

Review

ESSENTIAL OILS IN DANDRUFF MANAGEMENT: PHARMACOLOGICAL MECHANISMS, THERAPEUTIC EFFICACY, AND PROSPECTS FOR NATURAL SCALP CARE

Sharwari Sonawane^{✉*}, Yogesh Sharma^{OR}, Ganesh Sonawane^{OR}, Sunil Mahajan^{OR},
Deepak Sonawane^{OR}

Divine College of Pharmacy, Satana, Dist. Nashik-423301, Maharashtra, India.

*Correspondence, e-mail: sharwarisonawane2808@gmail.com

Received: 20.01.2026 / Revised: 27.03.2026 / Accepted: 06.04.2026 / Published: 30.06.2026

ABSTRACT

Dandruff is a common, chronic scalp disorder affecting approximately 40-50% of the adult population worldwide. It is characterized by excessive flaking, itching, irritation, and impaired scalp barrier function, primarily driven by *Malassezia* spp. fungal overgrowth, abnormal keratinocyte turnover, sebum imbalance, low-grade inflammation, and oxidative stress. Conventional anti-dandruff agents such as ketoconazole, zinc pyrithione, selenium sulfide, and ciclopirox olamine remain effective but are frequently associated with adverse effects, recurrence after discontinuation, reduced patient compliance, and concerns regarding long-term safety. These limitations have led to growing interest in natural, multi-targeted therapeutic alternatives. Essential oils are complex mixtures of bioactive phytochemicals, including terpenes, phenolics, aldehydes, and esters, that exhibit broad-spectrum antifungal, anti-inflammatory, antioxidant, keratolytic, sebum-regulating, and barrier-restorative properties. Oils such as tea tree, lemongrass, rosemary, thyme, clove, peppermint, neem, eucalyptus, and basil have demonstrated significant inhibitory activity against *Malassezia* species through membrane disruption, fungal lipase inhibition, cytokine modulation, and oxidative stress reduction. Clinical and experimental studies support their efficacy, with certain formulations showing substantial reductions in dandruff severity. This review summarizes the pathophysiology of dandruff, elucidates the pharmacological mechanisms of essential oils, and evaluates their therapeutic potential as safe, effective, and holistic alternatives for long-term dandruff management.

KEYWORDS: Dandruff, essential oils, *Malassezia* species, antifungal activity, scalp disorders.

Article is published under the CC BY license.

1. Introduction

Dandruff is a common scalp disorder marked by visible flakes, itching, irritation, and heightened scalp sensitivity. While it is non-inflammatory, it often manifests with symptoms that affect both the cosmetic appearance and overall health of the scalp [1]. Globally, dandruff affects nearly 40-50% of adults, with a higher prevalence among adolescents and young adults due to increased sebaceous activity [2]. Although not medically serious, dandruff significantly impacts quality of life, leading to a continuous demand for effective and safe treatment strategies.

The etiology of dandruff is multifactorial, with three major contributing factors consistently identified: overgrowth of *Malassezia* species, abnormal keratinocyte turnover, and alterations in scalp lipid composition. *Malassezia* yeasts metabolize sebum triglycerides, generating irritant by-products that disrupt the epidermal barrier, accelerate

desquamation, and trigger localized inflammation. These events collectively lead to the characteristic white or yellowish flakes observed on the scalp and hair shafts [3].

Conventional anti-dandruff agents such as ketoconazole, zinc pyrithione, selenium sulfide, ciclopirox, and coal tar are widely used in shampoos and topical formulations. Although effective, these synthetic agents are increasingly associated with limitations including scalp irritation, dryness, product buildup, unpleasant odor, and concerns regarding long-term safety [4,5]. Moreover, prolonged use may contribute to reduced efficacy or microbial tolerance. These challenges have encouraged a shift towards natural, plant-based remedies among consumers and formulators.

Essential oils are volatile aromatic extracts derived from medicinal plants and have gained substantial attention for their therapeutic potential in scalp disorders. Their complex composition of terpenes,

phenolics, aldehydes, and esters provides broad-spectrum antifungal, anti-inflammatory, keratolytic, soothing, and antioxidant actions. Several essential oils, such as tea tree, lemongrass, rosemary, thyme, peppermint, eucalyptus, clove, and neem, have demonstrated noteworthy inhibitory effects against *Malassezia spp.* in both in-vitro and clinical studies. In addition to their antimicrobial actions, essential oils help normalize sebum secretion, alleviate itching, and promote barrier repair, making them promising alternatives or adjuncts to chemical-based therapies [6,7].

Given the increasing demand for natural solutions and the growing body of scientific evidence supporting essential oils, understanding their mechanism of action and therapeutic suitability is essential. This review aims to provide a comprehensive overview of the role of essential oils in dandruff management, highlighting their pharmacological properties, comparative efficacy, formulation potential, and future research prospects.

2. Pathophysiology of dandruff and therapeutic targets

Dandruff is a multifactorial scalp disorder resulting from the interplay between microbial activity, epidermal dysfunction, and sebaceous gland alterations [8]. Although not a classical inflammatory condition, subtle inflammation and impaired barrier function play central roles in its development and progression. Understanding these mechanisms is essential for identifying therapeutic targets that essential oils can effectively modulate. The most widely accepted trigger in dandruff pathogenesis is the excessive proliferation of *Malassezia* species, particularly *M. globosa* and *M. restricta*. These lipophilic yeasts metabolize scalp sebum triglycerides using their endogenous lipases, releasing irritant-free fatty acids such as oleic acid. These metabolites penetrate the stratum corneum, disrupt intercellular cohesion, and provoke localized irritation, ultimately accelerating epidermal turnover. This rapid turnover results in the formation of loosely attached corneocyte clusters manifested clinically as white or yellowish flakes [9].

Another key factor is abnormal keratinocyte differentiation and increased scalp cell renewal rate. In dandruff, the normal turnover cycle of approximately 28 days is reduced to as little as 7-10 days. This premature shedding leads to incomplete maturation of corneocytes, weakening the barrier structure and contributing to dryness, scaling, and flaking [10]. Sebum imbalance also plays a critical role. Although dandruff occurs in both dry and

oily scalps, excessive sebum provides an ideal environment for *Malassezia* growth. The interaction between fungal metabolites and sebum components further intensifies irritation and barrier damage. Moreover, the altered lipid profile of dandruff-affected skin, particularly reduced levels of ceramides and natural moisturizing factors, compromises hydration and barrier integrity. Low-grade inflammation is an additional contributing mechanism. While dandruff is less inflammatory than seborrheic dermatitis, mild erythema, itching, and cytokine activation are frequently observed. Pro-inflammatory mediators such as interleukin-1 α (IL-1 α) and tumor necrosis factor- α (TNF- α) become elevated due to microbial irritation and barrier disruption, perpetuating the cycle of discomfort and scaling. Based on these mechanisms, several therapeutic targets emerge: inhibition of *Malassezia* proliferation, restoration of normal keratinization, regulation of sebum secretion, reinforcement of barrier integrity, reduction of oxidative stress, and suppression of inflammatory mediators. Essential oils are uniquely suited for this multifaceted approach, as many exhibit antifungal activity, keratolytic effects, sebum-modulating properties, anti-inflammatory actions, and antioxidant protection. Their broad spectrum of activity makes them valuable in addressing the root causes of dandruff rather than merely alleviating symptoms [11,12].

