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An Emerging of Essential Oils with Antifungal Activities as Anti-dandruff in Formulation

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ABSTRACT

Dandruff can be an extremely distressing scalp condition for many people. It has various causes, from fungi, bacteria, or scalp irritation due to factors like sun exposure or over-shampooing. As the world of beauty moves towards natural cosmetics, alternative anti-dandruff agents that use essential oils are quite popular these days. Essential oils such as tea tree, lemongrass, and lavender can act as antimicrobial agents against the causes of dandruff. This review describes the anti-dandruff potential of various essential oils on several dandruff-causing microorganisms such as *Malassezia furfur* and *Candida albicans*. This review used comparative literature analysis of articles retrieved from Scopus and Google Scholar (2013–2022) with topics that focused on essential oils with anti-dandruff and antifungal activity. The results of this review indicate that various essential oils, especially those highlighted in this article, show strong potential to inhibit the growth of dandruff-causing microorganisms and may be developed into stable anti-dandruff formulations.

Keywords: *Malassezia furfur*, *Candida albicans*, Essential oil, Anti-dandruff, Anti-fungal.

INTRODUCTION

Dandruff is a condition that makes many people uncomfortable and not confident. Dandruff is a group of corneocytes that have detached from the skin's stratum corneum in the scalp and then accumulated with parakeratosis cells. Dandruff can be caused by microbial and non-microbial factors. Non-microbial causes of dandruff include excessive sun exposure, scalp irritation from over-shampooing, excessive combing, dust and dirt exposure, and the use of specific cosmetic products. (Park et al., 2012).

Pathogenic microorganisms use sebum as food, like *Malassezia* spp. (Siddiqui, 2020). At first, *M. furfur* was identified as the cause of pathogenic dandruff on the scalp, but later it was revealed that *M. globosa* and *M. restricta* are mainly responsible. Since these fungi require a lipid-rich environment to grow as the main carbon source, sebum is an ideal substrate for microorganisms like *Malassezia* spp. (Gaitanis & Laurence, 2020), *Propionibacterium*, and *Staphylococcus* (Xu et al., 2016). As discussed in this review, sebaceous glands mature during puberty, increasing sebum production, which provides a nutrient source for lipophilic yeasts. All *Malassezia* species, except *M. pachydermatis*, rely on external lipids, which are essential substrates enabling *Malassezia* to trigger inflammation, hyperproliferation, and scaling in dandruff through lipase activity. Additionally, the cell wall of *Malassezia* is rich in complex lipids, underlying its lipid dependence. This lipid-rich wall also serves as a protective shield against phagocytosis (Meyar et al., 2018).

Lipases act as potential virulence factors in certain pathogenic bacteria and fungi (Brunke et al., 2006). Lipases, secreted by *Malassezia*, hydrolyze sebum and triacylglycerols, releasing free fatty acids that contribute to inflammation. As *Malassezia* consumes sebum, skin compensates by producing more, elevating free fatty acid levels, and releasing irritants like oleic acid. This irritant is known to cause scalp flaking (James et al., 2013). Ultimately, increased *Malassezia* growth heightens lipase activity, releasing free fatty acids such as oleic acid, which exacerbates irritation and dandruff symptoms (Meyar *et al*., 2018).

A healthy scalp has density ranges between 103-105 organisms/mm^2 (Park et al., 2012). *Malassezia* spp. is commonly found on the scalp, but this microbe will be replicated 1.5-2 times the normal level of the skin when the scalp is infected by dandruff (Chaisripipat et al., 2015). The most widely known microorganism that contributes greatly to dandruff, versicolor, atopic dermatitis, seborrheic dermatitis, pityriasis, and other folliculitis is *Malassezia* spp. (Siddiqui, 2020). Seborrheic dermatitis is caused by a non-specific immune response to *Malassezia* species, which triggers inflammation in seborrheic areas such as the scalp, face, chest, back, axilla, and groin (Billamboz & Jawhara, 2023). However, dandruff is a less severe form of seborrheic dermatitis, which is restricted to the scalp and causes itchy, flaking skin without visible inflammation. *Malassezia* is a monophyletic fungus that is found in 7 billion human skin and is related to the skin health condition. In someone who is immunocompromised, *Malassezia* also can cause systemic infection (Saunders et al., 2012). Dandruff can cause the skin to become inflamed and may also be itchy and produce white or yellow flakes. *M. furfur* is well known to cause dandruff, but then there is *Malassezia globosa* (Sibi, 2023).

Removing dandruff is so effective with chemical antifungals, but the side effect is inflammation that can harm the patient (Sahraie-Rad et al., 2015). Antifungals, like ketoconazole (imidazole derivatives), can't be used for the long term because of resistance issues (Pooja et al., 2013). Herbal substances are popular to use to overcome this problem and escalate its effectiveness (Sahraie-Rad et al., 2015). Along with the development of natural cosmetics, alternative antidandruff agents using essential oils are also gaining popularity (Jain, 2022). Essential oil is a hydrophobic liquid that contains high amounts of volatile aromatic chemicals from plants. Natural essential oil can give a potential alternative to the currently used control agent because the composition of essential oil is rich in bioactive chemical compounds (Selvakumar et al., 2012; Masyita et al., 2022; Bolouri et al., 2022), mainly monoterpenes, sesquiterpenes, benzenoids, and phenylpropanoids (Satana de Oliveira, 2023). In addition, these compounds were associated with various biological activities like antibacterial, antiviral, anti-leishmanial, antioxidant, and anticancer effects (Dagni et al., 2022).

The weakness of essential oils is their instability, which causes the preparation to quickly smell rancid and even lose its odor, easy reactivities, volatilities, and tendencies to degradation (Turek & Stintzing, 2013). Moreover, essential oils are highly unstable and easily degrade when exposed to external factors like oxidation, evaporation, heat, and light (Cimino et al., 2021). To address these challenges, various strategies have been explored to enhance their stability, one of which is the use of nanoencapsulation, a technique derived from nanotechnology. Nanoencapsulation has gained significant attention in industries such as pharmaceuticals and cosmetics for its ability to protect sensitive compounds (Maryam, 2015). This technique involves encapsulating the essential oils in nanoparticles, thus preventing evaporation and oxidation, and providing controlled release to ensure prolonged activity. For scalp applications, such as serum formulations, nanoencapsulation can be an ideal method to preserve the stability of essential oils, ensuring their efficacy over time by preventing rapid degradation (Pateiro et al., 2021).

MATERIALS AND METHODS

This review article conducts a comparative study of several sources of research journals on the internet. This literature study was conducted online through journals found by Google Scholar and Scopus. Inclusion criteria are journals and articles that discuss the potential of essential oils as anti-dandruff and were published 10 years prior to 2023 with the exclusion criteria for journals that were published before 2013 (2013-2023). The references are international journals with keywords "tea tree oil as anti-dandruff," "essential oils as anti-dandruff," "anti-dandruff," "formulation Design Expert® of essential oil serum," and "*Malassezia furfur*" (Figure 1).

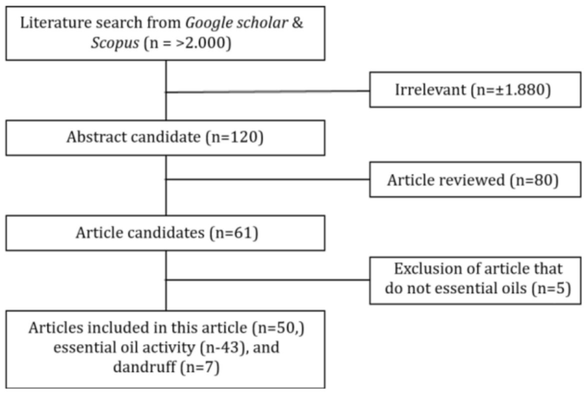

Figure 1. Diagram of Article Writing Method

RESULTS AND DISCUSSION

Dandruff and seborrheic dermatitis are caused by fungal colonies. Therefore, antifungal agents are commonly used for this kind of dandruff treatment. Despite antifungals being used for a long time, it could cause several problems like drug resistance, side effects, and patient non-adherence in its use (Lee et al., 2018). Gap analysis in these reviews shows the market for anti-dandruff products is predominantly populated by synthetic formulations containing active ingredients like zinc pyrithione or ketoconazole. While effective, these synthetic compounds may pose risks of adverse effects or environmental concerns. In contrast, natural anti-dandruff formulas utilizing ingredients such as essential oils or herbal extracts offer potential benefits in terms of safety, sustainability, and consumer appeal. However, there remains a notable gap in research regarding the transition from synthetic to natural anti-dandruff formulas.

