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NATURE'S ANTIMICROBIALS: ESSENTIAL OILS OF *THYMUS VULGARIS*, *SALVIA OFFICINALIS*, AND *CYMBOPOGON CITRATUS* IN COMBATING BACTERIAL INFECTIONS

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ABSTRACT

Looking beyond mainstream medicine, plant-based treatments are now widely recognized for offering health benefits while posing fewer risks than conventional drugs. Because they tend to produce milder reactions, herbal solutions attract growing attention in managing resistant bacteria. Oils drawn from plants show power against many types of microbes, sparking curiosity about how nature might fill gaps left by lab-made medicines. Instead of relying solely on chemical compounds, researchers examine specific green sources like *Thymus vulgaris*, *Salvia officinalis*, and *Cymbopogon citratus* for real-world usefulness. While rooted in ancient practices, these species reveal modern promise through scientific study into their makeup and function. Each herb brings unique qualities worth reviewing carefully. Alongside potency data comes analysis of safe dosage levels and possible dangers tied to misuse. Even so, results point toward viable paths where such plants could help form next-generation infection fighters. Though not replacements overnight, these botanical options stand out as tools that future medical plans might rely upon more heavily. When facing stubborn microbial strains, turning to well-studied herbs makes sense within broader efforts to preserve drug effectiveness.

KEYWORDS: *Thymus vulgaris*; *Salvia officinalis*; *Cymbopogon citratus;* Essential oils; Antibacterial activity.

INTRODUCTION

From ancient times, plant parts like roots, leaves, stems, bark, seeds, and flowers have served healing purposes - known today as phytomedicines or ethnomedicines. Though once limited to raw preparations within customary medical practices, their role has shifted subtly over time. Lately, global interest in these natural remedies has grown stronger, driven by views on their gentler impact, widespread availability, not just proven results but also long-standing trust across cultures.[1]

Though often overlooked, infections still weigh heavily on global health, accounting for about 41% of illness across populations. What makes matters worse is the growing spread of bacteria that resist standard antibiotics - this shift endangers treatment outcomes everywhere. With conventional options faltering, attention has turned toward plant-derived compounds used in traditional healing. Such botanicals, long part of cultural remedies, offer promising tools against stubborn microbes, functioning as effective antimicrobials when others fail.[2] Though conventional antibiotics can trigger harmful side effects, discovering fresh antimicrobial options demands significant time and expense. Centuries back, plants used for healing began fighting bacterial illnesses, often boosting treatment results when combined. One case stands out - herbal cures treated severe dysentery more than nine centuries ago. Today, an estimated 65% to 80% of individuals across poorer regions turn to plant-based medicine against infections. Unlike lab-made drugs, natural botanicals tend to bring fewer unwanted reactions, along with less risk of microbes adapting.[3]

Essential oils stand out among plant-based bioactives because they work against many types of microbes. These substances have shown abilities to stop bacteria, fungi, and viruses in studies. What makes them effective lies partly in how little water they mix with, allowing easier contact with fatty parts of microbe cell walls. Because of this match, the barriers around cells weaken and let internal materials escape. As a result, microbes break down and die when exposed long enough.[4]

Looking closely at *Thymus vulgaris*, *Salvia officinalis*, and *Cymbopogon citratus* reveals their role in fighting microbes through plant-based compounds. While long used in folk healing, these herbs now draw attention for how they tackle infections without relying on lab-made drugs. Their power often comes from complex mixtures like essential oils and other active molecules found naturally within them. Because of this makeup, each one shows activity

against bacteria, fungi, and even certain viruses. Instead of simply killing germs, some components interfere with microbial processes in subtle ways. Over time, such effects may reduce reliance on conventional antibiotics where resistance has become a problem. With rising concerns about drug-resistant strains, exploring these botanicals offers another path forward - not as quick fixes but as options grounded in long-standing practice. What stands out is not novelty, rather persistence - how ancient remedies still hold relevance when examined with modern tools.