3. Mechanisms of action of essential oils against dandruff

Essential oils are concentrated, volatile, and aromatic liquids obtained from various parts of plants such as leaves, flowers, bark, peels, roots, and seeds. They represent complex mixtures of bioactive secondary metabolites that contribute to the characteristic fragrance and therapeutic properties of the parent plant. Their composition varies widely depending on botanical species, geographical origin, climate, cultivation practices, and extraction method, resulting in significant chemotypic diversity across oils from the same plant [13]. Essential oils exert multiple therapeutic effects on the scalp, targeting several key pathways involved in the development of dandruff. Their diverse chemical constituents work synergistically to provide antifungal, anti-inflammatory, keratolytic, sebum-regulating, antioxidant, and barrier-restorative actions, as illustrated in Fig. 1. These mechanisms allow essential oils to address the root causes of dandruff rather than simply masking symptoms [14].

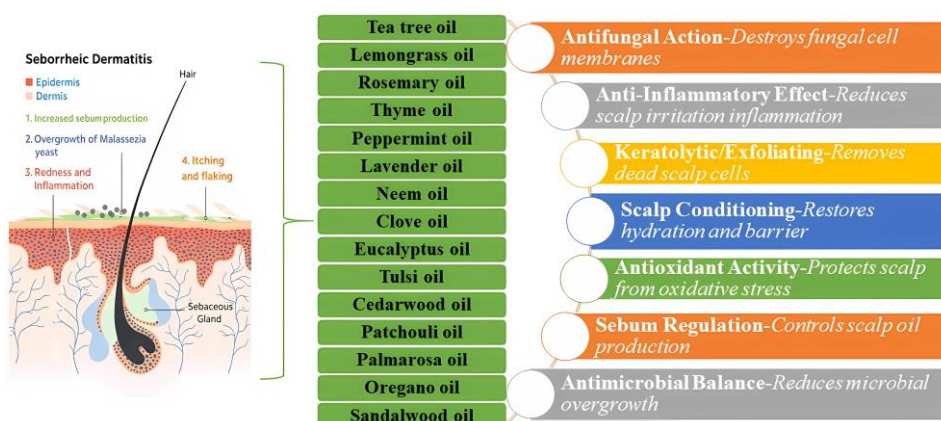


Fig. 1. Schematic representation of seborrheic dermatitis pathology and essential oils used and their mechanisms of action.

3.1. Antifungal activity against *Malassezia* spp.

The most critical mechanism is the inhibition of *Malassezia* proliferation. Monoterpenes such as terpinen-4-ol (tea tree oil), citral (lemongrass oil), thymol (thyme oil), eugenol (clove oil), and 1,8-cineole (eucalyptus oil) disrupt fungal cell membranes by altering permeability and causing leakage of intracellular components. These compounds also interfere with fungal enzyme systems, inhibiting lipase activity that converts scalp lipids into irritant free fatty acids. This directly reduces the primary trigger of dandruff pathogenesis [15].

3.2. Anti-inflammatory effects

Many essential oils contain phenolics, oxides, and esters with strong anti-inflammatory properties. Constituents such as linalool, α -pinene, rosmarinic acid derivatives, and menthol suppress the synthesis of pro-inflammatory mediators including TNF- α , IL-1 α , and nitric oxide. This helps alleviate itching, redness, and irritation associated with dandruff, contributing to overall scalp comfort [16].

3.3. Keratolytic and exfoliating Action

Essential oils such as lemongrass, eucalyptus, and peppermint exhibit mild keratolytic activity, promoting the shedding of retained corneocytes and reducing visible flakes. These oils enhance micro-exfoliation of the scalp, support normalization of epidermal turnover, and help remove dead skin build-up without causing irritation [17].

3.4. Barrier repair and scalp soothing

Several essential oils improve barrier integrity by enhancing lipid organization and increasing hydration. Oils containing esters (e.g., lavender oil's linalyl acetate) have soothing, anti-irritant effects that help restore scalp comfort. Their emollient properties reduce dryness, prevent microcracking, and strengthen the epidermal barrier [18].

3.5. Antioxidant protection

Oxidative stress plays a contributory role in dandruff by damaging scalp lipids and promoting inflammation. Essential oils rich in antioxidants such as rosemary (carnosol, carnosic acid), clove (eugenol), and thyme (thymol) neutralize reactive oxygen species (ROS) and prevent lipid peroxidation. This antioxidant defense helps maintain a healthier scalp environment [19].

3.6. Regulation of sebum secretion

Oils such as rosemary, tea tree, and peppermint possess sebum-balancing properties that help regulate excessive scalp oiliness. They modulate sebaceous gland activity and maintain physiological lipid composition, creating an unfavorable environment for *Malassezia* overgrowth. This effect is particularly beneficial in individuals with oily scalp and recurrent flaking [20].

3.7. Anti-microbial balance

Essential oils help sustain a balanced scalp microbiome by selectively controlling pathogenic microorganisms while preserving beneficial resident flora. Oils such as tea tree, thyme, oregano, and eucalyptus demonstrate effective

antimicrobial activity against *Malassezia* species and opportunistic microbes without completely disrupting the natural microbial ecosystem. This selective regulation prevents microbial imbalance, limits repeated colonization, and promotes long-term scalp stability. By maintaining microbial equilibrium, essential oils reduce inflammation, flaking, and recurrence often observed with conventional antifungal treatments.

4. Essential oils with proven anti-dandruff activity

A wide range of essential oils has demonstrated significant anti-dandruff potential due to their antifungal, anti-inflammatory, keratolytic, and scalp-restorative actions. The essential oils mentioned in Table 1 are supported by in-vitro, in-vivo, and limited clinical evidence, providing a strong scientific basis for their inclusion in anti-dandruff formulations.

