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Chemical Profiles and Antimicrobial Activity of Lamiaceae against Oral Pathogens: A Review with Focus on *Pogostemon cablin*

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Abstract

Oral diseases remain a major health concern, while the complexity of microbial communities and the limitations of conventional and antimicrobial agents have encouraged the exploration of natural sources as alternatives. The Lamiaceae family represents an important source of bioactive plants and essential oils (EOs), but variations in chemical composition and analytical approaches can affect the interpretation of their biological activities. This review aims to summarize the antimicrobial activity of Lamiaceae plants against oral pathogens, examine the use of gas chromatography-mass spectrometry (GC-MS) and retention index (RI) for the characterization of volatile compounds, and assess *Pogostemon cablin* as a potential source of bioactive EO. Open-access literature published between 2021 and 2026 was searched through PubMed and ScienceDirect using combinations of keywords related to Lamiaceae, oral pathogens, and retention index. Selected studies were grouped according to biological activity and chemical characterization, then analyzed narratively. Lamiaceae plants have demonstrated antibacterial, antifungal, and antibiofilm activities against cariogenic bacteria, periodontopathogens, and oral fungi, with responses varying according to plant species, preparation method, chemical composition, target microorganism, and assay parameters. GC-MS combined with RI provides complementary information for identifying volatile compounds and comparing species. *P. cablin* is characterized by a sesquiterpene-rich chemical profile, particularly patchoulol, which has demonstrated antimicrobial activity against certain oral pathogens. However, direct evidence linking the chemical composition of *P. cablin* EO to its activity against oral pathogens remains limited. Further studies integrating standardized GC-MS/RI based chemical profiling with targeted biological assays are needed to clarify this relationship and evaluate the potential of *P. cablin* EO for oral antimicrobial applications.



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1. Introduction

Oral diseases are among the most prevalent health concern on worldwide scales, affecting individuals across diverse life stages. The World Health Organization

reports that approximately 45% of the global population, equivalent to 3.5 billion people, experience oral health disorders [1], while the prevalence of dental and oral health problem in Indonesia reaches 56.9% of the total population [2]. Dental carries is one of the most prevalent

oral disease, accounting for 88.80% of all reported oral disease cases in Indonesia [2]. Other conditions, including periodontitis, gingivitis, salivary gland disorders, and oral cancer, contribute to the overall burden of oral disease. These conditions can affect quality of life, child development, self-confidence, and productivity. This substantial disease burden highlights the necessity of preventive and therapeutic strategies that focus on critical factors in the development of oral diseases [3, 4].

The development of various oral disease is closely associated with the colonization and activity of pathogenic microorganism in the oral cavity. Microorganism commonly associated with oral disease include *Streptococcus mutans*, *Porphyromonas gingivalis*, *Candida albicans*, *Fusobacterium nucleatum*, *Prevotella intermedia*, and *Parvimonas micra* [5]. These microorganisms can form biofilms on tooth surface and soft tissues, enhancing their ability to survive environmental changes and reducing their susceptibility to antimicrobial agents. *S. mutans* causes dental caries by fermenting carbohydrates into organic acids that demineralize tooth enamel. *P. gingivalis*, *P. intermedia*, and *F. nucleatum* contribute to periodontal disease by causing chronic inflammation and destroying tooth-supporting tissues. The complexity of these microbial communities and their ability to form biofilms are important factors to consider when developing antimicrobial agents for oral pathogens [6–9].

Current management of oral diseases includes mechanical interventions, antiseptics and antibiotics, and surgical procedures in certain conditions. Long-term use of antimicrobial agents has several limitations, including the development of microbial resistance, potential adverse effects on oral tissues, and disruption of the oral microbiota. Biofilm formation can reduce antimicrobial effectiveness because the microbial community structure provides protection against exposure to antimicrobials. These limitations have led to the investigation of other potential antimicrobial sources, including natural products such as plant extracts and essential oils (EOs), that can target oral microorganisms and biofilms. Various secondary metabolites in these natural products have been reported to exhibit antibacterial, antibiofilm, antifungal, anti-inflammatory, and antioxidant activities, which could contribute to the development of antimicrobial agents for oral pathogens [9, 10].

The Lamiaceae family comprises aromatic plants that are rich in secondary metabolites. Many of these plants produce EOs with diverse biological activities. A plethora Lamiaceae species, including *Origanum vulgare*, *Salvia*

officinalis, *Thymus spp.*, *Mentha spp.*, *Lavandula angustifolia*, *Rosmarinus officinalis*, and *Pogostemon cablin*, contain bioactive compounds such as carvacrol, thymol, linalool, camphor, pulegone, and patchoulol (patchouli alcohol), which may contribute to antimicrobial activity [11, 12]. Studies of various Lamiaceae species have demonstrated activity against cariogenic bacteria, periodontopathogens, oral fungi, and biofilm formation. These activities can vary according to plant species, plant part, extraction method, and the composition of the recovered secondary metabolites, making chemical characterization important for understanding the relationship between composition and biological activity [5, 13–18]. Such interspecies variation provides a basis for assessing the Lamiaceae family as a source of natural antimicrobial agents for oral pathogens and for identifying species for which scientific evidence remains limited.

Patchouli (*P. cablin*) is an important EO-producing plant in Indonesia, with patchoulol as one of its major constituents. The EO and compounds found in *P. cablin* have been reported to exhibit various biological activities, including antibacterial, anti-inflammatory, antioxidant, and anticancer activities. The chemical composition of patchouli EO can vary according to plant-related factors and production conditions, so accurate identification of volatile components is needed to establish a chemical profile that can be related to biological activity [18–22]. Gas chromatography-mass spectrometry (GC-MS) is commonly used to characterize volatile components of EOs and retention index (RI) provides an additional identification parameter alongside mass spectra [23–26]. Retention indices, including the Kovats index under isothermal conditions and the linear retention index under temperature-programmed identification because retention times are influenced by column conditions and analytical parameters [27, 28].

While various Lamiaceae species have shown effectiveness against oral pathogens, evidence for *P. cablin* remains relatively limited compared with that for other Lamiaceae species. Most studies on *P. cablin* have focused on its biological activity against nonoral microorganisms, while information on its activity spectrum against oral pathogens and the underlying mechanisms remains limited. This is an important gap because the antimicrobial activity of EO does not solely reflect the complex composition and interactions of multiple volatile constituents. Therefore, integrating information on chemical profiles, volatile-compound identification approaches, and antimicrobial against oral pathogen activity is necessary to provide a more comprehensive understanding of *P. cablin*'s potential.

The aims of this review are to summarize the scientific evidence on the activity of Lamiaceae plants against oral pathogens, examine the approaches for the chemical characterization of EOs, and emphasize GC-MS and RI as supporting parameters for compound identification. Additionally, this review will identify the current position and evidence gaps regarding *P. cablin* as a candidate antimicrobial agent for oral pathogens.

2. Literature Search Strategy

A literature search was conducted using PubMed and ScienceDirect from May to October 2026 to identify open-access articles published between 2021 and 2026. The search covered two areas: the chemical characterization and retention indices of Lamiaceae species and the antimicrobial activity against oral pathogens. The search queries used were "Lamiaceae AND retention index", "Lamiaceae AND retention indices", "Lamiaceae AND oral bacteria", and "Lamiaceae AND oral pathogens". Filters were applied for publication year, article type, and open-access availability. The combined searches yielded 576 records, including 492 records for the chemical characterization and RI stream, of which 240 were identified as duplicates, leaving 252 records. Meanwhile, 84 records were identified for further assessment in the oral antibacterial stream, of which 18 were duplicates, leaving 66 records. Eligible articles had to address at least one of the two literature streams and provide relevant information on the chemical composition, RI, or antibacterial activity of Lamiaceae species against oral bacteria. Records outside the scope of the review or lacking relevant information were excluded.

Sixteen articles were selected for the narrative synthesis, including nine articles on chemical characterization and RI data and seven articles on antibacterial activity against oral bacteria. Older publications were consulted separately, where necessary, to provide information or methodological context. These publications were not counted among the records retrieved through the formal literature search. Since the chemical characterization and biological activity searches were conducted separately, direct composition-activity interpretations were limited to studies that reported both analyses for the same preparation. Rather than establishing direct associations, comparisons across separate studies were used to identify potential relationships for further investigation.

