnip, oregano, lavender, thyme, hyssop, anise hyssop, patchouli, cumin, clove, coriander, chamomile, baccharises	Elsayed et al., 2023; Kitajima et al., 2004
Solvent-free microwave	Oregano, fragrant fern, rosemary, caraway, 5 flavour berry, cumin, cardamom, basil, garden mint, thyme, sea buckthorn, spearmint, pennyroyal	Bayramoglu et al., 2008; Li Y et al., 2013
Solvent extraction	Solvent sage, apiaceae, chasteberry, lemon	Borotová et al., 2021; Pereira et al., 2010
Solvent + Steam	Cumin, tobacco	Zhao et al., 2020; Ibrahim et al., 2022

include lipophilicity, which facilitates the penetration of biological membranes; low molecular weight; rapid onset of action; easy distribution to tissues and organs, including the lungs; low first-pass metabolism; relatively easy synthesis; low toxicity at therapeutic concentrations; and high volatility (Tiruppur Venkatachallam et al., 2010).

Antiviral activity

Many essential oils, including eucalyptus, clove, lemon, oregano, and thyme oils, have been shown to have inhibitory effects on various viruses, including influenza, herpes, and polioviruses. This mechanism is a promising target for developing new antiviral drugs, especially for the treatment of infections caused by enveloped viruses such as SARS-CoV-2, influenza, and herpes viruses (Elsebai et al., 2022; Sharifi-Rad et al., 2017).

For example, electron microscopy has shown that essential oils can cause visible damage to the envelope of herpes simplex virus (HSV) (Ma et al., 2020). Furthermore, some components of oils, such as shikimic acid from star anise, have been used to develop effective antiviral drugs, such as oseltamivir (Astani et al., 2011). In vitro studies have shown that essential oils are effective at concentrations that do not damage human cells and can inhibit viral replication even better than some conventional antiviral drugs (Bayala et al., 2014).

The strongest antiviral effects were observed for oils rich in phenols, alcohols, and aldehydes, especially thyme, oregano, and clove oils. These agents are promising alternatives to conventional agents (Schnitzler et al., 2007). The underlying mechanisms include direct viral inactivation, inhibition of adsorption and penetration into cells, disruption of nucleic acid replication and viral protein synthesis (Nazzaro et al., 2013). Although in vitro studies are promising, further clinical research in humans is needed to confirm the efficacy and safety of essential oils for treating viral infections. Current evidence is insufficient to recommend oils as standard therapy.

Antibacterial activity

Numerous in vitro studies indicate that essential oils exhibit potent bactericidal and bacteriostatic properties against various bacterial strains, including staphylococci, bacilli, streptococci, and mycobacteria (Guilhelmelli et al., 2013). The mechanisms of antibacterial action include damaging the cell membrane of microorganisms; disrupting enzymatic functions, ion transport, and ATP synthesis; and lowering the pH of the environment (Burt, 2004).

Essential oils containing high levels of phenolic compounds, such as carvacrol, eugenol, and thymol, demonstrate the strongest bactericidal effects (Oussalah et al., 2006). These substances damage the bacterial cell membrane, causing leakage of ions and cytoplasmic contents, ultimately resulting in cell death (Lambert et al., 2001). Carvacrol, present in oregano and thyme oils, is particularly active against bacteria. It has been shown to act on a broad spectrum of bacteria, including intestinal bacilli, staphylococci, Listeria, Salmonella, Campylobacter, lactic acid bacteria and *Helicobacter pylori* (Gutierrez et al., 2009; Langeveld et al., 2014).

Additionally, the efficacy of oils depends on the concentration and exposure time to microorganisms. The greater the concentration and length of contact are, the stronger the bactericidal effect (Yap et al., 2010). Therefore, essential oils are promising alternatives to antibiotics, especially for treating infections caused by drug-resistant strains. However, further clinical studies are needed to confirm the safety and efficacy of using essential oils to treat bacterial infections in humans, as the current evidence stems mainly from in vitro studies.

Antioxidant activity

Numerous studies indicate that essential oils are a valuable source of natural antioxidants capable of neutralizing reactive oxygen species and chelating transition metals (Kaur et al., 2024). The antioxidant activity of essential oils is primarily associated with the presence of phenolic compounds, flavonoids, and terpenoids (Yang et al., 2011).