4.1. Tea tree oil (*Melaleuca alternifolia*)

Tea tree oil, obtained through steam distillation of the leaves of *Melaleuca alternifolia*, family *Myrtaceae*, is one of the most extensively investigated essential oils for dandruff management. Its therapeutic activity is primarily attributed to terpinen-4-ol (Fig. 2), along with α -terpinene, γ -terpinene, α -terpineol, limonene, and small amounts of 1,8-cineole. These constituents exhibit potent antifungal action against *Malassezia* species by disrupting fungal cell membrane integrity, increasing permeability, and causing leakage of intracellular components, ultimately leading to cell lysis and growth inhibition. Terpinen-4-ol also suppresses fungal lipase activity responsible for the breakdown of scalp sebum into irritant-free fatty acids such as oleic acid, thereby preventing the inflammatory cascade that accelerates epidermal turnover and flake formation. In addition to its antifungal effects, tea tree oil demonstrates strong anti-inflammatory activity by downregulating pro-inflammatory mediators including TNF- α , IL-1 β , and IL-8, which helps alleviate itching and scalp irritation. Its mild astringent and sebum-modulating actions help rebalance oily scalp conditions, restricting further fungal proliferation [21]. The oil also provides keratolytic benefits, aiding the gentle removal of adherent corneocytes and normalizing desquamation. Furthermore, antioxidant terpenes present in tea tree oil protect scalp lipids from oxidative damage and support barrier repair. Collectively, these multifaceted mechanisms make tea tree oil a highly effective natural agent for controlling dandruff and restoring scalp health.

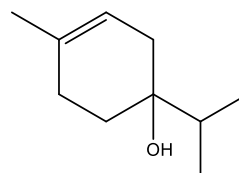


Fig. 2. The structure of terpinen-4-ol.

Table 1. Essential oils with anti-dandruff activity and their mechanisms.

Sr. no.	Essential oil	Botanical source	Major active constituents	Primary anti-dandruff mechanisms	Reference
1	Tea tree oil	<i>Melaleuca alternifolia</i> (Maiden & Betche) Cheel	Terpinen-4-ol, α -terpineol	Strong antifungal activity against <i>Malassezia</i> , anti-inflammatory action, inhibition of fungal lipase	[21]
2	Rosemary oil	<i>Rosmarinus officinalis</i> L.	1,8-Cineole, camphor	Antifungal and antioxidant effects, regulation of excess sebum	[22]
3	Lemongrass oil	<i>Cymbopogon citratus</i> (DC.) Stapf	Citral (neral, geranial)	Disrupts fungal cell membrane, antifungal effect, mild keratolytic action	[23]
4	Thyme oil	<i>Thymus vulgaris</i> L.	Thymol, carvacrol	Potent antifungal activity, anti-inflammatory action, inhibition of microbial growth	[24]
5	Peppermint oil	<i>Mentha \times piperita</i> L.	Menthol, menthone	Anti-pruritic effect, cooling sensation, sebum control and antimicrobial activity	[25]
6	Lavender oil	<i>Lavandula angustifolia</i> Mill.	Linalool, linalyl acetate	Soothing and anti-inflammatory effects, scalp barrier restoration	[26]
7	Neem oil	<i>Azadirachta indica</i> A.Juss	Azadirachtin, nimbidin	Antifungal and anti-inflammatory activity, enhancement of scalp barrier function	[27]
8	Clove oil	<i>Syzygium aromaticum</i> (L.) Merr. & L.M.Perry	Eugenol	Strong antifungal and antioxidant properties, reducing scalp inflammation	[28]
9	Eucalyptus oil	<i>Eucalyptus globulus</i> Labill.	1,8-Cineole	Antifungal activity, keratolytic effect, reduction of inflammation	[29]
10	Basil oil	<i>Ocimum tenuiflorum</i> L.	Eugenol, β -caryophyllene	Broad-spectrum antimicrobial action, antioxidant and anti-inflammatory effects	[30]
11	Cedarwood oil	<i>Cedrus atlantica</i> (Endl.) Manetti ex Carrière / <i>Juniperus virginiana</i> L.	Himachalenes (<i>Cedrus atlantica</i>), cedrol (<i>Juniperus virginiana</i>)	Sebum-regulating activity, antifungal effect, and reduction of scalp irritation	[31]
12	Patchouli oil	<i>Pogostemon cablin</i> (Blanco) Benth.	Patchoulol, α -bulnesene	Antifungal action, anti-inflammatory and skin-repair properties	[32]
13	Palmarosa oil	<i>Cymbopogon martinii</i> (Roxb.) W.Watson	Geraniol	Antifungal activity, hydration of scalp, barrier-strengthening effect	[33]
14	Oregano oil	<i>Origanum vulgare</i> L.	Carvacrol, thymol	Strong antifungal and antimicrobial activity against <i>Malassezia</i> species	[34]
15	Sandalwood oil	<i>Santalum album</i> L.	α -Santalol, β -santalol	Anti-inflammatory and soothing effects, reduction of scalp irritation	[35]

4.2. Rosemary oil (*Rosmarinus officinalis* L.)

Rosemary oil is obtained from the inflorescences of *Rosmarinus officinalis* L. and contains major constituents such as 1,8-cineole (Fig. 3a), camphor (Fig. 3b), α -pinene, and borneol, compounds known for their antifungal, anti-inflammatory, and antioxidant activities. Rosemary oil inhibits *Malassezia* spp. by compromising membrane integrity and inhibiting ergosterol synthesis, a vital component of fungal cell walls. Its active terpenoids also suppress fungal lipase enzymes, preventing sebum degradation into irritant metabolites that trigger inflammation and flaking. The oil additionally enhances scalp microcirculation, improving follicular oxygenation and promoting a healthier scalp environment less conducive to fungal proliferation. The strong antioxidant molecules carnosol and rosmarinic acid neutralize reactive oxygen species that contribute to scalp lipid peroxidation and barrier damage. By regulating sebum secretion and reducing inflammation, rosemary oil provides a multifaceted approach to dandruff management, supporting both microbial control and restoration of scalp homeostasis [22].

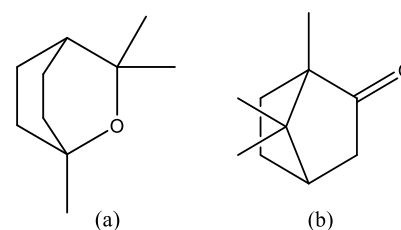


Fig. 3. The structure of 1,8-cineole (a) and camphor (b).