***Thymus vulgaris* L**

1.1 Introduction

Found across southern Europe, *Thymus vulgaris* - better recognized as thyme - is part of the Lamiaceae family. While its roots lie in Mediterranean climates, cultivation now spans continents. Used frequently in cooking, it also serves purposes beyond seasoning. Because of historical practices, people have turned to it for liver health, alongside digestive stimulation. Infections involving airways or bladder have seen traditional applications too. Even conditions tied to joint structures were once addressed using this herb.[5]

Found in gardens worldwide, thyme carries a sharp, clean scent that lingers easily in the air. Stemming from an old word tied to smoke rituals, its name hints at ancient cleansing uses. Because it slows spoilage, people once stored meats, birds, and seafood with sprigs tucked inside. Healing qualities helped damaged skin recover faster, making it common in traditional care routines. From high above the ground, early Europeans burned parts of the plant to ease breathing troubles and skin issues. While the Greeks relied on full-plant smoke, so did Roman healers using similar methods. During the 1300s plague outbreak, water-based preparations made from *Thymus vulgaris* appeared in medical notes as protective remedies. These same liquids later served communities aiming to reduce sickness from spoiled meals. Research today confirms strong germ-fighting power, including against stubborn microbes resistant to many drugs. Beyond bacteria and fungi control, this herb supports healing through cleansing, stimulating, tightening, digestion aid, and parasite removal traits. Thyme helps treat various skin issues like acne, dermatitis, oily skin, and reactions to insect bites or stings; at the same time, it eases discomfort from rheumatic pain and sciatica. Studies suggest its ability to lower oxidative stress stands alongside improved activity in cell-based immunity.[6] Among plants in the Thymus genus, shifts in chromosome number are common, showing up clearly in *Thymus vulgaris* L., where such irregularities define genetic structure.

Chromosome sets like 2n = 28, 30, 56, or 60 appear frequently across different individuals. These differences point toward deeper patterns of evolution driven by unequal distribution during cell division. For example, some samples of T. vulgaris L. display a count of 74 chromosomes instead of the usual 28. Such inconsistency reflects a broad internal flexibility, possibly behind the wide range of physical traits found in separate groups of this plant.[7]

Thymus vulgaris shows wide chemical variation, with roughly twenty distinct chemotypes identified so far. Thymol stands out among main types, alongside geraniol, linalool, carvacrol, sabinene hydrate, and borneol. Beyond single forms, combinations appear frequently in research records - examples include sabinene hydrate paired with terpinen-4-ol, or cyclocitral together with verbenol. Some plants express p-cymene and thymol at once; others show three-part blends like carvacrol, γ-terpinene, and thymol coexisting. Mixtures such as linalool-carvacrol-p-cymene occur, just as complex groupings involving sabinene hydrate with geraniol, geranyl acetate, and α-terpineol do. Chemotype variety extends to structures combining sabinene hydrate and α-terpinyl acetate with thymol, even those linking sabinene hydrate directly to linalool. Other instances feature α-terpinyl acetate plus carvacrol, or involve carvacrol along with α-terpineol and borneol. Repeated findings report sabinene hydrate again tied to terpinen-4-ol, while geranyl formate appears hand-in-hand with geraniol. Certain strains carry p-cymene-thymol-carvacrol simultaneously, whereas terpinene-4-ol often aligns with p-cymene. Camphor commonly occurs where camphene is present; similarly, 1,8-cineole turns up matched with α-terpinyl acetate. Differences in these mixtures shape how each plant behaves biologically, smells, and functions in practice.[8]

1.2. Botanical Description

Standing between 10 and 30 centimeters tall, *Thymus vulgaris* is a fragrant perennial plant with a firm, woody stem at its core. Small leaves, colored pale green to gray, grow directly across from one another on the stems, shaped anywhere from narrow lance forms to slender lines. Measuring roughly 5 to 10 millimeters long and less than three millimeters wide, these blades carry tiny oil-filled dots and have margins rolled under. Light purple blooms, structured with two distinct lip sections, stretch up to half a centimeter in size. Instead of tight bunches, blossoms emerge loosely through leaf-shaped bracts, forming ringed groupings tucked beside shoots or crowning ends as soft egg-shaped or circular tips. Each flower cup bears fine hairs and secretory spots across its outer layer. Under certain surroundings, the

plant may show different physical features. A detailed drawing appears in Figure 1.1, showing its structure.[6]

1.3. Chemical Composition

Thymus vulgaris is distinguished by a broad array of phytochemical components, mainly consisting of phenolic compounds, terpenoids, flavonoids, polysaccharides, and other secondary metabolites.

Phenolic Compounds: This plant is abundant in various phenolic constituents, primarily existing as derivatives of phenolic acids. These include derivatives of hydroxycinnamic acid like rosmarinic acid, caffeic acid, p-coumaric acid, and ferulic acid, as well as derivatives of hydroxybenzoic acid such as p-hydroxybenzoic acid, syringic acid, and gentisic acid. Additionally, quinic acid is present and regarded as a significant phenolic-related compound. **Terpenoids:** Terpenoids are chiefly found as volatile substances originating from isoprene units. This category encompasses phenolic monoterpenes like thymol and carvacrol, along with oxygenated monoterpene alcohols such as geraniol, linalool, and α-terpineol. Hydrocarbon monoterpenes, including limonene, γ-terpinene, p-cymene, and α- and β-pinene, are also found. Moreover, sesquiterpene compounds like β-caryophyllene have been detected in the plant (Fig. 1.2).