3. Chemical Composition and Bioactive Compounds of Lamiaceae

Various studies have reported GC-MS analyses that revealed differences in the composition of volatile compounds among Lamiaceae species. The studies examined different plant parts, primarily leaves and

other aerial parts (Table 1). Hydrodistillation and steam distillation were the predominant extraction methods used. The major compounds identified reflect differences in chemical profiles, such as pulegone in *H. ringens*, eucalyptol in *R. officinalis*, carvacrol in *O. vulgare*, thymol in *T. vulgaris*, and patchoulol in *P. cablin* [29–33]. These patterns indicate that individual species have distinct dominant constituents despite belonging to the same family. Such variation in major constituents provides a basis for comparing the chemical characteristics of Lamiaceae species.

These differences become more apparent when chemical profiles are compared across species. For example, *O. vulgare* and several *Thymus* species are characterized by monoterpene phenolics, particularly carvacrol and thymol, while *L. angustifolia* produces higher proportions of linalool and camphor. *Salvia* species have eucalyptol, camphor, and thujone as major constituents, while *M. pulegium* has carvone or pulegone as dominant compounds [13, 30–32]. These patterns demonstrate that Lamiaceae EO do not share a uniform composition and that dominant chemical classes vary among species. These differences are significant because dominant constituents may explain some of the variation in biological activity across species.

The volatile components (Table 1) were identified using a combination of GC-MS and RI data. The studies used different columns, including HP-5MS, DB-5MS, ZB-5MS, and BP-1, reflecting variations in chromatographic conditions. To improve comparability, this review focuses on RI values obtained using nonpolar stationary phases. Reference RI values available for the same or chemically comparable stationary phases were compared with the experimental RI values. RI provides an additional criterion for identifying compounds and strengthening the characterization of volatile profiles across species, along with mass-spectral matching against reference libraries such as NIST, Wiley, and Adams [28].

The extraction methods used to obtain the Lamiaceae EOs characterized also varied (Table 1). Several species, including *H. ringens*, *C. serpyllifolium*, *T. vulgaris*, *O. vulgare*, and *P. cablin*, were extracted using hydrodistillation, whereas steam distillation was used in some studies. Extraction conditions should be considered when comparing chemical profiles because the isolation process can influence the volatile components detected [34]. Despite the focus on nonpolar stationary phases, differences in column specifications and other chromatographic conditions may affect RI values. Therefore, both extraction methods and analytical conditions should be considered when interpreting

Table 1. The progression of antimicrobial research involves samples from patchouli.

Species	Plant Part	Extraction Methods	Instrument	Column	Major Compound	Experimental RI	RI Literature	Library	Ref.
<i>Hesperozygis ringens</i>	Leaves	Hydrodistillation	Shimadzu GC2010 Plus+GC-MS QP2110 Ultra	Rtx-5MS (30 m × 0.25 mm, 0.25 µm)	Pulegone	1245	1237	NIST 1.0 and NIST 11	[29]
<i>Marrubium vulgare</i>	Flowering aerial part	Solvent assisted hydrodistillation	Agilent GC 7890A+MS 5975 C MSD	HP-5MS (30 m × 0.25 mm, 0.25 µm)	E-caryophyllene	1423	1463	Adams4 and NIST11	[35]
<i>Clinopodium serpyllifolium</i> subsp. <i>barbatum</i>	Leaves	Hydrodistillation	Thermo Scientific ISQ + TR-FAME MS	5%Phenyl Polysilphenylene-siloxane	Pulegone	1630	1663	Wiley9	[30]
<i>Lavandula angustifolia</i>					Linalyl acetate	1548	1554		[30]
<i>Mentha × piperita</i>					Linalool	1537	1543		[30]
<i>Mentha pulegium</i>					Carvone	1722	1751		[30]
<i>Ocimum basilicum</i>					Linalool	1537	1543		[30]
<i>Rosmarinus officinalis</i>					Eucalyptol	1231	1231		[30]
<i>Salvia aramiensis</i>					Eucalyptol, Camphor	1231, 1521	1231, 1537		[30]
<i>Salvia fruticosa</i>					Eucalyptol, Camphor	1231, 1521	1231, 1537		[30]
<i>Satureja thymbra</i>					Carvacrol	1788	2140		[30]
<i>Thymbra spicata</i>					Carvacrol, p-cymene	1788, 1407	2140, 1437		[30]
<i>Salvia officinalis</i>					Thujone	1416	1452		[30]
<i>Ocimum basilicum</i>	Leaves	Steam distillation	Agilent GC 7890A + MS 5975C	HP-5MS (30 m × 0.25 mm, 0.25 µm)	Methyl chavicol	1202	1195	NIST and Adams 2017	[36]
<i>Teucrium marum</i>	Leaves	Hydrodistillation	Perkin Elmer GC-MS (Turbomass)	BP-1 (50 m x 0.22 mm, 0.25 µm)	Dolichodial, (E)-β-Caryophyllene	1253, 1412	NR	FFNSC2, Nist11W9, Perkin_ff2013, Wiley8	[37]
<i>Thymus vulgaris</i>	Flowering aerial part	Hydrodistillation	Hewlett Packard GC HP 6890 + MS HP 5973	ZB-5HT (30 m x 0.32 mm, 0.25 µm)	Thymol	1299-1305	NR	NIST 11	[32]
<i>Thymus pulegioides</i>					α-citral, β-citral	1274, 1247	NR		[32]
<i>Thymus serpyllum</i>					Thymol	1299-1305	NR		[32]
<i>Salvia sclarea</i>					Linalyl acetate, linalool	1264-1265, 1100	NR		[32]
<i>Monarda didyma</i>					Thymol	1299-1305	NR		[32]
<i>Origanum vulgare</i>	Aerial part	Hydrodistillation	Perkin Elmer 580 GC + SQ 8 S MS	DB-5MS (30 m x 0.25 mm, 0.25 µm)	Carvacrol	1318	1298	Adams, 2017	[31]
<i>Rosmarinus officinalis</i>					α-pinene, verbenone	930, 1204	932, 1204		[31]
<i>Salvia officinalis</i>					Thujone	1107	1103		[31]
<i>Thymus vulgaris</i>					Thymol, o-cymene	1296, 1026	1289, 1022		[31]
<i>Pogostemon cablin</i>	Leaves	Hydrodistillation	GC-MS Shimadzu QP 5050A	ZB-5 MS (30 m x 0.25 mm, 0.25 µm)	Patchouli alcohol	1673	NR	NIST 21 and NIST 107	[33]
<i>Eplingiella fruticosa</i>	Leaves	Hydrodistillation	Agilent GC-MS 5977B	HP-5MS (30 m × 0.25 mm, 0.25 µm)	Carvacrol, 1,8-cineole, (E)-Caryophyllene	1293, 1027, 1409	1298, 1026, 1417	NIST, Wiley, and Adams, 2007	[38]

similarities and differences in chemical composition across species.

P. cablin has a different pattern than several other Lamiaceae species because its EO profile is dominated by sesquiterpenes. GC-MS identifies patchoulol as a major *P. cablin* constituent, alongside other reported components, including seychellene, α -patchoulene, α -bulnesene, α -guaiene, pogostol, and β -caryophyllene [33]. The predominance of patchoulol distinguishes the chemical profile of *P. cablin* from species such as *O. vulgare* and *Thymus* spp., which are more strongly associated with monoterpenes such as carvacrol and thymol (Table 1). This difference indicates that *P. cablin* has a distinct chemical profile that warrants specific consideration when evaluating its biological activity. The chemical profile provides a basis for relating EO composition to activity against oral pathogens, as discussed in following section.

4. Antimicrobial and Antibiofilm Activity of Lamiaceae Against Oral Pathogens

The antimicrobial activity against oral microorganisms varied among the investigated Lamiaceae species and preparations. This variation was evident in *Origanum vulgare* and *Salvia triloba*, for which aqueous, ethanolic, and enzymatic extracts produced different responses against the same bacterial targets [5]. These differences should be interpreted within the context of each experimental system rather than used to establish a general ranking of species. Microbial susceptibility may depend on the physiological characteristics of the test organisms, while extraction procedures determine the constituents recovered from plant tissues. Thus, despite these factors potentially explaining the observed variability, the available evidence does not establish a direct causal relationship between individual chemical constituents and antimicrobial activity.