Due to these reasons, there have been numerous breakthroughs in antifungal substances that are safer to use on a regular basis; among them are essential oils. Several research findings in this article indicate that certain essential oils have anti-dandruff properties that work by stopping the growth of microorganisms that cause scalp dandruff. Excellent results can be obtained with both pure essential oils and essential oils that have been blended into a variety of hair preparations, which include shampoo (a rinse-off cosmetic), hair tonic (a leave-on cosmetic), and essential oil diluted with a carrier oil, as described in this journal review.

Essential oils have been shown to have a variety of medicinal properties, including analgesic, anesthetic, antiacne, antidiarrheal, antiseptic, antispasmodic, central nervous system stimulant, cosmetic, biopesticide, antiasthmatic, antibacterial, anti-inflammatory, and sedative. They also have a pleasant scent that is used in perfume (Saraswathy & Lavanya, 2013; Ali et al., 2015). Due to their qualities—which include a distinct scent that varies depending on the plant—essential oils are frequently favored to be used in the creation of cosmetic preparations. They also offer a variety of antibacterial, antifungal, and other properties. Some research suggests that mixing essential oils can have a synergistic effect on fungal growth inhibition (Rashed et al., 2021). This could serve as a stepping stone for additional investigation into other hair dose forms with anti-dandruff effects, and it might even be an option for individuals with seborrheic dermatitis brought on by *Malassezia* spp. as a regular scalp care product. The information below was gathered from the many journals reviewed in this article.

Mechanism of Anti-Dandruff Formulations

The mechanism of action for anti-dandruff formulations generally involves the use of antifungal, antibacterial, and skin-scaling properties to combat the root causes of dandruff. Dandruff is primarily caused by *Malassezia* fungi, which are naturally found on the scalp but proliferate excessively in conditions like an oily scalp or inflammation (Gadge et al., 2023). Anti-dandruff formulations often include agents that target this yeast, inhibit its growth, and reduce inflammation. Studies indicate that anti-dandruff shampoos can work through mechanisms such as the inhibition of fungal growth (e.g., using plant extracts like tea tree oil), improvement of scalp condition (e.g., with *aloe vera*'s soothing and anti-inflammatory effects), and the reduction of dead skin cell accumulation on the scalp (e.g., through selenium sulfide or herbal extracts) (Gadge et al., 2023). This review aims to demonstrate that many essential oils (Table I) have the potential to serve as the main active ingredients in an anti-dandruff formulation.

Anti-dandruff activity of essential oil

Tea tree oil

Tea tree oil contains terpenes like terpinen-4-ol, which has been shown to exhibit strong antifungal activity against *Malassezia* species. These terpenes interfere with the fungal cell membrane by disrupting cell wall synthesis and increasing membrane permeability, leading to fungal cell death. The commonly used microbes for testing the anti-dandruff efficacy of tea tree oil include *Malassezia* species, *Candida albicans*, and *Staphylococcus aureus* (Hammer et al., 1999). According to Umar et al. (2020), it was found that tea tree essential oil has anti-dandruff properties against the fungus *Candida albicans* that were better than the standard from 6 shampoo formulations containing tea tree oil with a gradual concentration (0.5%-3%) compared to the control (tea tree oil solution) with the same level of concentration. The samples from the six shampoo recipes fell within a 20.1-26.9 mm zone of inhibition. This inhibition zone is comparable to Selsun Blue shampoo's inhibition zone, which is 20.45±0.9 mm. These outcomes, nonetheless, are still inferior to those of other anti-dandruff shampoo manufacturers.

Table I. Anti-Dandruff Activity of Various Essential Oils

Essential oil	Study type	Microbes Used	Test Results	Active	Journal
Tea tree oil	*In Vivo*	*Malassezia furfur, Malassezia globosa*	Highly effective antifungal activity	Terpinen-4-ol, alpha-terpineol, cineole	(Das et al., 2023)
Rosemary oil	*In Vitro*	*Candida albicans*	Effective against *Candida albicans*	1,8-cineole, camphor, alpha-pinene	(Shahina et al., 2022)
Indian borage oil	*In Vitro*	*Staphylococcus aureus, Candida albicans*	Effective against bacteria and fungi	Thymol, carvacrol	(Wadikar & Patki, 2016)
Tasmanian blue gum oil	*In Vivo*	*Malassezia furfur, Malassezia globosa*	Highly effective antifungal activity	Terpinen-4-ol, alpha-terpineol, cineole	(Baptista et al., 2015)
Peppermint oil	*In Vivo*	*Malassezia furfur, Pityrosporum ovale*	Effective in fungal inhibition	Menthol, menthone, isomenthone	(Makkar et al., 2018)
Lemongrass oil	*In Vitro*	*Aspergillus* spp., *Candida* spp.	Moderate antifungal effect	Linalool, linalyl acetate	(Powers et al., 2018)
Lavender oil	*In Vitro*	*Candida albicans, Malassezia* spp.	Highly effective against fungi and bacteria	Cinnamaldehyde, eugenol	(Váczi et al., 2018)
Cinnamon oil	*In Vitro*	*Candida albicans, Escherichia coli*	Moderate to strong antimicrobial effect	Cineole, terpineol	(Moritz et al., 2015)
Cajeput oil	*In Vitro*	*Candida* spp., *Staphylococcus aureus*	Moderate antifungal properties	Eugenol, methyl eugenol	(Vu et al., 2024)
Kapoor tulsi oil	*In Vitro*	*Pityrosporum ovale, Malassezia* spp.	Effective antifungal properties	Limonene, methyleugenol	(Pinto et al., 2017)
Southern marigold oil	*In Vitro*	*Candida albicans, Aspergillus niger*	Moderate antimicrobial activity	Methyl chavicol, linalool	(Shirazi et al., 2014)
Lemon-scented gum oil	*In Vitro*	*Malassezia globosa*	Effective in fungal inhibition	Citronellal, isopulegol	(Tolba et al., 2015)
Basil oil	*In Vitro*	*Malassezia furfur*	Considerable antifungal activity	Cineol, d-linalool, methyl chavicol, p-cymene, a-terpineol	(Trupti & Gadekar, 2021)
Iruveli oil	*In Vitro*	*Candida albicans, Malassezia furfur*	Effective antifungal properties	a-Gurjunene, a-bisabolol, G-selinene	(Lakshmi & Nandagopal, 2021)
Sage oil	*In Vitro*	*Candida albicans*	Fungicidal and antimicrobial effects	1,8-cineole, β-thujone, borneol, β-elemene, camphor	(Sookto et al., 2013)
Dill seed oil	*In Vitro*	*Candida albicans*	Effective antifungal effect	Carvone, limonene, apiol	(Chen et al., 2013)
Geranium oil	*In Vitro*	*Candida albicans*	Excellent antifungal activity	Geraniol	(Leite et al., 2015)
Bay leaf oil	*In Vitro*	*Candida albicans*	Effective antifungal potential	1,8-cineole, a-pinene β-pinene, limonene, sabinene	(Peixoto et al., 2017)
Summer savory oil	*In Vitro*	*Candida albicans, Candida krusei, Candida parapsilosis*	Effective antifungal potential	Carvacrol, γ-terpinene, thymol, p-cymene	(Valizadeh et al., 2014)

Continuation of Table I. Anti-Dandruff Activity of Various Essential Oils

Essential oil	Study type	Microbes Used	Test Results	Active	Journal
Blend of cinnamon, clove, oregano, wild carrot, camelina oil	*In Vivo*	*Streptococcus* spp., *Pseudomonas* spp., *Candida* spp.	Fungistatic, fungicidal, and antibacterial activities	1,8-cineole, carvacrol, cinnamaldehyd e, eugenol, carotol	(Brochot et al., 2017)
Coriander oil	*In Vitro*	*Microsporum canis, Candida albicans*	Effective in fungal inhibition	Linalool, geraniol, neryl acetate	(Soares et al., 2012)
Juniper berry oil	*In Vitro*	*Candida albicans*	Effective antifungal activity against dermatophytes	Sabinene, α-pinene, limonene	(Cabral et al., 2012)
Fern leaf lavender oil	*In Vitro*	*Candida albicans*	Inhibit fungal filamentality	Carvacrol, cis-β-ocimene	(Zuzarte et al., 2012)

Due to its ability to pass through the cell wall and cytoplasmic membrane of the tested bacterial and fungal strains, tea tree oil possesses potential antimicrobial and antifungal properties. It is causing structural damage and cytoplasmic material loss as a result. Essential oils can penetrate through the cytoplasmic membrane due to their lipophilicity. Tea tree oil may also penetrate the organelle membranes of fungi and destroy those organelles. Last but not least, the long-lasting modifications brought on by tea tree oil result in cell death (Li et al., 2016). Also, tea tree's essential oils and their components are capable of altering both permeability and membrane fluidity of *Candida albicans* by altering membrane properties and compromising membrane-associated functions (Nazzaro et al., 2017).