Oils rich in phenols, such as cinnamon, nutmeg, basil, oregano, and thyme oils, exhibit particularly high antioxidant activity in vitro (Wang et al., 2017). By eliminating reactive oxygen species and chelating transition metal ions, these oils can counteract oxidative stress in cells and protect important biomolecules, such as DNA, lipids, and proteins, from oxidative damage. Thus, essential oils have preventive potential in the context of cancer, cardiovascular disease, and age-related cognitive impairment (Devi et al., 2023).

The proposed molecular mechanisms of the antioxidant action of essential oils include direct neutralization of free radicals, reduction of peroxides, chelation of transition metal ions, and modulation of the activity of endogenous antioxidant enzymes such as superoxide dismutase and glutathione peroxidase (Rungqu et al., 2023). However, further research is needed to assess the bioavailability of compounds found in essential oils after oral administration and to confirm the beneficial effects of oils in in vivo models to fully elucidate their therapeutic potential as natural antioxidants.

Anti-inflammatory activity

Numerous essential oils, such as oils derived from rosemary, cloves, ginger, and black pepper, have shown promising anti-inflammatory effects in in vitro studies (Riella et al., 2012). The anti-inflammatory activity of essential oils is mainly attributed to the presence of phenolic compounds, which can modulate key signalling pathways responsible for the synthesis and release of inflammatory mediators (Tousif et al., 2023).

The proposed molecular mechanisms of anti-inflammatory action include the inhibition of enzymes such as cyclooxygenase-2 (COX-2) and 5-lipoxygenase (5-LOX), which play important roles in the metabolism of arachidonic acid to proinflammatory eicosanoids, prostaglandins and leukotrienes (Yoon et al., 2010). Additionally, essential oils have been shown to decrease the expression and release of key proinflammatory cytokines, such as TNF-α, IL-1β, and IL-6, through interactions with intracellular pathways (Ling et al., 2014).

Inhibitors of COX and LOX enzymes are commonly used anti-inflammatory drugs from the nonsteroidal anti-inflammatory drug (NSAID) group. Therefore, through similar mechanisms of action, essential oils may provide safer alternatives to conventional NSAIDs for the treatment of inflammatory conditions, especially chronic conditions. Moreover, essential oils have been shown to alleviate inflammatory reactions in the skin and mucous membranes by modulating the immune system (Regnault-Roger et al., 2012). However, further clinical studies are necessary to confirm the efficacy and safety of using essential oils as anti-inflammatory medications in humans.

Insect repellents and insecticides

Many essential oils exhibit insect repellent and toxic properties, providing natural plant protection and an alternative to synthetic pesticides (Kumar et al., 2020). Tea tree, lavender, citrus, clove, geranium and mint oils demonstrate the strongest insecticidal and repellent abilities (Gupta et al., 2023). Oils have proven effective against stored-product pests, aphids, fruit flies, and ticks (Senthil-Nathan et al., 2020). They are also used as repellents against mosquitoes and ticks in humans. The underlying mechanisms involve disrupting enzymatic functions and neurotransmission, damaging the cuticle and inducing oxidative stress in insects (Isman 2006).

The advantages of oils include selective activity, a short degradation period, and a lower risk of resistance than synthetic agents

(Posadzki et al., 2013). However, further research is needed to determine the optimal doses and oil combinations for specific pest species. Overall, essential oils represent a promising alternative to conventional pesticides. Essential oils are obtained from various plant organs, most often from flowers, fruits, leaves, stems, bark and branches. These plants belong to many botanical families, including Asteraceae, Lamiaceae, Rutaceae, Lamiaceae, Myrtaceae and Apiaceae. The essential oils listed in the European Pharmacopoeia as medicinal raw materials are compiled in Table 4. The table shows the names of the essential oils, the Latin names of the plants from which they were obtained, and the plant parts used for extraction.

TOXICITY AND SAFETY OF USE

Although essential oils are commonly considered safer than synthetic chemicals, caution should be exercised when using them because they can cause adverse effects (Lanzerstorfer et al., 2020). Some oils, such as cedarwood, pine and juniper, can be toxic at high doses or when ingested and can cause acute kidney or liver failure (Lysdal et al., 2009).