The results for *O. vulgare* suggest that ethanolic extracts typically produced larger inhibition zones than aqueous and enzymatic extracts against the tested microorganisms, especially when 60% ethanol was used (Table 2). However, the response varied according to the target microorganism and the endpoint measured. The enzymatic extract also inhibited several targets, including *P. gingivalis*, against which it produced a larger inhibition zone than the other preparations evaluated in the same study. *S. triloba* exhibited a different response pattern, and the enzymatic extract produced a large inhibition zone against *P. gingivalis*, whereas the aqueous and ethanolic extracts showed different levels of activity against the other microorganisms (Table 2). These findings suggest that extraction procedures influence the

biological properties of the resulting preparations. However, differences in extract composition and microorganism-specific responses prevent us from concluding that increasing ethanol concentration consistently enhances antimicrobial activity.

The findings for *Salvia officinalis* and *Rosmarinus officinalis* further illustrate the importance of preparation type and experimental endpoint (Table 2). The ethanolic extract of *S. officinalis* produced a measurable inhibition zone against *S. mutans* but not against *C. albicans* under the reported assay conditions [14]. However, the absence of an inhibition zone does not establish the complete absence of antifungal activity, particularly since the study reported minimum inhibitory concentration (MIC) and minimum bactericidal/fungicidal concentration (MBC/MFC) values. Similarly, the ethyl acetate extract of *R. officinalis* was evaluated against several oral microorganisms using MIC and MBC endpoints. However, these results cannot be directly compared with inhibition-zone measurements because diffusion through the test medium and growth inhibition in a dilution assay reflect different experimental properties.

Essential oils exhibited variation in antimicrobial activity (Table 3). *O. vulgare*, *S. officinalis*, and *M. pulegium* were reported to have different MIC and MBC values against *S. mutans* and *C. albicans*. The EO of *O. vulgare* generally exhibited lower MIC values than the EOs of *S. officinalis* and *M. pulegium* under the conditions used in the study. The EOs' chemical profiles were also characterized. Carvacrol was identified as the major constituent of *O. vulgare*, α -thujone and 1,8-cineole as prominent constituents of *S. officinalis*, and pulegone as the major constituent of *M. pulegium* [13]. These data provide a basis for examining the relationship between chemical composition and antimicrobial activity within the same study. However, the relative abundance of a compound does not determine its contribution to the observed activity, as this may depend on other constituents and their interactions. In addition to its antimicrobial activity, *S. officinalis* was reported no detectable cytotoxic effects on L929 cells under the tested experimental conditions [14]. This finding provides preliminary evidence of cellular compatibility but does not establish safety for oral applications, which requires further evaluation using relevant oral cell models.

The findings for *Thymus fallax* provide further evidence of essential oil activity against oral pathogens. Its essential oil inhibited the tested strains at different MIC and MBC/MFC values, including *S. mutans*, *S. sobrinus*, *E. faecalis*, and *C. albicans* (Table 3). The study also characterized the oil's chemical composition, reporting thymol as the major constituent [17]. Since chemical

Table 2. Antimicrobial activity of Lamiaceae extracts against oral pathogens.

Species	Plant Preparation	Extract	Target Microorganism	Inhibition Zone (mm)	MIC	MBC/MFC	Ref.
<i>Origanum vulgare</i>	Leaves and flowers; maceration of water, ethanol 40%, ethanol 60%, enzymatic	Water	<i>S. mutans</i>	17.1 mm	3.1 mg/mL	6.3 mg/mL	[5]
		Ethanol 40%		17.3 mm	3.1 mg/mL	2.5 mg/mL	
		Ethanol 60%		28.6 mm	1.6 mg/mL	3.1 mg/mL	
		Enzymatic		18.8 mm	3.1 mg/mL	6.3 mg/mL	
		Water	<i>P. gingivalis</i>	18.2 mm	6.3 mg/mL	25 mg/mL	
		Ethanol 40%		19.5 mm	6.3 mg/mL	12.5 mg/mL	
		Ethanol 60%		29 mm	1.6 mg/mL	12.5 mg/mL	
		Enzymatic		19 mm	0.8 mg/mL	6.3 mg/mL	
		Water	<i>F. nucleatum</i>	15.3 mm	6.3 mg/mL	25 mg/mL	
		Ethanol 40%		18.1 mm	3.1 mg/mL	12.5 mg/mL	
		Ethanol 60%		28.2 mm	0.8 mg/mL	3.1 mg/mL	
		Enzymatic		18.7 mm	3.1 mg/mL	3.1 mg/mL	
		Water	<i>P. intermedia</i>	16.8 mm	6.3 mg/mL	25 mg/mL	
		Ethanol 40%		17.1 mm	3.1 mg/mL	12.5 mg/mL	
		Ethanol 60%		21.9 mm	0.8 mg/mL	6.3 mg/mL	
		Enzymatic		18.1 mm	3.1 mg/mL	12.5 mg/mL	
		Water	<i>P. micra</i>	16.9 mm	12.5 mg/mL	25 mg/mL	
		Ethanol 40%		24.2 mm	12.5 mg/mL	25 mg/mL	
		Ethanol 60%		27.9 mm	0.8 mg/mL	6.3 mg/mL	
		Enzymatic		18 mm	1.6 mg/mL	6.3 mg/mL	
<i>Salvia triloba</i>	Leaves and flowers; maceration of water, ethanol 40%, ethanol 60%, enzymatic	Water	<i>S. mutans</i>	20.7 mm	0.8 mg/mL	6.3 mg/mL	[5]
		Ethanol 40%		15.2 mm	6.3 mg/mL	25 mg/mL	
		Ethanol 60%		16.7 mm	3.1 mg/mL	12.5 mg/mL	
		Enzymatic		21.5 mm	0.8 mg/mL	6.3 mg/mL	
		Water	<i>P. gingivalis</i>	20.6 mm	0.8 mg/mL	6.3 mg/mL	
		Ethanol 40%		14.1 mm	6.3 mg/mL	25 mg/mL	
		Ethanol 60%		17 mm	6.3 mg/mL	12.5 mg/mL	
		Enzymatic		28.1 mm	0.8 mg/mL	1.6 mg/mL	
		Water	<i>F. nucleatum</i>	20.7 mm	12.5 mg/mL	50 mg/mL	
		Ethanol 40%		15.2 mm	6.3 mg/mL	12.5 mg/mL	
		Ethanol 60%		16.7 mm	1.6 mg/mL	3.1 mg/mL	
		Enzymatic		21.5 mm	1.6 mg/mL	1.6 mg/mL	
		Water	<i>P. intermedia</i>	20.6 mm	1.6 mg/mL	12.7 mg/mL	
		Ethanol 40%		14.1 mm	3.1 mg/mL	12.5 mg/mL	
		Ethanol 60%		17 mm	0.8 mg/mL	0.8 mg/mL	
		Enzymatic		28.1 mm	3.1 mg/mL	6.3 mg/mL	