Rosemary oil

Rosemary is a plant that can be used in different ways as an aromatic medicine and as a culinary plant. Accordingly, it is grown all over the world. This genus is extremely rich in essential oil, although there are large intraspecies differences in terms of the yield and quality of the essential oil produced. The mechanism of action of rosemary oil in anti-dandruff treatment involves multiple pathways. First, it disrupts the fungal cell membrane by interacting with ergosterol, a key component of the cell membrane in fungi, leading to cell death. Additionally, rosemary oil's antioxidant properties reduce oxidative stress on the scalp, which is often linked to dandruff exacerbation (Nieto, 2017). *M. furfur* and *M. sympodialis* were both successfully treated by rosemary oil, with MIC50 values of 0.25% and 1.25%, respectively. The results of the MFC test using rosemary oil were 0.5% against *M. furfur* and 0.25% against *M. sympodialis*. While *M. furfur* and *M. sympodialis* were both susceptible to the antifungal activity of rosemary oil, it was 9 mm for both (Lee et al., 2018). When the test findings for rosemary oil were compared to a positive control, zinc pyrithione, it was discovered that the positive control produced results that were far superior when compared with rosemary oil (Lee et al., 2018). In a different study, rosemary oil's MIC value for *M. furfur* was 0.5%. The outcomes demonstrated that rosemary essential oil possesses significant inhibitory effects on fungus (Trupti & Gadekar, 2021).

Additionally, Ksouri et al. (2017) found that the value of MIC80 of rosemary essential oil varied between 23.99 μg/mL and 31.08 μg/mL against ten isolates of *Candida albicans* and for the standard of *C. albicans* strain was at the same range (30.27 μg/mL). This indicates that rosemary oil has antifungal effects against *C. albicans*. The combination of Tween 80 with the components of rosemary oil—cineol, verbenone, and camphor—improves the effectiveness of antifungals against *C. albicans*, claimed Matsuzaki et al. (2013). Cineole, verbenone, and camphor all have identical MIC and MFC values at 1.25 μl/ml,

2.5 μL/mL, and 5.0 μL/mL, respectively (Matsuzaki et al., 2013). These studies suggest that the antifungal activity of rosemary oil against *Malassezia* sp. is stronger than the antifungal action of rosemary oil against *Candida albicans*.

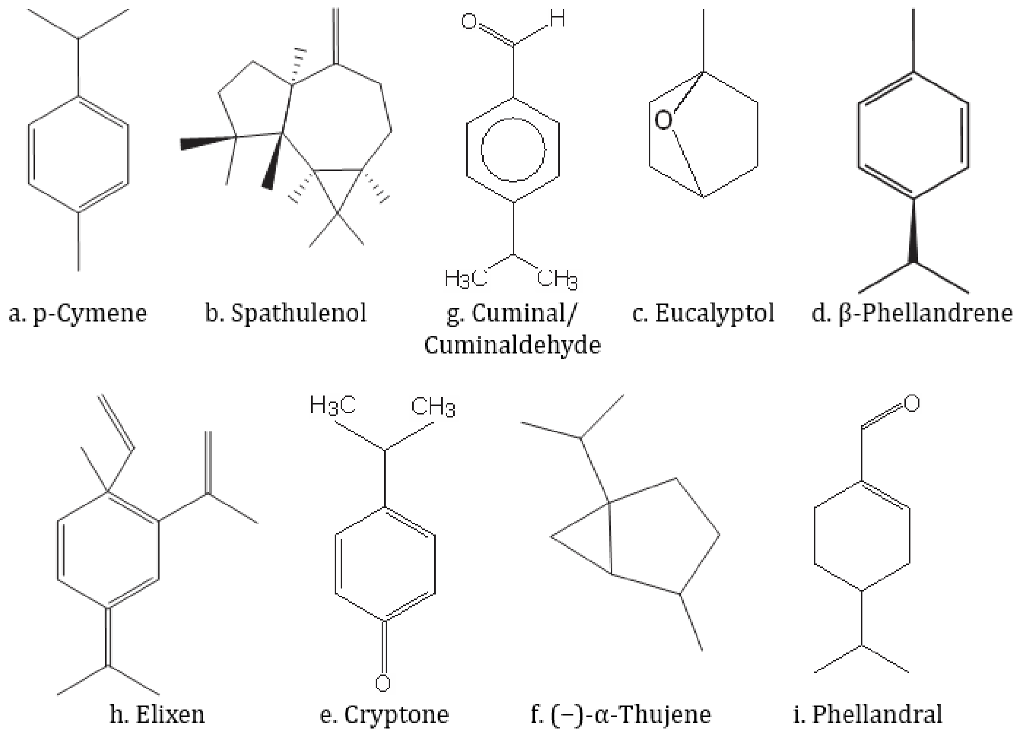

Figure 2. Components of *Eucalyptus globulus* essential oil

Indian borage oil and tasmanian blue gum oil

Indian borage (*Coleus amboinicus*) oil and Tasmanian blue oil (*Eucalyptus globulus)* oil have demonstrated promising antidandruff activities due to their antimicrobial properties, particularly against common dandruff-causing fungi like *M. furfur*. Both oils are effective due to their rich compositions of bioactive compounds, which target scalp microbes responsible for dandruff. Their mechanism of action includes disrupting microbial cell membranes and inhibiting the synthesis of essential cellular components, leading to the control of dandruff formation (Jadhav et al., 2023). The *Eucalyptus globulus* plant is one of the most widely used medicinal plants in the world. After being introduced to Australia, Ramel brought them to Algeria in 1854. There are currently more than 900 different species of *Eucalyptus* in the world, of which about 300 have volatile oils and 20 are used as traditional medicines (Sharifi-Rad et al., 2017). P-Cymene (20.24%), spathulenol (14.10%), and eucalyptol (11.30%) were discovered to be the main components of *E. globulus* essential oil. The essential oil also contained β-phellandrene (5.10%), cryptone (5.02%), (-)-α-thujene (3.40%), cuminal (2.64%), elixene (3.00), and phellandral (2.54%) (Figure 2) (Benabdesslem et al., 2020).

According to data from Selvakumar et al. (2012), the zones of inhibition for the anti-dandruff effects of *Coleus amboinicus* and *Eucalyptus globulus* essential oils were 31 mm and 37 mm, respectively. A MIC value of 0.9% was also seen for pure *Coleus amboinicus* (Trupti & Gadekar, 2021). *Coleus amboinicus* essential oil was diluted using coconut oil at a concentration of 75%, 50%, and 25%, while *Eucalyptus globulus* essential oil was diluted at a concentration of 31 mm, 24 mm, and 20 mm. The results demonstrated that the pure essential oil had more effective and superior anti-dandruff activity than the positive control, ketoconazole shampoo, when the two oils were compared.

Peppermint oil

Peppermint oil's effectiveness in treating dandruff is closely tied to its bioactive compounds, primarily menthol, which contribute to its antifungal and soothing properties. Menthol is believed to inhibit the growth of fungi like *Candida albicans* and *Aspergillus niger*, which are commonly implicated in dandruff formation. It acts by disrupting fungal cell membrane integrity and inhibiting fungal enzyme activity, thereby preventing scalp infections (Rashed et al., 2021). *Mentha arvensis* oil exhibits antifungal activity against *M. furfur* with an MIC value of 50 g/mL, according to Chandra & Ah's (2014) study. *Mentha arvensis* has a zone of inhibition against *M. furfur* of 22.44±1.26 mm, indicating moderate antifungal efficacy (Pandey et al., 2019).