4.3. Lemongrass oil (*Cymbopogon citratus* (DC.) Stapf)

Lemongrass oil, derived from the fresh leaves of *Cymbopogon citratus* (DC.) Stapf by steam distillation is rich in citral (Fig. 4) (a mixture of neral and geranial), along with geraniol, limonene, and β -myrcene, which collectively contribute to its strong antifungal potential against *Malassezia* species. Citral acts primarily by disrupting fungal cell membranes, increasing permeability, and causing irreversible leakage of intracellular proteins and ions, ultimately suppressing fungal viability. It also interferes with fungal respiration and lipid metabolism, reducing the production of inflammatory free fatty acids responsible for scalp irritation and accelerated desquamation. Lemongrass

oil additionally demonstrates significant anti-inflammatory activity by inhibiting pro-inflammatory cytokines and reducing oxidative stress through its high antioxidant content, thereby alleviating itching and irritation. Its mild keratolytic effect supports gentle exfoliation of compacted corneocytes, while its lipid-modulating properties help balance excess scalp oil that favors fungal growth. These combined mechanisms make lemongrass oil a valuable natural anti-dandruff agent with both antimicrobial and scalp restorative benefits [23].

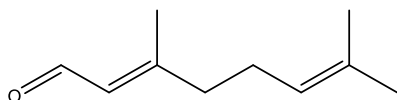


Fig. 4. The structure of citral.

4.4. Thyme oil (*Thymus vulgaris* L.)

Thyme oil, derived from *Thymus vulgaris* L., is exceptionally rich in thymol (Fig. 5) and carvacrol, two phenolic compounds with one of the highest documented antifungal activities against *Malassezia* spp. Thymol integrates into fungal cell membranes, disrupting their phospholipid structure, increasing permeability, and leading to rapid cytoplasmic leakage and cell death. Furthermore, thymol and carvacrol strongly inhibit fungal lipase enzymes, reducing the formation of oleic acid, a key irritant driving epidermal barrier dysfunction and dandruff flaking. Thyme oil's anti-inflammatory properties function through the inhibition of COX and LOX pathways, reducing the release of inflammatory cytokines and soothing scalp discomfort. Its potent antioxidant capability, due to phenolic content, prevents oxidative damage to scalp lipids and proteins [24]. Thyme oil also exhibits mild keratolytic effects, supporting the removal of adherent scales. Overall, its powerful antifungal and anti-inflammatory synergy positions thyme oil as one of the most effective natural agents for dandruff control.

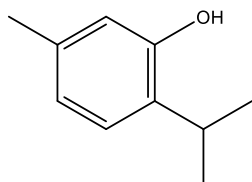


Fig. 5. The structure of thymol.

4.5. Peppermint oil (*Mentha × piperita* L.)

Peppermint oil, extracted from the leaves of *Mentha × piperita* L., contains menthol (Fig. 6), menthone, menthyl acetate, and limonene, which collectively offer cooling, anti-inflammatory, and antimicrobial benefits. Although not as potent an antifungal as tea tree or thyme oil, peppermint oil disrupts *Malassezia* spp. cell membranes and inhibits hyphal growth through menthol-mediated membrane destabilization. Menthol also reduces scalp inflammation by blocking calcium and sodium ion channels involved in pruritus transmission, thereby significantly relieving itching, a common symptom in dandruff. Peppermint oil regulates excessive scalp oiliness by modulating sebaceous gland activity, which indirectly limits fungal proliferation [25]. Its vasodilatory properties stimulate microcirculation in the scalp, improving nutrient

supply and promoting a healthier scalp environment. Antioxidant terpenes help reduce oxidative stress that contributes to dandruff-associated inflammation. Together, these mechanisms make peppermint oil a soothing and supportive ingredient in anti-dandruff formulations.

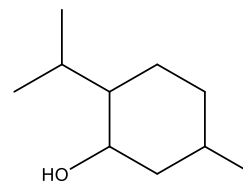


Fig. 6. The structure of menthol.

4.6. Lavender oil (*Lavandula angustifolia* Mill.)

Lavender oil is steam-distilled from the flowering spikes of *Lavandula angustifolia* Mill. and contains linalool (Fig. 7), linalyl acetate, lavandulol, and terpinene-4-ol. Although its antifungal potency against *Malassezia* is moderate, lavender oil's therapeutic strength lies in its strong anti-inflammatory, soothing, and barrier-restoring properties. Linalool and linalyl acetate inhibit inflammatory mediators, including TNF- α and IL-6, reducing scalp redness, itching, and irritation. Lavender oil also displays membrane-disrupting effects on fungi, contributing to reduced microbial load. Its calming properties help alleviate stress-related scalp conditions, which can exacerbate dandruff. Additionally, lavender supports barrier repair by enhancing lipid organization and improving hydration of the stratum corneum. Its antioxidant content further protects scalp lipids from oxidative degradation. Due to these properties, lavender oil is especially suitable for sensitive scalp types or for combination use with stronger antifungal oils [26].

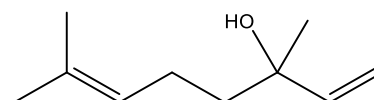


Fig. 7. The structure of linalool.

4.7. Neem oil (*Azadirachta indica* A. Juss.)

Neem oil, extracted from the seeds of *Azadirachta indica* A. Juss., is rich in biologically active limonoids such as azadirachtin, nimbin (Fig. 8), nimbidin, salannin, and gedunin. These compounds exhibit potent antifungal activity by interfering with fungal cell wall synthesis, inhibiting mitochondrial respiration, and disrupting membrane stability in *Malassezia* strains. Neem oil also inhibits fungal lipases and proteases that degrade scalp lipids and weaken the barrier function. Its strong anti-inflammatory effects are attributed to suppression of prostaglandins and cytokines, significantly reducing itching, erythema, and irritation associated with dandruff [27]. Neem oil additionally offers antibacterial protection, preventing secondary microbial infections common in chronic dandruff. Its high fatty acid content, including oleic, linoleic, and palmitic acids, nourishes the scalp, supports barrier restoration, and improves moisture retention. These combined antimicrobial, anti-inflammatory, and barrier supportive properties make neem oil a powerful natural remedy for persistent or severe dandruff.

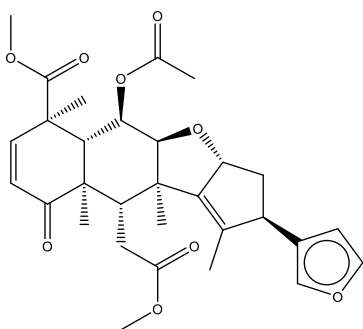


Fig. 8. The structure of nimbin.