Species	Plant Preparation	Extract	Target Microorganism	Inhibition Zone (mm)	MIC	MBC/MFC	Ref.
		Water	<i>P. micra</i>	20.7 mm	1.6 mg/mL	3.1 mg/mL	
		Ethanol 40%		15.2 mm	1.6 mg/mL	3.1 mg/mL	
		Ethanol 60%		16.7 mm	0.8 mg/mL	0.8 mg/mL	
		Enzymatic		21.5 mm	0.4 mg/mL	1.6 mg/mL	
<i>Salvia officinalis</i>	Aerial part; maceration of ethanol	Ethanol	<i>S. mutans</i> PTCC: 1683	12.16 mm	237.5 µg/mL	0.95×10 ³ µg/mL	[14]
			<i>C. albicans</i> PTCC: 5027	No inhibition	31.25 µg/mL	62.5×10 ³ µg/mL	
<i>Rosmarinus officinalis</i>	Aerial part; UAE of ethyl acetate	Ethyl acetate	<i>S. mutans</i> DSM20523	-	0.02 mg/mL	0.08 mg/mL	[15]
			<i>E. faecalis</i> ATCC29212	-	0.6 mg/mL	1.25 mg/mL	
			<i>P. micra</i> ATCC23195		0.01 mg/mL	0.02 mg/mL	
			<i>F. nucleatum</i> ATCC25586		0.15 mg/mL	0.15 mg/mL	
<i>Origanum vulgare</i>	Leaves and flowers; maceration of water, ethanol 40%, ethanol 60%, enzymatic	Water	<i>S. mutans</i>	17.1 mm	3.1 mg/mL	6.3 mg/mL	[5]
		Ethanol 40%		17.3 mm	3.1 mg/mL	2.5 mg/mL	
		Ethanol 60%		28.6 mm	1.6 mg/mL	3.1 mg/mL	
		Enzymatic		18.8 mm	3.1 mg/mL	6.3 mg/mL	
		Water	<i>P. gingivalis</i>	18.2 mm	6.3 mg/mL	25 mg/mL	
		Ethanol 40%		19.5 mm	6.3 mg/mL	12.5 mg/mL	
		Ethanol 60%		29 mm	1.6 mg/mL	12.5 mg/mL	
		Enzymatic		19 mm	0.8 mg/mL	6.3 mg/mL	
		Water	<i>F. nucleatum</i>	15.3 mm	6.3 mg/mL	25 mg/mL	
		Ethanol 40%		18.1 mm	3.1 mg/mL	12.5 mg/mL	
		Ethanol 60%		28.2 mm	0.8 mg/mL	3.1 mg/mL	
		Enzymatic		18.7 mm	3.1 mg/mL	3.1 mg/mL	
		Water	<i>P. intermedia</i>	16.8 mm	6.3 mg/mL	25 mg/mL	
		Ethanol 40%		17.1 mm	3.1 mg/mL	12.5 mg/mL	
		Ethanol 60%		21.9 mm	0.8 mg/mL	6.3 mg/mL	
		Enzymatic		18.1 mm	3.1 mg/mL	12.5 mg/mL	
		Water	<i>P. micra</i>	16.9 mm	12.5 mg/mL	25 mg/mL	
		Ethanol 40%		24.2 mm	12.5 mg/mL	25 mg/mL	
		Ethanol 60%		27.9 mm	0.8 mg/mL	6.3 mg/mL	
		Enzymatic		18 mm	1.6 mg/mL	6.3 mg/mL	
<i>Salvia triloba</i>	Leaves and flowers; maceration of water, ethanol 40%, ethanol 60%, enzymatic	Water	<i>S. mutans</i>	20.7 mm	0.8 mg/mL	6.3 mg/mL	[5]
		Ethanol 40%		15.2 mm	6.3 mg/mL	25 mg/mL	
		Ethanol 60%		16.7 mm	3.1 mg/mL	12.5 mg/mL	
		Enzymatic		21.5 mm	0.8 mg/mL	6.3 mg/mL	
		Water	<i>P. gingivalis</i>	20.6 mm	0.8 mg/mL	6.3 mg/mL	
		Ethanol 40%		14.1 mm	6.3 mg/mL	25 mg/mL	
		Ethanol 60%		17 mm	6.3 mg/mL	12.5 mg/mL	
		Enzymatic		28.1 mm	0.8 mg/mL	1.6 mg/mL	
		Water	<i>F. nucleatum</i>	20.7 mm	12.5 mg/mL	50 mg/mL	
		Ethanol 40%		15.2 mm	6.3 mg/mL	12.5 mg/mL	
		Ethanol 60%		16.7 mm	1.6 mg/mL	3.1 mg/mL	

Species	Plant Preparation	Extract	Target Microorganism	Inhibition Zone (mm)	MIC	MBC/MFC	Ref.
		Enzymatic	<i>P. intermedia</i>	21.5 mm	1.6 mg/mL	1.6 mg/mL	
		Water		20.6 mm	1.6 mg/mL	12.7 mg/mL	
		Ethanol 40%		14.1 mm	3.1 mg/mL	12.5 mg/mL	
		Ethanol 60%		17 mm	0.8 mg/mL	0.8 mg/mL	
		Enzymatic	<i>P. micra</i>	28.1 mm	3.1 mg/mL	6.3 mg/mL	
		Water		20.7 mm	1.6 mg/mL	3.1 mg/mL	
		Ethanol 40%		15.2 mm	1.6 mg/mL	3.1 mg/mL	
		Ethanol 60%		16.7 mm	0.8 mg/mL	0.8 mg/mL	
		Enzymatic		21.5 mm	0.4 mg/mL	1.6 mg/mL	
		Ethanol		12.16 mm	237.5 µg/mL	0.95×10 ³ µg/mL	
<i>Salvia officinalis</i>	Aerial part; maceration of ethanol		<i>S. mutans</i> PTCC: 1683				[14]
			<i>C. albicans</i> PTCC: 5027	No inhibition	31.25 µg/mL	62.5×10 ³ µg/mL	
<i>Rosmarinus officinalis</i>	Aerial part; UAE of ethyl acetate	Ethyl acetate	<i>S. mutans</i> DSM20523	-	0.02 mg/mL	0.08 mg/mL	[15]
			<i>E. faecalis</i> ATCC29212	-	0.6 mg/mL	1.25 mg/mL	
			<i>P. micra</i> ATCC23195	-	0.01 mg/mL	0.02 mg/mL	
			<i>F. nucleatum</i> ATCC25586	-	0.15 mg/mL	0.15 mg/mL	

Note: MIC: minimum inhibitory concentration, MBC: minimum bactericidal concentration, MFC: minimum fungicidal concentration, UAE: ultrasound-assisted extraction, ATCC: American Type Culture Collection, PTCC: Persian Type Culture Collection, DSM: German Collection of Microorganisms and Cell Cultures; "No inhibition" indicates that no inhibition was observed despite testing. A dash (-) indicates that the corresponding test was not performed. Bacterial strain identifiers are provided when specified in the original publication. When strain identifiers were not reported, the testing method or CLSI (Clinical and Laboratory Standards Institute) standard is indicated if available.

Table 3. Antimicrobial activity of Lamiaceae essential oil against oral pathogens

Species	Plant preparation	Target microorganism	Inhibition zone	MIC	MBC/MFC	Ref.
<i>Origanum vulgare</i>	Herbs; steam distillation	<i>S. mutans</i>	-	0.05% v/v	0.05% v/v	[13]
		<i>C. albicans</i>	-	0.05% v/v	0.05% v/v	
	Leaves; steam distillation	<i>E. faecalis</i> ATCC29212	7.8 mm	-	-	[16]
<i>Salvia officinalis</i>	Herbs; steam distillation	<i>C. albicans</i> ATCC10231	18.4 mm	-	-	[13]
		<i>S. mutans</i>	-	0.25% v/v	0.35% v/v	
		<i>C. albicans</i>	-	0.40% v/v	>0.50% v/v	
<i>Mentha pulegium</i>	Herbs; steam distillation	<i>S. mutans</i>	-	0.45% v/v	0.45% v/v	[13]
		<i>C. albicans</i>	-	0.25% v/v	0.25% v/v;	
<i>Thymus falllax</i>	Aerial part; hydrodistillation	<i>S. mutans</i> ATCC35668	-	0.031 µL/mL	0.062 µL/mL	[17]
		<i>S. sobrinus</i> ATCC27607	-	0.031 µL/mL	0.125 µL/mL	
		<i>E. faecalis</i> ATCC51299	-	0.125 µL/mL	0.250 µL/mL	
		<i>C. albicans</i> ATCC10261	-	0.06 µL/mL	0.125 µL/mL	
<i>Thymus vulgaris</i>	Leaves; steam distillation	<i>E. faecalis</i> ATCC29212	8.5 mm	-	-	[16]
		<i>C. albicans</i> ATCC10231	17.2 mm	-	-	
<i>Lavandula angustifolia</i>	Leaves; steam distillation	<i>E. faecalis</i> ATCC29212	No inhibition	-	-	[16]
		<i>C. albicans</i> ATCC10231	7.2 mm	-	-	
	Flowers; hydrodistillation	<i>F. nucleatum</i> PK1594	-	4 µL/mL	-	[39]

Note: MIC: minimum inhibitory concentration, MBC: minimum bactericidal concentration, MFC: minimum fungicidal concentration, "No inhibition" indicates that no inhibition was observed despite testing. A dash (-) indicates that the corresponding test was not performed. Bacterial strain identifiers are provided when specified in the original publication. When strain identifiers were not reported, the testing method or CLSI standard is indicated if available.

profiling and biological testing were conducted within the same study, the findings allow the chemical profile to be considered alongside the activity of that particular oil. However, the findings do not establish that thymol alone accounts for the observed effects. These results should

be interpreted in the context of the specific plant material, chemical composition, test microorganisms, and experimental conditions, rather than being directly extrapolated to other essential oils.