According to Saharkhiz et al. (2012), *Mentha piperita* oil from peppermint species showed antifungal activity against *Candida albicans* with MIC values between 1 and 2 μL/mL and MFC values between 2 and 4 μL/mL. Additionally, *Mentha piperita* oil, at a concentration of up to 2 μL/mL, can prevent the biofilm of *Candida albicans* (Saharkhiz et al., 2012). The MIC of *Mentha piperita* oil against *Candida albicans* was 1.50±0.16 g/mL, according to Reddy et al. (2017). The results of both studies were the same: there is a high antifungal activity of *Mentha piperita* essential oil against *Candida albicans*.

Lemongrass oil

Lemongrass oil has shown promise as an anti-dandruff agent due to its antimicrobial and anti-inflammatory properties. The effectiveness of lemongrass oil against dandruff is largely attributed to its high content of active compounds such as citral and geraniol. These compounds have been shown to exhibit antifungal activities, which are essential in targeting the yeast *Malassezia*, a key contributor to dandruff formation. Lemongrass oil can disrupt the cell membranes of *Malassezia* species, reducing their ability to proliferate and cause scalp irritation (Mukarram et al., 2022).

According to Chaisripipat et al. (2015), a hair tonic containing lemongrass oil in his investigation had a less effective anti-dandruff therapeutic effect compared to tea tree oil shampoo, which had the same 5% level. A 5% tea tree oil shampoo concentration reduced dandruff by 78.57% after two weeks of use. Nevertheless, lemongrass oil hair tonic produced notable benefits in reducing the appearance of scalp flakes, which indicates reducing the occurrence of dandruff, although it has the lowest concentration of 5%. With a MIC value of 60 μg/mL, pure lemongrass oil (*C. flexuosus*) was discovered to have antifungal activity against *M. furfur* in a broth dilution test (Chandra & Ah, 2014). In addition, two clinical studies used essential oils from *C. flexuosus* formulated in shampoo, cream, or lotion for the successful treatment of dandruff (Donato et al., 2020).

Lavender oil

Lavender essential oil has been studied for its effectiveness against microbes commonly implicated in dandruff, such as *Malassezia* species, and other pathogens contributing to scalp health issues. The active compounds in lavender oil, such as linalool, linalyl acetate, and terpinen-4-ol, are known for their antimicrobial and antifungal properties. These compounds disrupt microbial cell membranes, leading to leakage of cytoplasmic contents and eventual cell death (Białoń et al., 2019). *M. furfur* and *M. sympodialis* were not detected at MIC50 levels of 0.125% and 0.0625%, respectively, using lavender oil. Results of the lavender oil's minimal fungicidal concentration (MFC) test showed that it was only 0.5% effective against *M. furfur* and 0.25% effective against *M. sympodialis*. Lavender oil's antifungal efficacy leads to results against *M. furfur* and *M. sympodialis* of 9 mm and 13 mm, respectively (Lee et al., 2018).

When the test results for lavender oil were compared to a positive control substance called zinc pyrithione, it was discovered that the positive control had a much better impact than how the lavender oil did. The zinc pyrithione had MIC50 values of 0.000625%, 0.0025%, and 27 mm (antifungal activity) against *M. furfur*, followed with 0.00039%, 0.00078%, and 26 mm (antifungal activity) against *M. sympodialis*, respectively, were obtained (Lee et al., 2018).

Cinnamon oil, cajeput oil, and kapoor tulsi oil

The effectiveness of essential oils like cinnamon oil, cajeput oil, and kapoor tulsi oil against dandruff is primarily linked to their antifungal properties. Commonly used microbes in anti-dandruff testing include *M. furfur*, a major contributor to dandruff. These oils are tested against *M. furfur* using methods like disc diffusion and minimum inhibitory concentration (MIC) assays, demonstrating varying levels of activity depending on their chemical composition. These essential oils not only target fungal proliferation but also reduce biofilm formation, a significant factor in dandruff pathology (Mankar et al., 2022). According to studies by Pooja et al. (2013), the minimum inhibitory concentration (MIC) for *M. furfur* was 32 μg/mL for cinnamon oil, 128 μg/mL for kapoor tulsi oil, and 64 μg/mL for cajeput oil. The three MIC findings still fall short of the 16 μg/mL tea tree oil requirement. When two essential oils were combined, namely the MIC of cinnamon oil and kapoor tulsi oil of 4 μg/mL, different findings were found.

Southern marigold oil

Southern marigold (*Tagetes minuta)* is a marigold plant in the sunflower (Asteraceae) family. *Tagetes* species originally has been used as a source of essential oil for the flavoring in the food industries and has its potential in anti-dandruff treatments due to its active compounds and antimicrobial properties. Research indicates that the essential oil of *Tagetes minuta* contains various bioactive compounds, including terpenes, flavonoids, and alkaloids, which are believed to play a key role in combating dandruff by targeting the root causes such as fungal infections and scalp inflammation (Shirazi et al., 2014). With an inhibitory zone diameter of 31.07±2.01 mm and a MIC value of less than 5 µl/ml, *T. minuta* essential oil demonstrated antifungal efficacy against *M. furfur* (Pandey et al., 2019). Garcia et al. (2012) also found out that the essential oil of *T. minuta* was resistant to the growth of the fungus, which may have been caused by the presence of four monoterpene components, which are dihydrotagetone, limonene, tagetone, and ocimene. One of the most common components of *T. minuta* oils from plants gathered in a number of locations, including Kenya, which had been identified as dihydrotagetone (Garcia et al., 2012).

Lemon-scented gum oil

Eucalyptus citriodora (lemon-scented gum) oil, commonly known as lemon-scented eucalyptus oil, is often used in anti-dandruff formulations due to its antimicrobial properties. One of the key factors influencing its effectiveness is the presence of active compounds such as citronellal, which has been shown to exhibit antifungal and antimicrobial activity. A study by Tolba et al. (2015) demonstrated that citronellal can inhibit the growth of *Malassezia* species, a common fungus linked to dandruff formation. With an inhibitory zone diameter of 24.75±0.05 mm and a MIC value of less than 15 µl/ml, *E. citriodora* essential oil significantly inhibited *M. furfur* growth (Pandey et al., 2019).

Basil oil

Basil essential oils (BEOs), derived from *Ocimum basilicum* L., are natural volatile compounds rich in diverse chemical constituents generated through plant secondary metabolism (Ilić et al., 2019). These oils find applications across-various industries, including pharmaceuticals, cosmetics, perfumery, dental and oral care, as well as in aromatherapy and food sectors (Shiwakoti et al., 2017; Padalia et al., 2013). Traditionally, basil has been used in medicine to help alleviate symptoms of fever, cough, flu, asthma, and bronchitis (Shahrajabian *et al*., 2020).

Basil oil contains cineol, d-linalool (approximately 40%), methyl chavicol (around 25%), p-cymene, α-terpineol, and some sesquiterpene hydrocarbons (Trupti & Gadekar, 2018). The antimicrobial activity of basil oils varies based on the type of *Ocimum cultivar* and its growth stage (Voicu et al., 2020). Variations in antibacterial effects among basil extracts are attributed to differences in their phytochemical compositions. Eugenol, the primary compound in basil oil, has demonstrated effectiveness against protozoa and fungal species such as *Candida albicans* and *Cryptococcus neoformans* (Carrasco et al., 2012). Methyl chavicol, another component, is known for its antimicrobial and antioxidant properties. It helps reduce dandruff and hair loss by stimulating hair follicles, providing relief from scalp itching and flaking. Additionally, it promotes hair growth by enhancing blood circulation and brings shine to dull hair. This ingredient is commonly found in cosmetics, including lotions, soaps, shampoos, and perfumes (Skidmore-Rot, 2010).

To demonstrate basil oil's effectiveness as an anti-dandruff agent, it was compared with the synthetic chemical selenium sulfide, a commonly used anti-dandruff compound, especially as antibiotic-resistant strains of *M. furfur* have become more prevalent (Trupti & Gadekar, 2021). Basil oil showed significant antifungal activity, achieving a minimum inhibitory concentration (MIC) of 0.7% against *M. furfur* (Trupti & Gadekar, 2021). These findings suggest that basil oil may offer a preferable alternative to synthetic chemicals, with testing results showing it performs comparably to selenium sulfide in managing dandruff.