Table 4. Essential oils extracted from a variety of plants listed in European Pharmacopoeias (https://pheur.edqm.eu/home)

Essential oil name	Botanical name	Plant part used
Bitter-fennel fruit oil	*Foeniculum vulgare* Mill., spp. *vulgare* var. *vulgare*	ripe fruit
Bitter-fennel herb oil	*Foeniculum vulgare* Mill., spp. *vulgare* var. *vulgare*	aerial parts
Caraway oil	*Carum carvi* L.	dry fruit
Cassia oil	*Cinnamomum aromaticum* Nees	leave and young branches
Cinnamon bark oil, Ceylon	*Cinnamomum zeylanicum* Nees	bark of the shoot
Cinnamon leaf oil, Ceylon	*Cinnamomum zeylanicum* Nees	leaves
Citronella oil	*Cymbopogon winterianus* Jowitt ex Bor	fresh or partially dried aerial parts
Clary sage oil	*Salvia sclarea* L.	fresh or dried flowering stem
Clove oil	*Syzygium aromaticum* L.	dried flower buds
Coriander oil	*Coriandrum sativum* L.	fruits
Dwarf pine oil	*Pinus mugo* Turra	fresh leaves and twigs
Eucalyptus oil	genus *Eucalyptus*	fresh leaves or fresh terminal branches
Juniper oil	*Juniperus communis* L.	ripe, nonfermented berry cones
Lavender oil	*Lavandula angustifolia* Mill.	flowering tops
Lemon oil	*Citrus limon* L.	fresh peel
Mandarin oil	*Citrus reticulata* Blanco	fresh peel
Matricaria oil	*Matricaria recutita* L.	fresh or dried flower-heads or flowering tops
Mint oil	*Mentha canadensis* L.	fresh, flowering aerial parts
Neroli oil	*Citrus aurantium* L.	fresh flowers
Nutmeg oil	*Myristica fragrans* Houtt.	dried and crushed kernels
Peppermint oil	*Mentha piperita* L.	fresh aerial parts of the flowering plant
Pine sylvestris oil	*Pinus sylvestris* L.	fresh leaves and branches
Rose oil	*Rosa gallica* L., *Rosa damascene* Miller, *Rosa alba* L., *Rosa centifolia* L.	fresh flowers
Rosemary oil	*Rosmarinus officinalis* L.	flowering aerial parts
Spanish sage oil	*Salvia lavandulifolia* Vahl	flowering aerial parts
Spike lavender oil	*Lavandula latifolia* Medik	flowering tops
Star anise oil	*Illicium verum* Hook	dry ripe fruits
Sweet orange oil	*Citrus sinensis* (L.) *Osbeck*	fresh peel
Tea tree oil	genus *Melaleuca*	foliage and terminal branches
Thyme oil	*Thymus vulgaris* L. or *Thymus zygis* L.	fresh flowering aerial parts
Turpentine oil, Pinus pinaster type	*Pinus pinaster* Aiton	oleoresin obtained by tapping

The most common side effects of essential oils include skin and mucous membrane irritation; allergic reactions manifesting as rashes, swelling, and difficulty breathing; and respiratory issues associated with excessive inhalation of oils in aerosol form (Posadzki et al., 2012). Ingestion can lead to nausea, vomiting, diarrhea and digestive system disturbances. Some oils, especially those rich in phenols such as rosemary and sage, exhibit pro-oxidant activity, resulting in DNA damage and lipid peroxidation.

The safe and responsible use of essential oils requires strict adherence to guidelines on maximum doses and routes of administration. Oral intake without prior consultation with a doctor or dietician is not recommended. Pregnant and breastfeeding women should exercise extra caution (Dosoky et al., 2021).

However, further toxicological research is needed on the interactions of OOs with medications and their effects on individual organs. However, with proper precautions and dose adjustments, essential oils can provide a valuable alternative to synthetic chemical preparations.

CONCLUSIONS

Essential oils are complex mixtures of volatile compounds derived from plants that serve aromatic, communicative, and defensive functions. This paper provides an overview of the essential oil properties, extraction methods, composition, and medical applications of this plant. Essential oils exhibit broad biological activities, including antimicrobial, antiviral, anti-inflammatory, insecticidal, antioxidant, and smooth muscle relaxant effects, which are attributed to their diverse chemical constituents, such as terpenes, phenols and alcohols. Their lipophilicity facilitates penetration into cells and therapeutic action. Essential oils have potential uses as natural remedies for treating infections and inflammation, oxidative stress, and even cancer. However, human trials are still needed to fully confirm the efficacy and safety of these treatments. Ensuring appropriate quality control and standardization of preparations is crucial. With proper precautions, essential oils may provide valuable alternatives to synthetic chemicals, especially for the treatment of drug-resistant microbes. Further research should focus on evaluating the mechanisms of action, pharmacokinetics, and toxicity of these compounds in vivo.

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