Flavonoids and Other Secondary Metabolites: The flavonoid content in T. vulgaris is primarily composed of flavone derivatives, notably apigenin and luteolin, which are types of hydroxylated flavones. Additionally, more complex flavonoids like cirsimaritin and xanthomicrol are present, categorized as methoxylated flavone derivatives. *Thymus vulgaris* also contains other secondary metabolites such as alkaloids, tannins, saponins, and steroids. These are typically represented by nitrogen-containing heterocyclic alkaloids, polyphenolic tannins, glycosidic saponins, and sterol-based steroidal compounds, respectively. However, there is limited detailed information about their specific biological functions and mechanisms.

Polysaccharides and Structural Components: Besides these phytochemicals, *Thymus vulgaris* includes polysaccharides like cellulose, starch, homogalacturonan, and rhamnogalacturonan I. These substances are linked to antioxidant properties and may enhance the plant's nutritional and therapeutic value.[6] Furthermore, the nature and composition can vary greatly based on geographical location, climate, and environmental conditions.

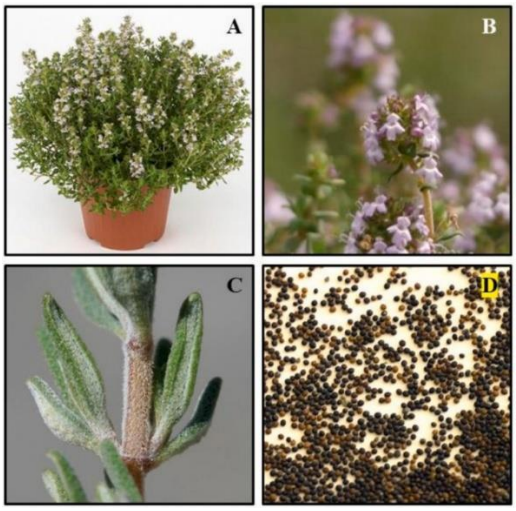
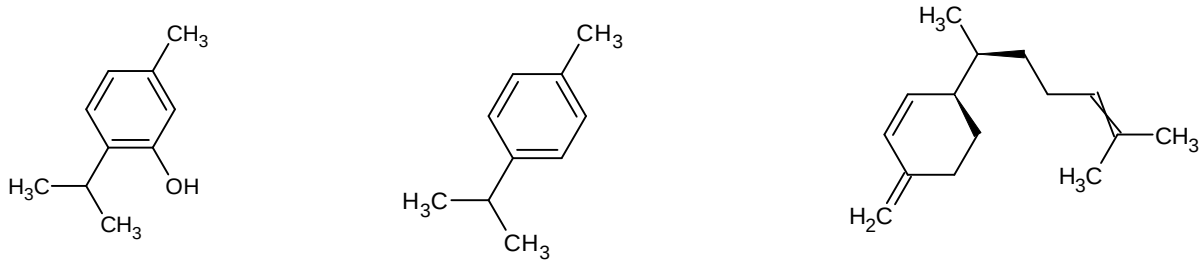


Figure 1.1. Morphological features of *Thymus vulgaris* L., showing the whole plant (A), flowers (B), leaves (C), and seeds (D).[6]



Thymol **p-Cymene** **beta-Sesquiphellandrene**

Figure 1.2 Major Antibacterial Phytoconstituents of *Thymus vulgaris* and Their Chemical Structures.

1.4 Safety and Toxicity profile

Though historical accounts and medical observations suggest thyme's blossoms and foliage pose little risk when used in cooking or briefly as medicine, the concentrated form demands caution. While diluted applications on skin may be acceptable, consuming the essence brings danger. Instead of swallowing, even small amounts might trigger disorientation or head pain, sometimes escalating toward convulsions or unconsciousness. From another angle, breathing in powdered plant matter could inflame eye tissue, leading to irritation. Though rare, such reactions underline a need for care.

Occupational environments often see skin reactions, such as redness or swelling, especially when people handle thymol-based preparations. Irritation around the mouth sometimes follows repeated contact. Allergic responses aren’t limited to the surface - one might develop nasal discomfort before progressing to breathing difficulties. In sensitive cases, airway

symptoms appear, varying from mild wheezing to intense constriction, though extreme episodes remain uncommon.