Iruveli oil

Iruveli essential oils, derived from *Coleus zeylanicus*, a significant aromatic medicinal plant in the Lamiaceae family, hold great therapeutic value that is widely recognized as an aromatic herb traditionally cultivated in India for medicinal purposes (Lakshmi & Nandagopal, 2017). It is highly regarded for its efficacy in treating urinary tract infections and enhancing digestion. Many of its components serve as anti-hepatotoxic, antiulcerogenic, and anti-inflammatory agents, as well as appetite stimulants, digestive aids, stomachic remedies, liver tonics, and cardiotonics (Rajkumar & Malathi, 2016). Coleus oil is abundant in medicinally valuable components, such as alkaloids, volatile compounds, sesquiterpenes, and flavonoids. Its therapeutic activity is largely attributed to the presence of compounds like α-gurjunene (62.91%), α-bisabolol (10.82%), β-selinene (4.26%), cadinol (4.17%), and lemonol (3.46%). Among these, α-bisabolol is particularly noteworthy for its anti-inflammatory, anti-irritant, and antimicrobial properties. Additionally, it has been reported to facilitate the percutaneous absorption of specific molecules (Lakshmi & Nandagopal, 2021).

To evaluate the effectiveness of *Coleus* oil as an anti-dandruff agent, it was compared to clotrimazole, a widely used synthetic anti-dandruff compound. A growing concern in antifungal treatments is the development of multidrug resistance, particularly among *Candida* species and dandruff-causing fungi such as *Malassezia* species. The antifungal activity of *Coleus zeylanicus* essential oil was tested against *Candida albicans* and *M. furfur*. The results showed that the oil exhibited significantly stronger antifungal activity against *M. furfur* (inhibition zone of 32.00 ± 0.50 mm) compared to *Candida albicans* (15.00 ± 1.25 mm). Remarkably, these results surpassed the efficacy of the positive control, clotrimazole (Lakshmi & Nandagopal, 2021).

Antifungal activity of essential oil

When *Malassezia sp.* is used to treat the scalp, essential oils are discovered to be an effective anti-dandruff agent. Other than that, numerous essential oils haven't been studied as dandruff-fighting agents, but they have a strong potential to be just as effective against *Candida albicans* as antifungal agents (Rudramurthy et al., 2014). These research findings show that essential oils have antifungal action with a range of potencies from weak to high when compared with positive controls (Table II). Here are the following essential oils.

Sage oil

Sage essential oils, derived from *Salvia officinalis* L., a perennial plant native to the Mediterranean region, possess a variety of medicinal properties, including spasmolytic, antimicrobial, and astringent effects (Mossi et al., 2011). Both the essential oil and leaf extracts of sage have demonstrated significant antimicrobial activity. These effects are primarily attributed to its chemical constituents, which are dominated by oxygenated hydrocarbons, monoterpene hydrocarbons, and sesquiterpene hydrocarbons, particularly 1,8-cineole, α- and β-thujone, and borneol (Hayouni et al., 2008).

Salvia officinalis oil's antifungal effectiveness against *Candida albicans* was demonstrated in two studies by Badiee et al. (2012) and Sookto et al. (2013). *Salvia officinalis* oil's MIC against *C. albicans* was reported by Badiee et al. (2012) to be 15.6 μg/mL in standard species and 31.3 μg/mL in *C. albicans* that were isolated from patients. The MIC of *Salvia officinalis* oil against *C. albicans*, however, was 2.78 μg/L, according to Sookto et al. (2013).

Dill seeds oil

Dill seed essential oil (DSEO), extracted from *Anethum graveolens* of the Umbelliferae family, is a traditional Chinese herb with a history of use spanning over 2,000 years. While it is widely utilized as a flavoring agent in the food industry, dill also has notable therapeutic applications. It is commonly employed in the treatment of gastrointestinal issues, including flatulence, indigestion, stomach colic, and intestinal discomfort (Editor Committee of National Chinese Medical Manage Bureau, 2005).

The mechanism of action of dill seed essential oil against *Candida albicans* was studied by Chen et al. (2013). The study's findings included the oil from *Anethum graveolens* seed's MIC and MFC values. Dill seed oil has a MIC of 0.625 μg/ml and an MFC of 1.25 μg/ml. The positive control, fluconazole, was used to examine the effects of dill seed essential oil. Results from the positive control showed that the MIC and MFC were, respectively, 3.12 μg/ml and 6.25 μg/ml. Compared to the positive control, the effects of dill seed essential oil were quite potent against *C. albicans* (Chen et al., 2013).

Geranium oil

A typical essential oil used in aromatherapy, geranium oil has also been used historically as a mosquito repellant and as a treatment for vaginal candidiasis. A marker substance called geraniol is found in *Geranium*. A significant portion of *Geranium* oil, up to 20%, is geraniol (Leite et al., 2015). Geraniol is a monoterpene alcohol with a pleasant rose-like aroma. However, geraniol has a number of biological activities, such as antioxidant and anti-inflammatory properties (Maczka et al., 2020). Geraniol's antifungal activity against *Candida albicans* was demonstrated by Leite et al. (2015) with MICs of geraniol that were stable at 16 μg/ml for 10 isolates of *C. albicans*, including the reference strain. Geraniol's MIC was 32 μg/ml in only one isolation. The MIC value for the other ten isolates of *C. albicans* in this investigation was 2 μg/ml when compared to a positive control, amphotericin B. This proves that geraniol effectively combats *C. albicans* as a fungus.

Table II. Anti-dandruff activities of some essential oils

Name of Essential Oil	MIC	MIC_{50}	MFC	Zone of Inhibition
Tea tree oil (0.5%-3%) against *C. albicans*	-	-	-	20.1 mm-26.9 mm
Cinnamon oil	32 µg/mL	-	-	-
Kapoor tulsi oil	128 µg/mL	-	-	-
Cajeput oil	64 µg/mL	-	-	-
Tea tree oil (pure)	16 µg/mL	-	-	-
Cinnamon oil and kapoor tulsi oil against *M. furfur*	4 µg/mL	-	-	-
Lavender oil against *M. furfur*	-	0.125%	0.5%	9 mm
Lavender oil against *M. sympodialis*	-	0.0625%	0.25%	13 mm
Rosemary oil against *M. furfur*	0.5%	0.25%	0.5%	9 mm
Rosemary oil against *M. sympodialis*	-	0.125%	0.25%	9 mm
Rosemary oil against *C. albicans*	23.99-31.08 µg/mL	-	-	-
Pure *C. amboinicus* oil	0.9%	-	-	31 mm
Pure *E. globulus* oil	-	-	-	37 mm
C. amboinicus oil diluted in coconut oil 75%	-	-	-	27 mm
C. amboinicus oil diluted in coconut oil 50%	-	-	-	23 mm
C. amboinicus oil diluted in coconut oil 25%	-	-	-	16 mm
Eucalyptus globulus oil diluted in coconut oil 75%	-	-	-	31 mm
E. globulus oil diluted in coconut oil 50%	-	-	-	24 mm
E. globulus oil diluted in coconut oil 25%	-	-	-	20 mm
C. flexuosus oil against *M. furfur*	60 µg/mL	-	-	-
M. arvensis oil against *M. furfur*	50 µg/mL	-	-	22.44±1.26 mm
M. piperita oil against *C. albicans*	1-2 µL/mL	-	2-4 µL/mL	-
T. minuta oil against *M. furfur*	<5 µL/mL	-	-	31.07±2.01 mm
E. citriodora oil against M. *furfur*	<15 µL/mL	-	-	24.75±0.05 mm
Basil oil against *M. furfur*	0.7%	-	-	-
C. zeylanicus oil against *M. furfur*	-	-	-	32.00±0.50 mm
C. zeylanicus oil against *C. albicans*	-	-	-	15.00±1.25 mm

Bay leaves oil

Bay leaf essential oil, derived from *Laurus nobilis*, family Lauraceae, is native to the southern Mediterranean region (Guenane et al., 2016). The leaves of *L. nobilis* are the most exploited part of the plant due not only to the high produced quantity but also to the large benefits and extensive use in different fields, including culinary, cosmetic, therapeutic, and pharmacologic (Khodja et al., 2023). The various beneficial health properties attributed to bay leaves are related to the presence of various bioactive compounds. Due to the presence of cited chemical constituents in bay leaves, various biological and pharmacological properties have been reported, such as antioxidant, antibacterial, fungicidal, antiviral, insecticidal, wound healing, antimutagen, anticonvulsant, analgesic, anti-inflammatory, and immuno-stimulatory activities (Bendjersi et al., 2016; Nabila et al., 2022; Zibi et al., 2022).