4.8. Clove oil (*Syzygium aromaticum* (L.) Merr. & L.M.Perry)

Clove oil, distilled from the dried flower buds of *Syzygium aromaticum* (L.) Merr. & L.M.Perry, is dominated by eugenol (Fig. 9), along with eugenyl acetate and β -caryophyllene. Eugenol is one of the strongest natural antifungal agents and acts by inserting into fungal membranes, causing structural disorganization, leakage of cytoplasmic contents, and inhibition of cellular respiration. It also interferes with ergosterol biosynthesis, weakening fungal cell walls and preventing growth of *Malassezia* spp. Clove oil exhibits powerful antioxidant capacity due to its phenolic structure, protecting scalp lipids from free radical damage and reducing oxidative stress, a contributing factor in dandruff-related inflammation. Its anti-inflammatory action involves inhibition of COX enzymes and decreased production of prostaglandins, which helps alleviate itching and irritation. Due to its intensity, clove oil is often used in low concentrations but offers exceptionally strong antifungal benefits essential for controlling stubborn dandruff [28].

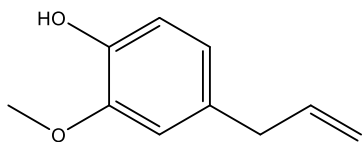


Fig. 9. The structure of eugenol.

4.9. Eucalyptus oil (*Eucalyptus globulus* Labill.)

Eucalyptus oil, extracted from the leaves of *Eucalyptus globulus*, contains high levels of 1,8-cineole (eucalyptol) (Fig. 3a), α -pinene, limonene, and globulol. 1,8-Cineole disrupts fungal membrane integrity, inhibits ergosterol synthesis, and reduces the metabolic activity of *Malassezia* yeasts. Eucalyptus oil also demonstrates strong anti-inflammatory activity by suppressing cytokines such as IL-6 and TNF- α , reducing scalp irritation and pruritus. Its natural keratolytic effect helps loosen adherent flakes and supports the removal of dead skin buildup. Additionally, eucalyptus oil improves blood microcirculation in the scalp, aiding nutrient delivery and promoting barrier recovery. The antioxidant terpenes present in eucalyptus oil mitigate oxidative stress that contributes to irritation and scalp barrier dysfunction. Overall, eucalyptus oil offers antifungal, soothing, keratolytic, and antioxidant benefits ideal for clarifying anti-dandruff formulations [29].

4.10. Basil oil (*Ocimum tenuiflorum* L.)

Basil oil, derived from the leaves of *Ocimum tenuiflorum* L., contains eugenol (Fig. 9), methyl chavicol, caryophyllene, and linalool, which collectively provide strong antimicrobial, anti-inflammatory, and antioxidant

activity. Eugenol acts on fungal membranes, causing leakage of intracellular enzymes and disruption of cell wall synthesis in *Malassezia* species. Basil oil also inhibits fungal lipases, decreasing the formation of irritant-free fatty acids that worsen flaking and inflammation. Its anti-inflammatory activity occurs through the suppression of nitric oxide, TNF- α , and IL-1 β , reducing scalp redness and itching [30]. Additionally, basil oil exhibits strong antioxidant capacity due to phenolic constituents, protecting scalp lipids from oxidative degradation. Its purifying action reduces microbial load, supports scalp detoxification, and promotes a balanced scalp microbiome. These properties make basil oil an effective natural component in anti-dandruff treatments.

4.11. Cedarwood oil (*Cedrus atlantica* (Endl.) Manetti ex Carrière and *Juniperus virginiana* L.)

Cedarwood oil used in anti-dandruff formulations is derived from two distinct botanical sources, *Cedrus atlantica* (Endl.) Manetti ex Carrière, which belongs to the family Pinaceae, and *Juniperus virginiana* L. which belongs to the family Cupressaceae, which differ substantially in phytochemical composition and biological activity despite sharing a common trade name. The essential oil of *Cedrus atlantica* is predominantly composed of sesquiterpene hydrocarbons, particularly α -, β -, and γ -himachalene, which contribute to its anti-inflammatory, sebum-modulating, and scalp-soothing properties. By helping regulate excessive sebum production and reducing inflammatory mediators, this oil may limit the lipid-rich environment that supports *Malassezia* proliferation and assist in normalizing scalp desquamation. In contrast, *Juniperus virginiana* oil contains higher concentrations of cedrol (Fig. 10) and cedrene, compounds associated with notable antiseptic and antimicrobial activity. These constituents may contribute to controlling scalp microbial load, including *Malassezia* species, while also reducing irritation and secondary colonization [31].

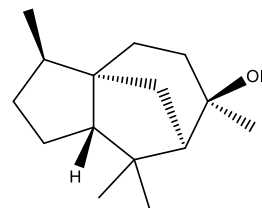


Fig. 10. The structure of cedrol.

4.12. Patchouli oil (*Pogostemon cablin* (Blanco) Benth.)

Patchouli oil is obtained from the leaves of *Pogostemon cablin* (Blanco) Benth., a member of the family Lamiaceae. It is rich in tricyclic sesquiterpenes, including patchoulol (Fig. 11), α -bulnesene, and α -guaiene, which contribute to its broad antimicrobial and anti-inflammatory properties. The major constituents of patchouli oil exhibit antifungal activity against *Malassezia* species by disrupting fungal cell membrane integrity and interfering with essential enzymatic pathways necessary for fungal growth and survival. By inhibiting fungal lipase enzymes, patchouli oil reduces the hydrolysis of sebum triglycerides into pro-inflammatory free fatty acids that trigger scalp irritation and hyperproliferation of corneocytes. Patchoulol and related sesquiterpenes also demonstrate significant anti-inflammatory effects

by downregulating pro-inflammatory cytokines and reducing oxidative stress, which helps alleviate itching, erythema, and flaking associated with dandruff. In addition, patchouli oil's mild keratolytic and sebo-regulatory actions support the normalization of scalp desquamation and sebum balance, thereby creating a scalp environment less conducive to fungal overgrowth. These combined mechanisms make patchouli oil a promising natural therapeutic option for managing dandruff and enhancing overall scalp health [32].

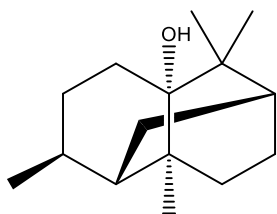


Fig. 11. The structure of patchoulol.

4.13. Palmarosa oil (*Cymbopogon martinii* (Roxb.) W. Watson)

Palmarosa oil, obtained by steam distillation of the fresh or partially dried aerial parts of *Cymbopogon martinii* (Roxb.) W. Watson, family *Poaceae*, is predominantly rich in the monoterpene alcohol geraniol (Fig. 12), along with minor components such as geranyl acetate, linalool, and myrcene, which collectively contribute to its antifungal and scalp conditioning effects. The oil exhibits significant antifungal activity against *Malassezia* species by disrupting fungal cell membrane structure and interfering with membrane-bound enzymes essential for fungal growth and viability, thereby limiting colonization on the scalp. Geraniol has also been shown to inhibit fungal lipase activity, reducing the breakdown of sebum triglycerides into irritant free fatty acids that trigger inflammation and abnormal scaling. In addition, palmarosa oil demonstrates anti-inflammatory action by modulating cytokine release and attenuating oxidative stress, which helps to alleviate pruritus, erythema, and scalp irritation associated with dandruff. Its mild keratolytic and hydrating properties support the gentle removal of compacted corneocytes and help restore scalp barrier function, while its ability to balance sebum production further establishes a scalp environment less hospitable to fungal overgrowth. These combined antifungal, anti-inflammatory, and sebum-modulating mechanisms make palmarosa oil a promising natural intervention for dandruff management and overall scalp health [33].