Though taken by mouth, thyme may lead to stomach-related issues like nausea or irritation, sometimes progressing to vomiting or diarrhoea. Blood pressure changes appear irregularly, though low readings have been seen; extreme instances involve a slowed heartbeat. Reports, rare yet noted, point to muscle fatigue after ingestion. Urinary discomfort might intensify, particularly when pre-existing inflammation is present in the bladder region.

Most of the time, eating thyme in food poses little danger - yet misusing its concentrated oil can lead to serious health effects, including body-wide poisoning or allergy symptoms.[9]

1.5 Antibacterial Action of *Thymus vulgaris* L

Thymus vulgaris essential oil catches attention because of strong germ-fighting properties. Though many plant extracts show promise, this one works across a wide range of harmful microbes. Its power mainly comes from chemicals called thymol and carvacrol. These substances appear frequently within the oil's makeup. Scientists study such oils more closely now, given rising problems with drug-resistant infections. Rather than fading into background research, they've moved toward practical exploration. Activity spans bacteria, fungi, even some viruses - making results harder to ignore.

Essential oils and methanolic extracts from *Thymus vulgaris* along with Pimpinella anisum displayed strong antibacterial properties, according to Al-Bayati and colleagues. Most effective was thyme oil, especially when tested on Staphylococcus aureus, Bacillus cereus, and Proteus vulgaris - effects likely due to compounds like thymol and carvacrol. While Maxipime failed, certain microbes such as Pseudomonas aeruginosa responded only when oils were paired with plant-based alcohol extracts. Together, these mixtures enhanced suppression where single applications fell short. Findings suggest blended natural oils may offer new paths for tackling stubborn infections.[10]

Thyme oil, according to Kobacy et al. (2025), surpassed parsley oil in both antimicrobial and antioxidant strength - matching even garlic oil's performance. When targeting E. coli, garlic stood out; yet thyme took the lead against K. pneumoniae, S. dysenteriae, and S. aureus, leaving parsley behind as the least potent of the three. Blends played a key role: combining garlic with thyme led to greater effects than each could achieve solo. Even more notable, the

trio of garlic, parsley, and thyme together delivered peak activity, especially when challenging A. niger. The order of effectiveness formed a clear line - garlic plus parsley plus thyme at the top, followed by garlic-thyme, then garlic-parsley, thyme-parsley, garlic alone, thyme alone, and finally parsley oil trailing at number eleven.[11]

Studies indicate *Thymus vulgaris* essential oil acts strongly on E. coli found in meat, requiring just 512 µg/mL to inhibit growth. Because it contains large amounts of thymol, its ability to disrupt biofilms stands out - surpassing chlorhexidine at 0.12%. Despite this edge, mixing the oil with lab-made antibiotics often weakens overall effect. Yet, under certain conditions, improved results emerged when paired with ampicillin or ciprofloxacin. Such findings point toward thyme oil playing a role in managing harmful microbes and surface-colonizing infections (Brito-Junior et al., 2025).[12]

Though its impact shifts depending on bacterial type, thyme essential oil alters how other oils fight microbes. With S. aureus, cooperation happens more often than not. Paired with Norway spruce, cinnamon, juniper berry, clove, thuja, or Siberian cedar, the effect grows stronger. Lemongrass and eucalyptus, weak on their own, start working when mixed in. When facing E. coli, only rosewood, peppermint, and lemon balm team up effectively. Lavender, sandalwood, and calamus disrupt instead. Most disruptive is calamus, particularly where E. coli is concerned.[13]

Thyme essential oil works well against drug-resistant forms of S. aureus. Ranging between 48.67 and 52.5 millimeters, zones where bacterial growth stops appear clearly in tests. Instead of just slowing growth, it kills bacteria - shown by an MBC-to-MIC ratio under four. Concentrations needed are low: one to two microliters per milliliter for MIC, one to four for MBC.[14]

Even though antibiotic resistance is common, Slovakian *Thymus vulgaris* essential oil still works well against tough Enterobacteriaceae, such as those making ESBL enzymes, showing consistently low MIC levels. When paired with cefotaxime, the oil boosts effectiveness toward E. coli that carry blaSHV-12, while enhancing results more mildly in ESBL-positive Enterobacter cloacae.[15]

Thyme essential oil additionally shows antimycobacterial activity against Mycobacterium tuberculosis, including drug-resistant strains, with bactericidal effects at low concentrations