Peixoto et al. (2017). used the MIC test against *Candida* spp. to compare the antifungal activity of *Laurus nobilis* oil to nystatin. The results are *Laurus nobilis* oil has an MIC value against *Candida albicans* (2 strains) at 250 µg/mL, while nystatin is at 0.4 µg/mL; against *Candida krusei* (2 strains) at 500 µg/mL, while nystatin is at 0.8 and 1.6 µg/mL; against *Candida tropicalis* strain CBS 94 at 500 µg/mL, while nystatin is at 0.4 µg/mL; against *C. tropicalis* strain ATCC 750 at 250 µg/mL, while nystatin is at 0.4 µg/mL; and against *Candida glabrata* at 500 µg/mL while nystatin is at 0.4 µg/mL (Khodja et al., 2023).

Summer savory oil

Summer savory essential oils, derived from *Satureja hortensis*, a genus of fragrant plants in the Lamiaceae family. Satureja species are aromatic plants widely used for producing essential oils and aromatic water in the Mediterranean region of Turkey (Maral, 2022). The aerial parts of these plants are utilized in cooking, such as in stuffing and sausages, offering distinctive flavors. In traditional Chinese medicine, the leaves, flowers, and stems are employed to prepare herbal teas and to treat conditions such as infections, cramps, and muscle pain (Valizadeh et al., 2014). Studies on the genus *Satureja* L. highlight its health benefits, including its potential for alleviating pain associated with oxidative stress. The essential oils from the leaves and stems of *Satureja hortensis* L. are noted for their antioxidant properties (Navroski, 2014). These oils are particularly rich in bioactive compounds such as carvacrol, γ-terpinene, thymol, and p-cymene (Valizadeh et al., 2014).

Conducting tests for minimum fungicidal concentration and minimum inhibitory concentration against *Candida* spp. (C*andida albicans*, *Candida krusei*, and *Candida parapsilosis*), Valizadeh et al. (2014). evaluated the antifungal activity of *Satureja* essential oil. *Satureja* essential oil has MIC values of 0.048%, 0.012%, and 0.024% against *Candida albicans, Candida krusei,* and *Candida parapsilosis*, respectively. The MFC's values for *Satureja* essential oil against *Candida albicans*, *Candida krusei*, and *Candida parapsilosis* are identical to the MIC's value (Najibzadeh & Yadegary, 2018).

Blend of cinnamon, clove, oregano, wild carrot, and camelina oil

Brochot et al. (2017) made an essential oil blend that contains equal parts (3.53% each) of *Cinnamomum zeylanicum* CT cinnamaldehyde (bark), *Syzygium aromaticum* CT eugenol (synonymous: *Eugenia caryophyllus* Sprengel, cloves), and *Origanum vulgare* CT carvacrol (aerial parts), 1.04% of *Daucus* carota CT carotol (seed), and 88.35% of *Camelina sativa* oil (seed). EOs from *C. zeylanicum*, *E. caryophyllus*, and *O. vulgare* and their main compounds (cinnamaldehyde, eugenol, and carvacrol) were fungicidal against *C. albicans* and other *Candida* species whether or not they were resistant to common antifungal drugs (fluconazole or amphotericin B) (Pinto et al., 2006; Khosravi et al., 2011).

This blend had fungistatic and fungicidal activities against all *Candida* strains tested with MICs ranging from 0.01% to 0.05% v/v and minimal fungicidal concentrations (MFCs) from 0.02% to 0.05% v/v (Brochot et al., 2017).

Coriander oil

Coriander essential oil, derived from *Coriandrum sativum*, a member of the Umbelliferae (Apiaceae) family, is widely utilized as both a spice and a medicinal agent in the pharmaceutical and food industries. It is abundant in bioactive compounds such as linalool and geranyl acetate, which exhibit antioxidant, anti-inflammatory, and antimicrobial properties (Das et al., 2023).

The antifungal effects of *C. sativum* fruit essential oil are primarily attributed to its key components, including linalool (58.65%), geraniol (17.87%), and neryl acetate (12.22%) (Soares et al., 2012). *Candida* spp. was used to assess the essential oil of *Coriandrum sativum*'s antifungal activity using the MIC test, MFC test, and growth inhibition zone. The results showed that the mean value of MFC was 872 μg/mL, the mean of the growth inhibition zone was 9.25±0.5 mm, and the MIC of *Coriandrum sativum* oil was at 434 μg/mL. amphotericin B's growth inhibition zone measured 10.25 mm ± 1.26 mm (Soares et al., 2012).

Juniper berry oil

Juniper berry essential oil, derived from *Juniperus communis* L., has long been recognized as a powerful detoxifier and immune system booster, with a rich history of use in traditional medicine to address opportunistic infections and as a flavoring agent (Hoferl et al., 2014; Bais et al., 2014). They are commonly employed in natural remedies for conditions such as sore throat, respiratory infections, fatigue, muscle aches, and arthritis. Additionally, juniper berries are known to soothe skin flare-ups, enhance immune function, promote restful sleep, and support digestive health. In Bulgaria, the stems of the plant have also been traditionally used to prevent both short- and long-term illnesses (Ruberto & Baratta, 2000).

The chemical composition of juniper berry essential oil was analyzed using GC/MS, revealing that its major components are α-pinene (51.85%) and limonene (25.1%). In addition, several minor compounds were identified, including β-caryophyllene (1.42%), δ-cadinene (0.51%), α-terpinene (0.37%), tripionela (0.37%), o-cymene (0.57%), isopinocarveol (0.57%), cis-carveol (0.35%), β-cedrene (1.42%), γ-elemene (0.31%), cis-thiopsene (0.31%), β-cubebene (0.41%), α-muurolene (0.51%), cadinene (0.06%), β-cadinene (0.51%), elixene (0.45%), and cedrol (0.64%). These compounds contribute to the diverse bioactivity and therapeutic potential of the oil (Cabral et al., 2012). In the MIC test, Cabral et al. (2012) assessed the antifungal efficacy of *Juniperus communis* essential oil against *Candida albicans*. The MIC result differed from fluconazole as the positive control. The MIC value of conventional fluconazole was 1 μg/mL, but the MIC value of *J. communis* essential oil was 2.5 μL/mL.

Fern leaf lavender oil

Fern leaf lavender essential oils, derived from *Lavandula multifida* L., of the Lavandula family, is the sole species in the *Pterostoechas* section commonly found in the Mediterranean region. It is native to countries such as Portugal, Spain, Morocco, Algeria, Tunisia, and Libya (Upson & Andrew, 2004). The *Lavandula* genus includes several highly promising plants that have been extensively studied in screening assays for their diverse biological properties. These include antioxidant, antimicrobial, insecticidal, antifeedant, parasiticidal, and herbicidal activities (González-Coloma et al., 2011). The essential oil of *L. multifida* and its primary components, carvacrol and cis-β-ocimene, demonstrated significant antifungal activity by almost completely inhibiting filamentation in the tested *Candida albicans* strains. The high concentration of carvacrol in *L. multifida* is notable, as this phenol is typically found in much lower amounts in other lavender species. This is particularly intriguing given the limited natural occurrence of carvacrol (Zuzarte et al., 2012).

Lavandula multifida essential oil's antifungal efficacy on *Candida albicans* has been studied by Zuzarte et al. (2012), with the MIC value of *L. multifida* essential oil against *C. albicans* being 0.32 μL/mL, which demonstrated the antifungal action. This finding differed from the MIC value of conventional fluconazole, which was 1 μg/mL.

Assays used in anti-dandruff studies Agar well diffusion assay

The purpose of this method is to measure the zone of inhibition of microbial growth around a well containing the test substance. It is commonly used to assess the antifungal activity of formulations against pathogens such as *M. furfur*. For example, a study using polyherbal formulations recorded inhibition zones of up to 30 mm, demonstrating strong activity against *M. furfur* (Barve et al., 2023).

Broth dilution assay

The purpose of this experiment is to determine the minimum inhibitory concentration (MIC) of an anti-dandruff agent in liquid culture. The procedure involves diluting the test agent in broth containing the pathogen, with inhibition quantified through spectrophotometric readings. For example, polyherbal oils demonstrated up to 90% inhibition against *M. furfur* when tested using broth dilution methods (Sathishkumar et al., 2019).

Cytostatic and keratolytic activity assays

The study evaluates the efficacy of formulations in reducing excessive scalp cell turnover, a characteristic feature of dandruff. The procedure involves the use of cultured human keratinocytes, such as HaCaT cells, to determine IC_{50} values for both keratolytic and cytostatic effects. For example, selenium-based shampoos and polyherbal formulations have demonstrated significant keratolytic effects in these assays (Barve et al., 2023).