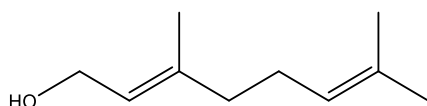


Fig. 12. The structure of geraniol.

4.14. Oregano oil (*Origanum vulgare* L.)

Oregano oil, distilled from the leaves and flowering tops of *Origanum vulgare* L., family *Lamiaceae*, is a complex essential oil dominated by phenolic monoterpenes such as carvacrol (Fig. 13) and thymol (Fig. 5), along with lesser amounts of p-cymene, γ -terpinene, and terpinen-4-ol (Fig. 2). These phenolic constituents confer potent broad-spectrum antimicrobial activity, including robust antifungal effects against a range of pathogenic yeasts and moulds by

perturbing cell membrane integrity, increasing membrane permeability, and inducing reactive oxygen species accumulation that compromise fungal viability. *In vitro* studies demonstrate that oregano oil and its principal phenols disrupt lipid bilayers and inhibit fungal enzymatic systems critical for growth and proliferation, leading to cytoplasmic leakage and cell death. Such membrane-targeted antifungal action suggests oregano oil could reduce colonization by *Malassezia* spp., the lipid-dependent yeasts implicated in dandruff pathogenesis, and may attenuate associated scalp inflammation by reducing fungal-driven immune activation. Beyond antifungal effects, oregano oil exhibits anti-inflammatory and antioxidant activity, which can mitigate cytokine mediated inflammatory cascades and oxidative stress on the scalp, potentially alleviating pruritus and erythema. The combined antimicrobial and soothing mechanisms make oregano oil a compelling natural candidate for dandruff-targeted cosmeceuticals and scalp health formulations [34].

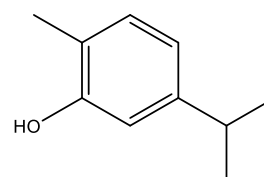


Fig. 13. The structure of carvacrol.

4.15. Sandalwood oil (*Santalum album* L.)

Sandalwood oil, obtained by steam distillation of the heartwood of *Santalum album* L., family *Santalaceae*, is principally composed of sesquiterpene alcohols such as α -santalol (Fig. 14) and β -santalol. These sesquiterpenoids exhibit multifaceted antimicrobial and anti-inflammatory properties that contribute to scalp health. The antimicrobial action of sandalwood oil involves disruption of microbial cell functions and impairment of protein synthesis in a range of dermatologically relevant pathogens, demonstrating activity against diverse fungi in *in vitro* assays. In addition to direct antifungal potential, sandalwood oil modulates key inflammatory pathways, attenuating pro-inflammatory mediators and oxidative stress, which may help reduce scalp irritation, redness, and flaking associated with dandruff. Its soothing and hydrating effects further support the restoration of impaired scalp barrier function and balance sebum production, creating an environment less conducive to fungal overgrowth. The characteristic lipid-soluble sesquiterpenes also contribute to scalp conditioning and mild keratolytic activity that can assist in the gentle release of compacted corneocytes, promoting desquamation without harsh exfoliation. Together, these antimicrobial and modulatory effects position sandalwood oil as a multifunctional botanical ingredient for scalp care systems targeting dandruff and inflammation [35].

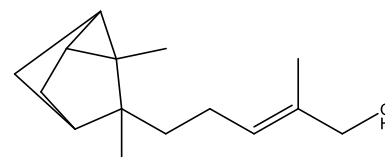


Fig. 14. The structure of α -santalol.

Table 1 summarizes essential oils with reported anti-dandruff activity and their principal mechanisms of action.

5. Comparative efficacy of essential oils vs. conventional agents

Conventional anti-dandruff agents such as ketoconazole, zinc pyrithione (ZPT), selenium sulfide, and ciclopirox olamine remain the standard pharmacological treatments due to their well-established antifungal activity against *Malassezia* species. Ketoconazole acts by inhibiting ergosterol synthesis in fungal membranes, while ZPT disrupts membrane transport mechanisms, and selenium sulfide reduces epithelial turnover. Although effective, these agents are associated with several drawbacks, including scalp irritation, dryness, unpleasant odor, residue formation, altered hair texture, and reduced patient adherence. Furthermore, repeated long-term use may contribute to microbial tolerance, diminishing efficacy in chronic or recurrent cases [36].

In contrast, essential oils provide a complementary or alternative therapeutic approach characterized by multi-targeted mechanisms and better cosmetic acceptability. Oils such as tea tree, lemongrass, thyme, clove, rosemary, and neem demonstrate strong in-vitro inhibitory effects against *Malassezia globosa*, *M. restricta*, and *M. furfur*, often comparable to or exceeding the activity of synthetic agents at equivalent concentrations. For example, tea tree oil-based formulations (5%) have shown approximately a 41% reduction in dandruff severity in clinical evaluations, while lemongrass and rosemary oils have demonstrated dose-dependent antifungal effects comparable to low-dose ketoconazole in laboratory studies [37]. Unlike conventional drugs that target a single pathway, essential oils modulate multiple pathogenic factors simultaneously, including fungal growth, lipase activity, inflammation, oxidative stress, sebum imbalance, and epidermal hyperproliferation.

Another significant advantage of essential oils is their favorable safety and tolerability profile when used at appropriate concentrations. They are less likely to cause scalp dryness or irritation and often contribute to improved sensory qualities, such as pleasant fragrance and cooling or soothing effects, which enhance user experience. Essential oils also exhibit broad-spectrum antimicrobial activity, reducing not only *Malassezia* but also bacteria that can contribute to secondary infections in chronic dandruff. However, essential oils are not without limitations; issues such as variability in chemical composition, potential allergenicity, and sensitivity in high concentrations necessitate careful formulation, standardization, and patch testing [38,39]. Overall, while conventional agents remain potent first-line therapies, essential oils offer a promising natural alternative with strong antifungal activity and multi-dimensional scalp benefits. Their combination with synthetic agents may provide synergistic effects, improving outcomes while reducing the dosage and side effects of conventional drugs. Integrating essential oils into modern anti-dandruff formulations thus represents a balanced approach that unites clinical efficacy with enhanced safety and user preference [40].