Table 4. Antibiofilm activity of Lamiaceae.

Species	Preparation	Target Microorganism	Minimum Biofilm Inhibition Concentration	Ref.
<i>Lavandula stoechas</i>	Ethyl acetate extract; UAE	<i>S. mutans</i>	0.15 mg/mL	[15]
<i>Thymus fallax</i>	Essential oil; hydrodistillation	<i>C. albicans</i>	0.015 µL/m	[17]

A complementary pattern was reported for the essential oils of *Thymus vulgaris* and *Lavandula angustifolia* when evaluated against *E. faecalis* and *C. albicans* [16]. *T. vulgaris* EO showed a more pronounced response against *C. albicans* than against *E. faecalis*. In contrast, *L. angustifolia* EO displayed a more limited response in the disc-diffusion assay (Table 3). These findings highlight the importance of considering the assay endpoint when interpreting antimicrobial activity. Although the response differed between the two microorganisms, disc diffusion results alone are insufficient to establish the absence of activity under other experimental conditions. Therefore, any MIC findings reported for lavender oil should be interpreted alongside the corresponding assay results rather than inferred from the inhibition-zone pattern. Overall, these studies illustrate that the antimicrobial response of an essential oil depends on the target microorganism and the experimental method. This precludes drawing general conclusions about the oil's activity across different oral pathogens.

Collectively, these investigations reveal differences in the antimicrobial reactions of Lamiaceae essential oils against bacterial and fungal targets. However, since inhibition-zone diameters and MIC or MBC/MFC values represent different endpoints, directly comparing them is not appropriate. Inhibition zones depend partly on the diffusion of constituents through the test medium. In contrast, MIC and MBC/MFC values assess growth inhibition and microbial killing under dilution-assay conditions. Differences in units, plant material, distillation methods, chemical profiles, and test microorganisms also limit direct comparisons across studies. Accordingly, the results support a descriptive assessment of each EO's activity against the tested microorganisms rather than a general ranking of Lamiaceae species' antimicrobial potency.

Antibiofilm findings provide complementary evidence because the inhibition of microbial growth does not necessarily indicate the inhibition of biofilm formation or the disruption of an established biofilm. Biofilms are organized microbial communities embedded in an extracellular matrix that can limit the penetration of antimicrobial compounds and reduce their effectiveness [10]. Therefore, antibiofilm activity is an important additional parameter when evaluating natural products for oral applications. For example, ethyl acetate extract of *L. stoechas* was reported to inhibit *S. mutans* biofilm

formation. The essential oil of *T. fallax* also demonstrated biofilm-inhibitory activity against the microorganisms (Table 4). These findings suggest that some Lamiaceae preparations have been studied for their effects on more than just planktonic cell growth. However, the results should be interpreted according to the specific biofilm model and endpoint used in each study because inhibition of biofilm formation does not necessarily indicate disruption of an established biofilm. Differences in assay design also limit direct comparisons of antibiofilm activity across preparations.

5. Relationship Between Chemical Composition and Antimicrobial Activity Against Oral Pathogens

The relationship between the chemical composition of Lamiaceae EOs and their antimicrobial activity against oral pathogens must be interpreted carefully. The studies included in this review examined chemical characterization and biological activity via distinct literature searches. Consequently, not all chemical profiles could be directly associated with the reported antimicrobial outcomes. Comparisons are more informative when the same EO preparation is characterized chemically and tested for antimicrobial activity. Even in such cases, the co-occurrence of major constituents and antimicrobial activity does not prove that a specific compound is responsible for the observed effect.

Some studies reported the chemical profiles and antimicrobial activity of the investigated EOs. For instance, studies on *O. vulgare*, *S. officinalis*, and *M. pulegium* reported the chemical composition alongside the antimicrobial findings [13]. Similarly, both chemical characterization and antimicrobial testing were reported for *T. fallax* [17]. Other studies reported both antimicrobial testing and chemical characterization using GC-MS, but were not characterized using RI [16, 39]. These studies provide a basis for exploring potential relationships between the chemical composition of the preparations examined and their antimicrobial activity. However, the presence of major constituents, such as carvacrol or thymol, does not prove that these compounds individually account for the observed activity. This activity may reflect interactions among multiple constituents and differences in the susceptibility of target microorganisms.

Comparisons between chemical profiles and antimicrobial findings from separate studies were treated as hypotheses for further investigation rather than evidence of a direct association. Results may be influenced by differences in geographical origin, plant part, extraction procedure, chemical composition, microbial strain, and antimicrobial assay conditions. Although compounds such as carvacrol, thymol, 1,8-cineole, linalool, and camphor have been discussed in relation to potential antimicrobial mechanisms [40, 41], their presence in a particular EO does not, by itself, establish the mechanism or intensity of its activity against oral pathogens [42].

The same caution applies to *P. cablin*, whose EO is characterized by sesquiterpenes, including patchoulol [33, 43]. While its chemical profile can be used to identify compounds of interest, its antimicrobial activity against oral pathogens must be established through biological testing of the same preparation. The activity of *P. cablin* should not be inferred solely from its chemical composition or from comparisons with other Lamiaceae species. More reliable relationships between chemical composition and antimicrobial activity can be established through studies that characterize and test the same preparation under clearly reported experimental conditions.

6. From Lamiaceae Antimicrobial Activity Against Oral Pathogens to *Pogostemon cablin*

Pogostemon cablin (Blanco) Benth., an aromatic plant in Lamiaceae family, is widely cultivated in tropical Asia, including Indonesia, for the production of patchouli EO. It is a perennial herb with aromatic leaves that serve as the primary plant material for EO production. Patchouli EO is obtained mainly by hydrodistillation or steam distillation of the leaves, yielding an oil rich in volatile compounds. The oil has a characteristic woody and earthy aroma, making it an important raw material for the perfume, cosmetic, and fragrance industries. The economic importance of *P. cablin* is further enhanced by its potential as a source of volatile compounds with biological activity [19, 43–45].

The chemical profile of patchouli oil is mainly characterized by sesquiterpenes, with patchoulol being one of its major constituents and has been extensively studied. *P. cablin* also contains various other sesquiterpenes, including α -patchoulene, α -guaiene, seychellene, β -patchoulene, β -caryophyllene, and their derivatives. These compounds contribute to the chemical and aromatic characteristic of oil. The composition can vary according to the part of the plant, its geographical

origin, the cultivation conditions, the drying process, fermentation, and distillation method. These factors underscore the importance of systematically identifying and quantifying patchouli oil constituents before interpreting the relationships between composition and biological activity [46, 47].

GC-MS is one of the main methods used to characterize the volatile constituents of patchouli EO because it provides chromatographic profiles and mass spectral information for individual components. Compound identification is strengthened by comparing mass spectra with reference libraries and evaluating RI values so that the presence of a constituent is not determined by single analytical parameter. This approach has been used to identify various sesquiterpenes in *P. cablin* oil, including patchoulol and other sesquiterpene hydrocarbons [33]. GC-MS and RI data also allow for the comparison of patchouli oil profiles across studies despite differences in material origin and analytical conditions. This is important because the chemical composition of a substance can influence its biological activity [27, 28].