Filamentation inhibition assay

The study observes the disruption of fungal filamentation, a critical growth form for fungal pathogenesis. For example, essential oils such as fern leaf lavender oil have demonstrated significant inhibition of *Candida albicans* filamentation (Sathishkumar et al., 2019).

Lipase activity assay

The lipase activity assay is designed to evaluate the inhibition of fungal lipase, an enzyme essential for the survival of *Malassezia* on the lipid-rich scalp, and has been employed to measure the efficacy of active ingredients in reducing fungal metabolism (Barve et al., 2023).

Clinical scalp testing

Clinical scalp testing involves human trials where anti-dandruff formulations are applied, and scalp conditions, including dandruff scales, itching, and sebum production, are monitored to evaluate the effectiveness of the treatments. For example, double-blind trials comparing various shampoos have demonstrated their efficacy in managing dandruff symptoms (Barve et al., 2023).

Herbal for anti-dandruff preparations

Utilizing shampoo, hair conditioner, or hair tonic formulations can help treat dandruff. Shampoo is required to remove surface dirt and oil from the scalp and hair shaft. The main task of shampoo is to carry out cleansing or detergent action (Khaloud & Shah, 2014). The herbal shampoo, with essential oils as the main ingredient, (Table III) is a cosmetic preparation made from plant-derived herbs. It functions similarly to a regular shampoo, typically used for cleansing the hair and scalp. Nowadays herbals help people in building their good health with the help of natural sources (Bhojane et al., 2023).

Table III. Anti-fungal activities against *Candida albicans* of several essential oils

Name of Essential Oil	MIC	MFC	Zone of Inhibition	Dosage Form	Use of Nanotechnology	Journal Reference
Sage oil (standard species)	15.6 μg/mL	-	-	Essential oil encapsulation and nanoemulsions	A study investigated the encapsulation and nanoemulsions of *Salvia officinalis* essential oil in β-cyclodextrin to improve solubility and stability, facilitating more effective delivery against *C. albicans*.	(Bachir et al., 2022)
Sage oil (isolated species from the patient)	31.3 μg/mL	-	-			
Sage oil	2.78 g/L (2780 μg/mL)	-	-			
Dill seeds oil	0.625 μg/mL	1.25 μg/mL	-	Direct use of the oil in nanoparticles	Nanocarriers, such as chitosan nanoparticles, for delivering plant extracts. These nanocarriers can Improve the bioavailability and targeted delivery of the oil's active compounds, enhancing its antifungal properties.	(Abdullah, 2023)
Geranium oil (as geraniol)	6–32 μg/mL	-	-	Nanoemulsions	Nanoemulsion technology significantly enhances geraniol's stability and bioavailability. This approach not only improves its antifungal action but also reduces cytotoxicity when applied to human cells.	(Pontes et al., 2023)
Bay leaf oil	250 μg/mL	-	-	Direct use of the oil in nanoparticles tested in liquid or vaporized forms.	Nanoparticle carriers, such as liposomes or metallic nanoparticles (e.g., silver or gold nanoparticles), have been studied to improve the oil's stability, targeted delivery, and efficacy against resistant biofilms of Candida albicans.	(Susanti et al., 2022)
Summer savory oil	0.048% v/v	0.048 % v/v	-	Direct use of the oil in nanoparticles tested in liquid forms.	Recent advancements include the incorporation of nanostructured materials, such as functionalized magnetite nanoparticles, to enhance the delivery and efficacy of the oil. This approach improves the physical and antimicrobial properties of materials like wound dressings, significantly inhibiting fungal adhesion and biofilm formation.	(Anghel et al., 2013)
Blend oil consist of: Cinnamon oil, clove oil, oregano oil, carrot seed oil, and camelina oil	0.02% v/v	0.02% v/v	-	Commonly formulated as essential oils for topical application or vapor delivery.	Not specifically highlighted in available data. Potentially explored in encapsulation forms.	(Zhong et al., 2023)
Coriander oil	434 μg/mL	872 μg/mL	9.25±0.5 mm	Nanoemulgel	Nanotechnology improves the delivery and efficacy of Coriandrum sativum oil against Candida albicans.	(Eid et al., 2021)
Juniper berry oil	2.5 μL/mL	-	-	Liposomal and nanoparticle-ba sed	Nanotechnology has been applied to enhance the antifungal activity of Juniperus communis oil. Studies have explored using nanoparticles (e.g., silver nanoparticles or liposomes) to improve the bioavailability and stability of the oil.	(Gao et al., 2024)
Fern leaf lavender oil	0.32 μL/mL	-	-	Nanocapsules and liposome-encap sulated	Nanocapsules enhanced encapsulation efficiency and controlled the release of active compounds and liposome-based target biofilms effectively, leveraging the oils' reactive oxygen species (ROS)-generating properties to disrupt fungal cells.	(Gonçalves et al, 2021; Alteriis et al., 2021)

Salvia officinalis L. (sage) has demonstrated antifungal activity against *Candida albicans*, with research exploring various formulations and optimization strategies. Research has explored the creation of encapsulation and nanoemulsions incorporating *Salvia officinalis* essential oil, utilizing nanotechnology to improve bioavailability and efficacy against fungal pathogens. The encapsulation of *Salvia officinalis* essential oil in β-cyclodextrin was optimized to improve its antifungal activity against *C. albicans*. The study assessed the chemical composition and antifungal efficacy of the encapsulated oil, demonstrating enhanced activity compared to the free essential oil (Bachir et al., 2021).

The essential oil from dill *(Anethum graveolens)* demonstrated strong antifungal effects, inhibiting the growth and conidia germination of fungi like *Candida albicans* and *Aspergillus flavus.* It was shown to target the plasma membrane and mitochondria of fungal cells, causing damage that leads to cell death. The optimization of concentrations and delivery methods further enhanced its efficacy (Abdullah, 2023). Geraniol, a key component of *Geranium* oil, has been incorporated into nanoemulsions to enhance its antifungal efficacy. The nanoemulsion system consists of an oil phase, surfactants, and an aqueous phase, designed for better solubility and controlled release. Geraniol in its optimized nanoemulsion form showed significant antifungal activity against *C. albicans*. Studies highlighted reductions of more than 6 $\log_{10}$ in fungal counts in biofilm models (Pontes et al., 2023). *Laurus nobilis* essential oil has primarily been tested in liquid or vaporized forms for antifungal activity. Studies suggest its effectiveness in inhibiting the growth of *Candida albicans* in vitro through direct application to microbial cultures or as part of biofilm experiments. However, specific clinical dosage forms like topical formulations are less commonly reported in these studies. Nanotechnology-enhanced formulations improve bioavailability and reduce MIC further, enabling more efficient delivery to fungal cells and biofilm disruption (Susanti et al., 2022). Summer savory *(Satureja hortensis)* essential oil is often used in liquid forms for direct application or incorporated into other mediums like wound dressings. For example, a nano-modified wound dressing infused with the oil has been tested for its efficacy in preventing fungal biofilms caused by *C. albicans*. Studies optimize the formulation of essential oil-infused nanomaterials by characterizing their physical and chemical properties using methods like GC-MS, XRD, and TEM. These analyses ensure the functional stability of the nanostructures and the essential oil's bioactivity. The optimized formulations demonstrate enhanced antifungal activity, as evidenced by reduced fungal viability and biofilm formation. Broth microdilution and disk diffusion methods confirm the minimum inhibitory concentrations (MICs) of the essential oil against *C. albicans*, validating its efficacy (Anghel et al., 2013). A blend of oils including, cinnamon (*Cinnamomum zeylanicum),* clove *(Syzygium aromaticum),* oregano *(Origanum vulgare),* carrot seed (*Daucus carota),* and camelina *(Camelina sativa)* is commonly formulated as essential oils for topical application or vapor delivery. The expert design optimization is focused on blend ratios and bioactive compound enhancement. Demonstrated antifungal activity with MIC values of 0.01–0.05% v/v against resistant strains. This blend is effective against fluconazole-resistant *Candida* strains, and its synergistic effects could reduce drug resistance. Further research into nanotechnology applications could enhance its potential (Zhong et al., 2023).