6. Conclusion

Dandruff is a multifactorial scalp disorder involving *Malassezia* overgrowth, abnormal keratinocyte turnover, sebum imbalance, inflammation, and oxidative stress. Although conventional antifungal agents are effective,

their long-term use is often limited by adverse effects and recurrence. Essential oils provide a holistic and multi-targeted alternative due to their antifungal, anti-inflammatory, antioxidant, keratolytic, sebum-regulating, and barrier-restorative properties. Oils such as tea tree, lemongrass, rosemary, thyme, neem, clove, and eucalyptus have demonstrated significant efficacy against *Malassezia* species with improved tolerability and cosmetic acceptability. However, challenges including variability in composition and limited large-scale clinical trials remain. Future research should focus on standardized formulations, optimized delivery systems, and well-designed clinical studies to establish their long-term safety and therapeutic effectiveness.

Author Contributions: Conceptualization, S.S. and Y.S.; methodology, S.S.; validation, G.S., S.S., and S.M.; investigation, S.M.; resources, D.D.; data curation, S.S.; writing-original draft preparation, G.S.; writing-review and editing, S.S, G.S.; visualization, Y.S.; supervision, S.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The author acknowledges the Management, and Principal of Divine College of Pharmacy, Satana, for providing the necessary facilities and constant support while preparing the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Chan, C. S.; Smith, T.; He, Z.; Garter, C. The Sequelae and Moderators of Influence of Dandruff on Mental Health among Mainland Chinese Adults. *Clin. Cosmet. Investig. Dermatol.* **2024**, *17*, 1333-1346. DOI: 10.2147/CCID.S468921
2. Borda, L. J.; Wikramanayake, T. C. Seborrheic Dermatitis and Dandruff: A Comprehensive Review. *J. Clin. Investig. Dermatol.* **2015**, *3*(2), Art. No: 10. DOI: 10.13188/2373-1044.1000019
3. Jourdain, R.; Alain, M. O.; Magiatis, P.; et al. *Malassezia restricta*-Mediated Lipoperoxidation: A Novel Trigger in Dandruff. *Acta Derm. Venereol.* **2023**, *103*, Art. No: adv4808. DOI: 10.2340/actadv.v103.4808
4. Vidal, S. I.; Menta, N.; Green, L. Child and Adult Seborrheic Dermatitis: A Narrative Review of the Current Treatment Landscape. *Dermatol. Ther.* **2025**, *15*, Art. No: e16488. DOI: 10.1111/dth.16488
5. Godse, G.; Godse, K. Safety, Efficacy and Attributes of 2.5% Selenium Sulfide Shampoo in the Treatment of Dandruff. *Cureus* **2024**, *16*(3), Art. No: e56734. DOI: 10.7759/cureus.56734
6. Bolouri, P.; Salami, R.; Kouhi, S.; et al. Applications of Essential Oils and Plant Extracts in Different Industries. *Molecules* **2022**, *27*(24), Art. No: 8999. DOI: 10.3390/molecules27248999
7. Donato, R.; Sacco, C.; Pini, G.; Bilia, A. R. Antifungal Activity of Different Essential Oils against *Malassezia* Species. *J. Ethnopharmacol.* **2020**, *249*, Art. No: 112376. DOI: 10.1016/j.jep.2019.112376