Biological evidence indicates that the potential of *P. cablin* extends beyond its activity against oral pathogens. Patchouli EO has been reported to exhibit antibacterial and antifungal activity against various microorganisms. Some studies have shown differences in susceptibility between Gram-positive and Gram-negative bacteria. Patchoulol has also been reported to exhibit biological activity, including antibacterial activity against various bacterial strains. This indicates that the biological effects of *P. cablin* cannot always be simply separated into whole-oil activity and the contribution of individual constituents. In addition to its antimicrobial and antibiofilm effects [48, 49], research has revealed aphrodisiac [45], anti-inflammatory, antioxidant, analgesic, and other pharmacological properties of the oil, extracts, and compounds derived from *P. cablin* [50]. This range of evidence suggests that the bioactivity of *P. cablin* is multidimensional and must be carefully interpreted in relation to the form of the preparation and the chemical constituents investigated. The available evidence on patchoulol relevant to oral health included direct antimicrobial activity against oral pathogens and host-modulating effects in an experimental periodontitis model (Table 5).

Patchoulol has demonstrated antimicrobial activity against oral health-associated microorganisms, including *C. albicans* and *S. mutans* (Table 5). Patchoulol exhibited an MIC and an MFC of 64 $\mu\text{g/mL}$ against *C. albicans*, indicating antifungal activity under in vitro test conditions. Against *S. mutans*, a bacterium associated

Table 5. Antimicrobial activities of patchoulol relevant to oral health.

Sample	Microorganism/ Model	Findings	Parameters Assessed	Type of Evidence	Ref
Patchoulol	<i>C. albicans</i> ATCC10231	MIC 64 µg/mL MFC 64 µg/mL	Antifungal and antibiofilm activities	In vitro, direct antifungal evidence	[49]
Patchoulol	<i>S. mutans</i> ATCC 25175	MIC 40 µg/mL MBC 80 µg/mL	Antibacterial, antibiofilm, and anti-virulence activities	In vitro, direct antibacterial evidence	[51]
Patchoulol	Experimental periodontitis in rats	20 and 40 mg/kg/day, administered by oral gavage	Alveolar bone loss, periodontal inflammation	In vivo, host-modulating effects	[43]

with dental caries, patchoulol exhibited an MIC of 40 µg/mL and an MBC of 80 µg/mL. These findings suggest potential antifungal and anticariogenic activity, although further research is needed to establish its efficacy and safety for oral applications.

In addition to its direct antimicrobial activity, patchoulol was studied in an experimental rat model of periodontitis at oral doses of 20 and 40 mg/kg/day. The study evaluated alveolar bone loss, periodontal inflammation, inflammatory mediators, and related signaling pathways. This research provides evidence of potential host-modulatory effects rather than direct inhibition of oral pathogens (Table 5). Overall, the available evidence suggests that patchoulol may be relevant to oral health due to its antimicrobial activity and modulation of the periodontal response. However, these effects were studied using different experimental models and should therefore be interpreted separately.

The available evidence on the antimicrobial activity of *P. cablin* against oral pathogens remain limited compared with reports involving another microorganism. Patchoulol has shown antifungal activity against *C. albicans* and antibacterial activity against *S. mutans*, while an experimental periodontitis model suggested potential host-modulating effects (Table 5). However, these findings do not establish equivalent activities for the whole *P. cablin* EO or directly link its chemical profile to activity against oral pathogens. Further studies should integrate GC-MS and RI-based profiling with standardized assays against defined oral pathogens to determine whether the sesquiterpene-rich composition of *P. cablin* EO, particularly its patchoulol content, is associated with specific antimicrobial activity patterns.

7. Conclusions

Lamiaceae represents a potential source of natural products with antibacterial, antifungal, and antibiofilm activities against various oral pathogens, but biological responses vary according to species, preparation, chemical composition, and assay methodology. GC-MS supported by RI can serve as a complementary approach to strengthen characterization of volatile components and facilitate the interpretation of chemical profiles. *Pogostemon cablin* has a distinctive chemical profile

dominated by sesquiterpenes, particularly patchoulol. It has demonstrated diverse biological activities, though specific evidence against oral pathogens is limited. Although patchoulol has shown antimicrobial activity against certain oral pathogens, direct evidence linking the chemical composition of *P. cablin* EO to its activity against defined oral pathogens remains limited. Therefore, a direct relationship between patchouli oil composition and antimicrobial activity against oral pathogen cannot be established based solely from the presence of patchoulol as a major constituent. Integrating standardized chemical profiling with targeted biological assays is necessary to clarify the potential of *P. cablin* EO for antimicrobial applications against oral pathogens. These conclusions are interpreted within the scope of this narrative review, which was based on open-access articles published from 2021 to 2026 and obtained from PubMed and ScienceDirect. Older publications were reviewed separately to provide background or methodological context. Therefore, these findings may not reflect the full body of available evidence regarding the Lamiaceae family and oral pathogens.

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References

1. WHO. (2022). Global Status Report on Oral Health 2022.
2. Indonesian Ministry of Health. (2023). Dental and Oral Health in Indonesia.
3. Fu, D., Shu, X., Zhou, G., Ji, M., Liao, G., and Zou, L. (2025). Connection between Oral Health and Chronic Diseases, *MedComm*, Vol. 6, No. 1, 1–27. doi:10.1002/mco2.70052.