Coriandrum sativum, or coriander, has been widely studied for its antifungal activity, particularly against *Candida albicans*. Regarding dosage forms, recent research has explored novel formulations such as nanoemulgels to enhance the bioavailability and efficacy of *Coriandrum sativum* oil. Nanoemulgel systems allow for better penetration and targeted delivery, particularly useful in the treatment of fungal infections. These formulations are often optimized using expert design techniques such as Design Expert 13.0's simplex lattice design, which allows for the precise adjustment of ingredients to maximize the oil's efficacy against pathogens like *Candida.* The optimization of these formulations often involves testing various parameters like surfactant concentration, oil content, and pH levels, which are refined using statistical design methods (Eid et al., 2021). The essential oil of *Juniperus communis* can be used in liposomal or nanoparticle-based delivery systems for improved penetration and sustained release. Studies have explored using nanoparticles (e.g., silver nanoparticles or liposomes) to improve the bioavailability and stability of the oil. These nanoformulations help increase the oil's effectiveness against fungal biofilms, which are typically more resistant to treatments. In some studies, optimization techniques have been employed to fine-tune the formulation of essential oils, such as adjusting particle size or surface charge to improve delivery and reduce side effects. The results of such optimization efforts often show improved antimicrobial properties, such as greater inhibition of *Candida albicans* growth and better penetration through skin layers or biofilms (Gao et al., 2024).

Lavandula multifida and *Lavandula angustifolia* essential oils have been formulated in various dosage forms such as nanocapsules and liposome-encapsulated systems. These forms are designed to improve the bioavailability and stability of the essential oils for therapeutic applications, including antifungal treatments against biofilm-forming fungi like *Candida albicans.* Studies employed factorial design and response surface methodologies to optimize nanocapsule formulations. Variables such as polymer concentrations, stabilizers (e.g., Span 80, Tween 80), and encapsulation parameters were systematically varied to maximize encapsulation efficiency and ensure desirable physical and chemical properties. The optimized formulations demonstrated significant antifungal activity. For example, the nanocapsules achieved high encapsulation efficiencies, with their hydrodynamic diameter and zeta potential tailored for stability and effective delivery. Liposomal formulations also showed effectiveness in eradicating both primary and persister-derived biofilms of *Candida albicans*, illustrating the potential for combating resistant fungal infections (Gonçalves et al., 2021; Alteriis et al., 2021).

Using natural extracts from plants including, *Sida cordifolia*, *Ocimum sanctum*, and C*itrus limon* as active components, Chandran et al. (2013) conducted a study on anti-dandruff shampoo formulations. These findings demonstrated that the anti-dandruff shampoo composition has properties similar to those of a popular synthetic anti-dandruff shampoo brand. Punyoyai et al. (2018) conducted research on fermented *O. sanctum* products to be formulated in anti-dandruff shampoo and discovered that the product may have successfully inhibited *M. furfur*.

Patel & Talathi have looked into the herbal shampoo's composition and performed a physicochemical analysis on the formulation. The criteria of the physicochemical analysis of the herbal shampoo to compare the activity of the formulation include cleaning action, detergency ability, foamability, and foam stability test. The ingredients in the shampoo must have both cleansing and detergency qualities. Hydrophobic substances like phenolics and flavonoids show grease-encapsulating, or cleansing, activity. The amount of surfactant contained in the sample extracts determines the ability to deter. It has been demonstrated that saponins are surfactant molecules that reduce surface tension and enhance cleaning effectiveness (Patel & Talathi, 2016).

The development of a powder shampoo containing herbal ingredients that have anti-dandruff properties was carried out by Madhusudhan et al. (2021). The research variety of numerous natural shampoo formulations ranges from 2.5% to 24.5% w/w *Hibiscus* concentrations, 1% to 3% lemon, and 5% to 15% w/w peppermint. Commercial shampoos are outperformed by powdered shampoo formulations with 15% peppermint, 1% to 3% lemon, and 12.5% to 14.5% *Hibiscus*. The optimized herbal powdered shampoos offer excellent cleaning, detergency, conditioning, and foaming actions when compared to commercial formulations, are suitable for normal hair, and have acceptable pH and organoleptic stability features (Telrandhe et al., 2023).

In addition to shampoo, Chaudhari et al. (2020) conducted research on the composition and assessment of hair gel that contained an anti-dandruff herbal ingredient. For its anti-dandruff properties, celery seed extract is utilized. The current study concluded that *Apium graveolens* (celery seeds) can be used to create and test the anti-dandruff gel and that it may be used more effectively since the formulation's stability characteristics showed a significant fluctuation throughout the stability research.

In this day and age, there are many different types of cosmetics. Nowadays, serum preparation is one cosmetic product that attracts attention. A serum is a substance that may quickly absorb and reach the deeper layers of the skin. A very high concentration of active ingredients can be found in the serum (Aggnihotri, 2021). Like many other industries, nanotechnology has made significant inroads into the cosmetics industry. This is because nanomaterials have numerous advantages, such as increased surface area, good stability, high encapsulation efficiency and loading capacity, prolonged retention time, and site-specific delivery (Bilal & Iqbal, 2020). It might be a brand-new advancement in very efficient scalp treatment products.

By paying close attention to the scalp barrier, anti-dandruff treatments must work in harmony with scalp care. According to Kim et al. (2021), strengthening the scalp barrier can promote the continuous use of scalp care products. Many people who have dandruff have sensitive scalps. Other than selecting an anti-dandruff agent, dealing with a mild formula is more crucial in this condition.

Design of experiment for optimization formulation

A new method of formulation to generate the optimized formula is to use the Design of Experiment (DoE), like Design Expert® software. For instance, Costa (2019) demonstrated the application of DoE in developing a stable cosmetic formulation by optimizing key physicochemical properties such as viscosity and stability. The DoE can assist in optimizing natural formulations of cosmetics by providing statistical analysis of physicochemical evaluations. The DoE not only facilitates optimization but also enables screening, characterization, and optimization through features such as simplex lattice design, factorial design, response surface methodology (RSM), and Box-Behnken design. Sopyan et al. (2022) applied RSM in optimizing a nanoemulsion formulation, successfully improving its efficiency.

Simulations have also become a widely used strategy to support the optimization of experimental runs across engineering and technological fields, including cosmetics. Jankovic et al. (2021) showed that simulations combined with DoE improved predictive accuracy in material performance. However, the success of DoE depends on the appropriate selection of statistical methods, variables, and factor levels. Luiz et al. (2021) emphasized that prior to optimization by RSM, screening designs are crucial to reducing the number of factors and determining factor levels to evaluate parameters such as nanocarrier stability and response values.

CONCLUSION

Numerous essential oils have the potential to be antifungal and anti-dandruff, according to the review source's data. Tea tree oil is the most efficient and widely available essential oil for preventing dandruff on the scalp, while other essential oils can also be used in its place using a variety of essential oils in combination to boost its efficacy. Preparation of essential oil-based scalp care products can have the same therapeutic impact as using pure essential oils. You can use a variety of herbal anti-dandruff scalp care formulas to make cosmetics like shampoo, powdered shampoo, conditioner, and many more. The findings of this article review can be used to enhance the development of scalp preparations that effectively prevent the development of dandruff. Design of Experiment (DoE) can be used to develop the formulation of scalp care products when the researcher knows well about the tools.

The review highlights the anti-dandruff potential of various essential oils against key dandruff-causing microorganisms such as *M. furfur* and *M. globosa*. This provides a basis for formulating anti-dandruff serum using the experimental design approach, specifically Design Expert®. Numerous essential oils demonstrate antifungal and anti-dandruff properties, with tea tree oil identified as particularly effective and accessible for scalp applications. Other essential oils may also be utilized individually or in combination to enhance their effectiveness. Preparing scalp care products containing essential oils can replicate the therapeutic effects of pure essential oils, allowing for diverse formulations, such as shampoos, powdered shampoos, conditioners, and other products with anti-dandruff properties. Insights from this review may aid in advancing the formulation of effective anti-dandruff scalp care products. Further, the Design of Experiments (DoE) method can be applied to optimize formulation development, provided that researchers are well-versed with the tools.

For future research, the author recommends exploring the production of micro- or nano-emulsions to minimize the volatility and oxidation of essential oils within formulations, thus enhancing stability. The authors also suggest that there is significant promise in these natural alternatives. Research is moving towards exploring more potent essential oils and optimizing their delivery in formulations, such as through encapsulation techniques that enhance stability and effectiveness. This review is expected to support further studies in the development of cosmetic products, specifically herbal scalp treatments for dandruff.

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CONFLICT OF INTEREST

All authors have declared that they do not have any conflicts of interest.

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