8. Pople, J. E.; Bhogal, R. K.; Moore, A. E.; Jenkins, G. Changes in Epidermal Morphology Associated with Dandruff. *Int. J. Cosmet. Sci.* **2019**, *41*(4), 357-363. DOI: 10.1111/ics.12546
9. DeAngelis, Y. M.; Gemmer, C. M.; Kaczvinsky, J. R.; et al. Three Etiologic Facets of Dandruff and Seborrheic Dermatitis. *J. Investig. Dermatol. Symp. Proc.* **2005**, *10*(3), 295-297. DOI: 10.1111/j.1087-0024.2005.10115.x
10. Wang, W.; Cai, S.; Wang, Y.; et al. *Cinnamomum burmannii* Essential Oil against *Malassezia furfur*. *Microorganisms* **2025**, *13*(6), Art. No: 1241. DOI: 10.3390/microorganisms13061241
11. Piacentini, F.; Camera, E.; Di Nardo, A.; Dell'Anna, M. L. Seborrheic Dermatitis and *Malassezia*. *Int. J. Mol. Sci.* **2025**, *26*(6), Art. No: 2650. DOI: 10.3390/ijms26062650
12. Kartal, M.; Yildirim, A.; Er, O.; et al. Palmarosa Essential Oil against *Malassezia furfur*. *Microb. Pathog.* **2025**, *200*, Art. No: 10732. DOI: 10.1016/j.micpath.2025.10732
13. El Asbahani, A.; Miladi, K.; Badri, W.; et al. Essential Oils: From Extraction to Encapsulation. *Int. J. Pharm.* **2015**, *483*(1-2), 220-243. DOI: 10.1016/j.ijpharm.2014.12.069
14. Niu, Y.; Ren, C.; Liao, H.; et al. Autologous FUE in Cicatricial Alopecia. *J. Cosmet. Dermatol.* **2024**, *23*(2), 585-590. DOI: 10.1111/jocd.15892
15. Čonková, E.; Váczi, P.; Malinová, Z. Antifungal Efficacy against *Malassezia pachydermatis*. *Microorganisms* **2025**, *13*(12), Art. No: 2675. DOI: 10.3390/microorganisms13122675
16. Zhang, Y.; Sun, Y.; Liu, Y.; et al. *Polygonum sibiricum* Polysaccharides and Depression. *Phytother. Res.* **2023**, *37*(8), 3408-3423. DOI: 10.1002/ptr.7801
17. Smith, K. B.; Jones, S. C.; Lim, P. Keratolytic Activities of Essential Oils. *Int. J. Dermatol.* **2023**, *62*(9), 1123-1132. DOI: 10.1111/ijd.16854
18. Park, J. H.; Lee, S. J.; Kim, Y. H. Essential Oils and Skin Barrier. *Skin Res. Technol.* **2022**, *28*(6), 829-840. DOI: 10.1111/srt.13163
19. Reddy, K. B.; Gupta, S.; Sha, H. Antioxidant Mechanisms of Essential Oils. *Free Radic. Biol. Med.* **2025**, *189*, 46-60. DOI: 10.1016/j.freeradbiomed.2024.12.021
20. Kumari, K. U.; Yadav, N. P.; Luqman, S. Promising Essential Oils and Plant Extracts in the Prevention and Treatment of Dandruff Pathogenesis. *Curr. Top. Med. Chem.* **2022**, *22*(13), 1104-1133. DOI: 10.2174/1568026622666220207111556
21. Satchell, A. C.; Saurajen, A.; Bell, C.; Barnetson, R. S. Treatment of Dandruff with 5% Tea Tree Oil Shampoo. *J. Am. Acad. Dermatol.* **2002**, *47*(6), 852-855. DOI: 10.1067/mjd.2002.126483
22. Silva Britto, J.; da Silva, M. B.; da Silva, J. R.; et al. Synergism between Essential Oils and Evaluation of Their Activities with a Focus on *Malassezia furfur* Control. *Rev. Inst. Med. Trop. Sao Paulo* **2023**, *65*, Art. No: e17. DOI: 10.1590/S1678-9946202365017
23. Rhimi, W.; Mohammed, M. A.; Zarea, A. A.; Greco, G.; Tempesta, M.; Otranto, D.; Cafarchia, C. Antifungal, Antioxidant and Antibiofilm Activities of Essential Oils of *Cymbopogon* spp. *Antibiotics* **2022**, *11*(6), Art. No: 829. DOI: 10.3390/antibiotics11060829
24. Cassola F, Ramirez N, Ribeiro G, da Silva LH, Gambero A, de Oliveira AD, de Moraes Vieira PM, Nogueira FA, Duarte MC. Synergism between essential oils and evaluation of their activities with a focus on *Malassezia furfur* control. *Planta Med.* **2024**, *90*(02), 111-125. DOI: 10.1055/a-2196-2087
25. Chakraborty, K.; Chakravarti, A. R.; Bhattacharjee, S. Bioactive Components of Peppermint (*Mentha piperita* L.), Their Pharmacological and Ethnomedicinal Benefits: A Review. *J. Pharmacogn. Phytochem.* **2022**, *11*(1), 109-114. DOI: 10.22271/phyto.2022.v11.i1b.14322
26. Turek, C.; Stintzing, F. C. Antimicrobial and Anti-Inflammatory Potential of Lavender Essential Oil and Its Major Constituents. *Evid.-Based Complement. Altern. Med.* **2024**, *2024*, Art. No: 9894132. DOI: 10.1155/2024/9894132
27. Wylie, M. R.; Merrell, D. S. The Antimicrobial Potential of the Neem Tree (*Azadirachta indica*). *Front. Pharmacol.* **2022**, *13*, Art. No: 891535. DOI: 10.3389/fphar.2022.891535
28. Chaieb, K.; Hajlaoui, H.; Zmantar, T.; et al. The Chemical Composition and Biological Activity of Clove Essential Oil (*Eugenia caryophyllata*): A Short Review. *Phytother. Res.* **2007**, *21*(6), 501-506. DOI: 10.1002/ptr.2124
29. Salvatori, E. S.; Morgan, L. V.; Ferrarini, S.; et al. Anti-Inflammatory and Antimicrobial Effects of *Eucalyptus* spp. Essential Oils: A Valuable Use for an Industry Byproduct. *Evid.-Based Complement. Altern. Med.* **2023**, *2023*, Art. No: 2582698. DOI: 10.1155/2023/2582698
30. Khan, A.; Ahmad, A.; Akhtar, F.; Yousuf, S.; Xess, I.; Khan, L. A.; Manzoor, N. *Ocimum sanctum* Essential Oil and Its Active Principles Disrupt Ergosterol Biosynthesis and Membrane Integrity. *Res. Microbiol.* **2010**, *161*(10), 816-823. DOI: 10.1016/j.resmic.2010.09.008
31. Gonçalves, S. D.; et al. Cedarwood Essential Oil (*Cedrus* spp.): A Forgotten Pharmacological Resource with Emerging Therapeutic Potential. *Explor. Drug Sci.* **2025**, *3*, Art. No: 1008131. DOI: 10.1016/j.xphs.2025.1008131
32. Mrisho, I. I.; Musazade, E.; Chen, H.; Zhao, H.; Xing, J.; Li, X.; Han, J.; Cai, E. Unlocking the Therapeutic Potential of Patchouli Leaves: A Comprehensive Review of Phytochemical and Pharmacological Insights. *Plants* **2025**, *14*(7), Art. No: 1034. DOI: 10.3390/plants14071034
33. Cebollada, P.; Alvarado, E.; Seral, C.; López, V. Antibacterial Activity of Palmarosa Essential Oil and Geraniol against Clinical Isolates. *Pharmaceutics* **2025**, *18*(1), Art. No: 39. DOI: 10.3390/pharmaceutics18010039

34. Mezzomo, L.; Butzge, J.; Fiorio, M.; Bastiani, C.; Mezzari, A.; Fuentefria, A.; Apel, M. A. *Origanum* Essential Oil and Antifungal Activity: A Systematic Review. *Chem. Biodivers.* **2025**, *22*(6), Art. No: e202402296. DOI: 10.1002/cbdv.202402296
35. Yan, X.; David, S. D.; Du, G.; et al. Biological Properties of Sandalwood Oil and Microbial Synthesis of Its Major Sesquiterpenoids. *Biomolecules* **2024**, *14*(8), Art. No: 971. DOI: 10.3390/biom14080971
36. Wasilewski, T.; Lima Filho, J. V.; Marques, L.; et al. Inhibitory Effect of Lemongrass (*Cymbopogon citratus*) Essential Oil against *Malassezia furfur* in Shampoo Formulations. *J. Dermatol. Treat.* **2011**, *22*(2), 119-124. DOI: 10.3109/09546634.2010.487605
37. Singh, S. P.; Kumar, B.; Misra, A.; Rawat, P.; Tripathi, D.; Srivastava, S. A Synergistic Herbal Formulation Targeting *Malassezia furfur* and *Staphylococcus epidermidis* for Effective Dandruff Management. *Front. Microbiol.* **2025**, *16*, Art. No: 1654658. DOI: 10.3389/fmicb.2025.1654658
38. Pezantes Orellana, C.; Bermúdez, F. A. G.; Montalvo, J.; Packer, T.; Orellana-Manzano, A. Evaluating Efficacy, Safety, and Innovation in Skin Care Applications of Essential Oils. *Front. Med.* **2025**, *12*, Art. No: 1589691. DOI: 10.3389/fmed.2025.1589691
39. Sindle, A.; Martin, K. Essential Oils—Natural Products Not Necessarily Safe. *Int. J. Womens Dermatol.* **2021**, *7*(3), 304-308. DOI: 10.1016/j.ijwd.2020.12.002
40. Jain, S.; Arora, P.; Nainwal, L. M. Essential Oils as a Potential Source of Anti-Dandruff Agents: A Review. *Comb. Chem. High Throughput Screen.* **2022**, *25*(9), 1411-1426. DOI: 10.2174/1386207324666211201110637