4. Han, S. Y., Chang, C. L., Wang, Y. L., Wang, C. S., Lee, W. J., Vo, T. T., Chen, Y. L., Cheng, C. Y., and Lee, I. T. (2025). A Narrative Review on Advancing Pediatric Oral Health: Comprehensive Strategies for the Prevention and Management of Dental Challenges in Children, *Children*, Vol. 12, No. 3, 1–17. doi:10.3390/children12030286.
5. Antoniadou, M., Rozos, G., Vaou, N., Zaralis, K., Ersanli, C., Alexopoulos, A., Dadamoglia, A., Varzakas, T., Tzora, A., and Voidarou, C. C. (2024). Comprehensive Bio-Screening of Phytochemistry and Biological Capacity of Oregano (*Origanum Vulgare*) and Salvia Triloba Extracts against Oral Cariogenic and Food-Origin Pathogenic Bacteria., *Biomolecules*, Vol. 14, No. 6. doi:10.3390/biom14060619.
6. Xu, D., Xiao, J., Jiang, D., Liu, Y., Gou, Z., Li, J., Shi, M., Wang, X., Guo, Y., Ma, L., Yin, H., Guo, L., Zhu, C., Zhang, Y., and Guo, H. (2022). Inhibitory Effects of a Water-Soluble Jujube Polysaccharide against Biofilm-Forming Oral Pathogenic Bacteria, *International Journal of Biological Macromolecules*, Vol. 208, No. January, 1046–1062. doi:10.1016/j.ijbiomac.2022.03.196.
7. Foroughi, M., Torabinejad, M., Angelov, N., Ojcius, D. M., Parang, K., Ravnan, M., and Lam, J. (2025). Bridging Oral and Systemic Health: Exploring Pathogenesis, Biomarkers, and Diagnostic Innovations in Periodontal Disease, *Infection*, Vol. 53, No. 6, 2277–2302. doi:10.1007/s15010-025-02568-y.
8. Guan, Z., Qi, H., and Feng, Q. (2025). Unveiling the Complex Extra-Oral Colonization Pathways and Pathogenic Mechanisms of *Fusobacterium Nucleatum*, a Heterogeneous Oral Pathogen, *View*, Vol. 6, No. 3, 1–20. doi:10.1002/VIW.20240153.
9. Zhou, S., Ji, Y., Yao, H., Guo, H., Zhang, Z., Wang, Z., and Du, M. (2022). Application of Ginsenoside Rd in Periodontitis With Inhibitory Effects on Pathogenicity, Inflammation, and Bone Resorption, *Frontiers in Cellular and Infection Microbiology*, Vol. 12, No. April, 1–14. doi:10.3389/fcimb.2022.813953.
10. Ray, R. R., and Pattnaik, S. (2023). Contribution of Phytoextracts in Challenging the Biofilms of Pathogenic Bacteria, *Biocatalysis and Agricultural Biotechnology*, Vol. 48, No. September 2022, 102642. doi:10.1016/j.bcab.2023.102642.
11. Karageçili, H., and Gülçin, İ. (2025). The Lamiaceae Family Plants Ethnobotanical Properties, Ethnopharmacological Uses, Phytochemical Studies and Their Utilization in Public or Current Clinical Practices: A Review, *Records of Natural Products*, Vol. 19, No. Special Issue, 466–487. doi:10.25135/rnp.529.2505.3521.
12. Luo, W., Du, Z., Zheng, Y., Liang, X., Huang, G., Zhang, Q., Liu, Z., Zhang, K., Zheng, X., Lin, L., and Zhang, L. (2019). Phytochemical Composition and Bioactivities of Essential Oils from Six Lamiaceae Species, *Industrial Crops and Products*, Vol. 133, No. December 2018, 357–364. doi:10.1016/j.indcrop.2019.03.025.
13. Bairamis, A., Sotiropoulou, N. S. D., Tsadila, C., Tarantilis, P., and Mossialos, D. (2024). Chemical Composition and Antimicrobial Activity of Essential Oils and Hydrosols from Oregano, Sage and Pennyroyal against Oral Pathogens, *Applied Sciences (Switzerland)*, Vol. 14, No. 3238. doi:10.3390/app14083238.
14. Ghadaksaz, S., Farajnia, S., Pournaghiazar, F., Leylabadlo, H. E., Salahlou, R., Delazar, A., and Zandesh, A. (2025). Antimicrobial Efficacy and Cytotoxicity of Ethanolic Extracts of Salvia Officinalis and Juglans Regia against Oral Pathogens, *Journal of Advanced Periodontology and Implant Dentistry*, Vol. 17, No. 1, 46–53. doi:10.34172/japid.025.3710.
15. Hickl, J., Argyropoulou, A., Al-Ahmad, A., Hellwig, E., Skaltsounis, A. L., Wittmer, A., Vach, K., and Karygianni, L. (2024). Unleashing Nature's Defense: Potent Antimicrobial Power of Plant Extracts against Oral Pathogens and Streptococcus Mutans Biofilms, *Frontiers in Oral Health*, Vol. 5, No. 1469174, 1–17. doi:10.3389/froh.2024.1469174.
16. Radu, C. M., Radu, C. C., Venter, I. D., Bogdan, M. A., and Zaha, D. C. (2025). Antimicrobial Activity of Oregano, Thyme, and Lavender Oils Against Oral Pathogens: Perspectives for AI-Supported Research, *Oral*, Vol. 5, No. 87, 1–12. doi:10.3390/oral5040087.
17. Moshaverinia, M., Sahmeddini, S., Lavee, F., Zareshahrabadi, Z., and Zomorodian, K. (2022). Antimicrobial and Anti-Biofilm Activities of Thymus Fallax Essential Oil against Oral Pathogens, *BioMed Research International*, Vol. 2022. doi:10.1155/2022/9744153.
18. Yu, J. (2025). Chemical Composition of Essential Oils and Their Potential Applications in Postharvest Storage of Cereal Grains, *Molecules*, Vol. 30, No. 3, 1–31. doi:10.3390/molecules30030683.
19. Astuti, P., Khairan, K., Marthoenis, M., and Hasballah, K. (2022). Antidepressant-like Activity of Patchouli Oil Var. Tapak Tuan (*Pogostemon Cablin Benth*) via Elevated Dopamine Level: A Study Using Rat Model, *Pharmaceutics*, Vol. 15, No. 5. doi:10.3390/ph15050608.
20. Cai, J., Zhao, J., Gao, P., and Xia, Y. (2022). Patchouli Alcohol Suppresses Castration-Resistant Prostate Cancer Progression by Inhibiting NF-KB Signal Pathways, *Translational Andrology and Urology*, Vol. 11, No. 4, 528–542. doi:10.21037/tau-22-220.
21. Liang, C. Y., Chang, K. F., Huang, Y. C., Huang, X. F., Sheu, G. T., Kuo, C. F., Hsiao, C. Y., and Tsai, N. M. (2023). Patchouli Alcohol Induces G0/G1 Cell Cycle Arrest and Apoptosis in Vincristine-Resistant Non-Small Cell Lung Cancer through ROS-Mediated DNA Damage, *Thoracic Cancer*, Vol. 14, No. 21, 2007–2017. doi:10.1111/1759-7714.14982.
22. Muhammad, S., Isnaini, N., Ginting, B., Aiman, H. R., Ernawati, Prajaputra, V., and Sufriadi, E. (2025). Chemical Characterization and Antimicrobial Potential of Purified Aceh Patchouli Oil (*Pogostemon Cablin Benth.*) Residue for Floor Cleaning Product Innovation, *South African Journal of Chemical Engineering*, Vol. 54, No. June, 335–347. doi:10.1016/j.sajce.2025.08.010.
23. Frolova, N., Orlova, A., Popova, V., Bilova, T., and Frolov, A. (2026). Gas Chromatography–Mass Spectrometry (GC-MS) in the Plant Metabolomics Toolbox: Sample Preparation and Instrumental Analysis, *Biomolecules*, Vol. 16, No. 1, 1–33. doi:10.3390/biom16010016.
24. Bilova, T., Frolova, N., Orlova, A., Silinskaia, S., Mailov, A., Popova, V., and Frolov, A. (2026). Analyzing Plant Low-Molecular-Weight Polar Metabolites: A GC-MS Approach, *Plants*, Vol. 15, No. 3, 1–35. doi:10.3390/plants15030445.
25. Bolouri, P., Salami, R., Kouhi, S., Kordi, M., Lajayer, B. A., Hadian, J., and Astatkie, T. (2022). Applications of Essential Oils and Plant Extracts in Different Industries, *Molecules*, Vol. 27, 1–17.
26. Żukowska, G., and Durczyńska, Z. (2024). Properties and Applications of Essential Oils: A Review, *Journal of Ecological Engineering*, Vol. 25, No. 2, 333–340. doi:10.12911/22998993/177404.
27. Novandy, T. R., Maulana, A., Sasmita, N. R., Suhendra, R., Irvanizam, I., Muslem, M., Idroes, G. M., Yusuf, M., Sofyan, H., Abidin, T. F., and Idroes, R. (2022). The Prediction of Kovats Retention Indices of Essential Oils at Gas Chromatography Using Genetic Algorithm-Multiple Linear Regression and Support Vector Regression, *Journal of Engineering Science and Technology*, Vol. 17, No. 1, 306–326.
28. Anjum, A., Liigand, J., Milford, R., Gautam, V., and Wishart, D. S. (2023). Accurate Prediction of Isothermal Gas Chromatographic Kovats Retention Indices, *Journal of Chromatography A*, 464176.
29. Bruxel, F., Schneider, C. E., Gastmann, J., Orlandi, C. R., Gastmann, R., Hoehne, L., Soares, G. L. G., Ethur, E. M., Sperotto, R. A., and de Freitas, E. M. (2022). Phytotoxicity of *Hesperozygis Ringens* (Benth.) Epling Essential Oil on *Eragrostis Plana* Nees, *Flora: Morphology, Distribution, Functional Ecology of Plants*, Vol. 297, No. July. doi:10.1016/j.flora.2022.152167.
30. Gezici, S., Turkmen, M., and Karahan, F. (2024). Exploring the Anti-Cancer Properties of Essential Oils from Some Lamiaceae Species against Human Cancer Cells with Multivariate Analysis, *South African Journal of Botany*, Vol. 166, 287–296. doi:10.1016/j.sajb.2023.10.057.

31. Spréa, R. M., Caleja, C., Finimundy, T. C., Calhelha, R. C., Pires, T. C. S. P., Amaral, J. S., Prieto, M. A., Ferreira, I. C. F. R., Pereira, E., and Barros, L. (2024). Chemical and Bioactive Evaluation of Essential Oils from Edible and Aromatic Mediterranean Lamiaceae Plants, *Molecules*, Vol. 29, No. 12, 1–12. doi:10.3390/molecules29122827.
32. Shanaida, M., Hudz, N., Białoń, M., Krytsowa, M., Svydenko, L., Filipiska, A., and Paweł Wieczorek, P. (2021). Chromatographic Profiles and Antimicrobial Activity of the Essential Oils Obtained from Some Species and Cultivars of the Mentheae Tribe (Lamiaceae), *Saudi Journal of Biological Sciences*, Vol. 28, No. 11, 6145–6152. doi:10.1016/j.sjbs.2021.06.068.
33. Santos, Á. M. O., Araújo, A. P. A., Alves, P. B., Blank, A. F., Pereira, E. J. G., Guedes, R. N. C., Nunes, R. S., Picanço, M. C., Masiulionis, V. E., and Bacci, L. (2026). Characterization and Insecticidal Effects of the Essential Oil and Nanoemulsion of Pogostemon Cablin on Populations of Sitophilus Zeamais, *Crop Protection*, Vol. 199, No. September 2025. doi:10.1016/j.cropro.2025.107410.
34. Georgiu, I. A., Gal, E., Dan, C., Sestras, R. E., Vicente, O., Boscaiu, M., and Sestras, A. F. (2026). Influence of Extraction Technology on the Volatile Composition of Lavandula Angustifolia Essential Oils, *Industrial Crops and Products*, Vol. 251, No. March, 124260. doi:10.1016/j.indcrop.2026.124260.
35. Aćimović, M., Ivanović, S., Simić, K., Pezo, L., Zeremski, T., Ovuka, J., and Sikora, V. (2021). Chemical Characterization of Marrubium Vulgare Volatiles from Serbia, *Plants*, Vol. 10, No. 3, 7–17. doi:10.3390/plants10030600.
36. Díaz, A. S., Luz, T. Z., Mendes, G. R., Andrade, E. D., Bertolucci, S. K. V., Alves, D. S., and Carvalho, G. A. (2026). Toxicity of Ocimum Basilicum L. (Lamiaceae) Essential Oil to Spodoptera Frugiperda (J.E. Smith, 1797) (Lepidoptera: Noctuidae) and Its Selectivity for Telenomus Remus Nixon, 1937 (Hymenoptera: Scelionidae), *Crop Protection*, Vol. 203, No. January, 107551. doi:10.1016/j.cropro.2026.107551.
37. Maccioni, A., Macis, S., Gibernau, M., and Farris, E. (2023). Phytochemical Diversity within and among Sardinian Populations of the Endemic Teucrium Marum L. (Lamiaceae) Is Determined by Ecological Factors, *Heliyon*, Vol. 9, No. 7, e17728. doi:10.1016/j.heliyon.2023.e17728.
38. de Alcântara Vilarim, Q. H. S. P., da Silva Lira, T. L., de Oliveira Farias de Aguiar, J. C. R., da Silva, A. C., Paiva, P. M. G., Navarro, D. M. do A. F., de Albuquerque Lima, T., dos Santos, P. É. M., and Napoleão, T. H. (2026). Essential Oil from Leaves of Eplingiella Fruticosa (Lamiaceae): Chemical Characterization and Insecticidal Activity against Sitophilus Zeamais (Coleoptera: Dryophthoridae), *Biocatalysis and Agricultural Biotechnology*, Vol. 76, No. April, 104179. doi:10.1016/j.bcab.2026.104179.
39. Rosner, O., Livne, S., Bsharat, M., Dviker, S., Jeffet, U., Matalon, S., and Sterer, N. (2024). Lavandula Angustifolia Essential Oil Inhibits the Ability of Fusobacterium Nucleatum to Produce Volatile Sulfide Compounds, a Key Components in Oral Malodor, *Molecules*, Vol. 29, No. 2982. doi:10.3390/molecules29132982.
40. Rathod, N. B., Kulawik, P., Ozogul, F., Regenstein, J. M., and Ozogul, Y. (2021). Biological Activity of Plant-Based Carvacrol and Thymol and Their Impact on Human Health and Food Quality, *Trends in Food Science and Technology*, Vol. 116, No. March, 733–748. doi:10.1016/j.tifs.2021.08.023.
41. Yuan, Y., Sun, J., Song, Y., Raka, R. N., Xiang, J., Wu, H., Xiao, J., Jin, J., and Hui, X. L. (2023). Antibacterial Activity of Oregano Essential Oils against Streptococcus Mutans in Vitro and Analysis of Active Components, *BMC Complementary Medicine and Therapies*, Vol. 23, No. 1, 1–13. doi:10.1186/s12906-023-03890-4.
42. Marcos-Herraiz, S., Alonso Fernández, S., Irisarri, M. J., Arroyo Díaz, J., Ponce-Gordo, F., González-Coloma, A., Navarro Rocha, J., Azami-Conesa, I., Gómez-Muñoz, M. T., and Bailén, M. (2026). Phytotherapeutic Potential of Lamiaceae Essential Oils and Their Monoterpenes against Giardia Duodenalis., *Veterinary Parasitology*, Vol. 343, No. November 2025, 110702. doi:10.1016/j.vetpar.2026.110702.
43. Zhang, S., Duan, F., He, T., Sun, C., Zhen, M., Liang, E., Liu, X., Dai, Y., Zhan, R., Hu, N., Xia, Y., and Liu, S. (2025). The Effects and Mechanisms of Patchouli Alcohol on Experimental Periodontitis Rats Based on the OPG/RANK/RANKL/P38 MAPK Signaling Pathway, *Journal of Inflammation Research*, Vol. 18, No. August, 12599–12617. doi:10.2147/JIR.S530534.
44. Khairan, ., Muhammad, S., and Diah, M. (2019). Patchouli (Pogostemon Cablin Benth): Chemistry, Biology, and Anti-Inflammatory Activities: A Review, *Proceedings of the 2nd International Conference of Essential Oils*, SCITEPRESS - Science and Technology Publications, 67–73. doi:10.5220/0009956600670073.
45. Khairan, K., Amanda, R., Hasbi, S. Y., Diah, M., and Hasballah, K. (2023). A Perspective Study of Pogostemon Cablin Benth as an Aphrodisiac, *Malacca Pharmaceutics*, Vol. 1, No. 2, 62–70. doi:10.60084/mp.v1i2.61.
46. Wahyudiono, Asri, A. A. T., Gautama, P. R. B., Winardi, S., Adschiri, T., Goto, M., and Machmudah, S. (2025). Enrichment of Patchouli Alcohol in Extracted Patchouli Oil from Pogostemon Cablin Benth Leaves Using Supercritical Carbon Dioxide, *Case Studies in Chemical and Environmental Engineering*, Vol. 11, No. December 2024, 101046. doi:10.1016/j.csee.2024.101046.
47. Sufriadi, E., Meilina, H., Munawar, A. A., and Idroes, R. (2021). Fourier Transformed Infrared (FTIR) Spectroscopy Analysis of Patchouli Essential Oils Based on Different Geographical Area in Aceh, *IOP Conference Series: Materials Science and Engineering*, Vol. 1087, No. 1, 012067. doi:10.1088/1757-899X/1087/1/012067.
48. Kemala, P., Idroes, R., Khairan, K., Ramli, M., Tallei, T. E., Helwani, Z., and Rahman, S. A. (2024). The Potent Antimicrobial Spectrum of Patchouli: Systematic Review of Its Antifungal, Antibacterial, and Antiviral Properties, *Malacca Pharmaceutics*, Vol. 2, No. 1, 10–17. doi:10.60084/mp.v2i1.156.
49. Zhang, Q., Zhang, J., Zhang, Y., Sui, Y., Du, Y., Yang, L., and Yin, Y. (2024). Antifungal and Anti-Biofilm Activities of Patchouli Alcohol against Candida Albicans, *International Journal of Medical Microbiology*, Vol. 314, 151596. doi:10.1016/j.ijmm.2023.151596.
50. Singh, S., and Agrawal, N. (2024). Exploring the Pharmacological Potential and Bioactive Components of Pogostemon Cablin (Blanco) Benth, Traditional Chinese Medicine, *Pharmacological Research - Modern Chinese Medicine*, Vol. 10, No. January. doi:10.1016/j.prmcm.2024.100382.
51. Chen, Q., Feng, C., Zhao, Z., Yang, D., and Yang, W. (2026). Patchouli Alcohol as a Potential Anti-Cariogenic Compound Targeting Streptococcus Mutans, *Molecules*, Vol. 31, No. 15, 1–16. doi:10.3390/molecules31152577.