(MIC 0.5-40 µg/mL) - highlighting its potential as a natural therapeutic candidate for resistant tuberculosis.[16]

MIC of *Thymus vulgaris* Essential Oil Against Selected Microorganisms

Despite its effectiveness across many bacterial types, thyme essential oil shows stronger effects on Gram-positive species because Gram-negatives possess an outer shield made of lipopolysaccharides that resists penetration. This barrier limits how deeply the oil can enter, reducing potency where such structures exist.[17]

S.NO	Part of the plant used/ brand from which the essential oil was purchased	Extraction procedure	Micro organism	Organism type	MIC 50 (µL/mL)	MIC 90 (µL/mL)	Reference
1	Partially dried stalk.	steam distillation	Enterococcus faecalis	Bacteria (Gram-positive)	13.85 µg/mL	16.43 µg/mL	[18]
2	Partially dried stalk.	steam distillation	Bacillus subtilis	Bacteria (Gram-positive)	12.12 µg/mL	16.56 µg/mL	[18]
3	Partially dried stalk.	steam distillation	Staphylococcus aureus	Bacteria (Gram-positive)	16.56 µg/mL	19.26 µg/mL	[18]
4	Partially dried stalk.	steam distillation	Yersinia enterocolitica	Bacteria (Gram-negative)	64.49 µg/mL	71.59 µg/mL	[18]
5	Partially dried stalk.	steam distillation	Pseudomonas fluorescens	Bacteria (Gram-negative)	97.78 µg/mL	108.82 µg/mL	[18]
6	Partially dried stalk.	steam distillation	Salmonella enterica subsp. enterica serovar Enteritidis	Bacteria (Gram-negative)	86.35 µg/mL	121.31 µg/mL	[18]
7	Partially dried stalk.	steam distillation	Serratia marcescens	Bacteria (Gram-negative)	84.27 µg/mL	136.41 µg/mL	[18]
8	Partially dried stalk.	steam distillation	Pseudomonas aeruginosa	Bacteria (Gram-negative)	103.28 µg/mL	169.19 µg/mL	[18]
9	Partially dried stalk.	steam distillation	Salmonella enterica serovar Enteritidis (biofilm)	Bacteria (Gram-negative)	274.37 µg/mL	311.56 µg/mL	[18]

S.NO	Part of the plant used/ brand from which the essential oil was purchased	Extraction procedure	Micro organism	Organism type	MIC (mean ± SD)	Reference
1	Dried leaves	Steam Distillation	Streptococcus pyogenes	Bacteria (Gram-positive)	3.6 ± 0.9 µg/mL	[19]
2	Dried leaves	Steam Distillation	Streptococcus mutans	Bacteria (Gram-positive)	1.9 ± 0.2 µg/mL	[19]
3	Dried leaves	Steam Distillation	Porphyromonas gingivalis	Bacteria (Gram-negative)	32 ± 0 µg/mL	[19]
4	Dried leaves	Steam Distillation	Aggregatibacter actinomycetemcomitans	Bacteria (Gram-negative)	32 ± 0 µg/mL	[19]

Mechanisms of Antibacterial Action

The antimicrobial action of these bioactive compounds operates through several mechanisms that target essential microbial cellular processes.

Anti-biofilm activity: Compounds of this type affect biofilm formation through changes in protein architecture linked to biofilms. Because structural shifts occur, attachment at microbial surfaces becomes less effective. In place of strong bonding, weak interactions appear due to interference. Where EPS (extracellular polymeric substance) synthesis once thrived, it now declines. As a result, early development slows down. Without sufficient matrix support, growth reaches limited stages. Eventually, resilience diminishes across established communities.[18]

Membrane disruption: Hydroxyl moieties present in thymol and carvacrol engage the cytoplasmic membrane without delay. As a result, permeability shifts occur alongside disturbances in lipid arrangement together with weakening of the bilayer's structural balance. With such changes, protons enter freely where control is absent. Integrity of the membrane fades under these conditions. Cellular material escapes steadily once containment fails. Death of the cell follows as an endpoint after disruption becomes irreversible.[19]

Enzymatic and genetic disruption: Protein regulation becomes disrupted when thymol is present, while DNA synthesis slows - this limits how bacteria grow and multiply. Enzyme function weakens under influence of minor compounds like β-sesquiphellandrene;

specifically targeted are topoisomerase II along with DNA and RNA polymerases. These interactions add layers to the substance's ability to resist microbial activity.[20]

ROS-mediated oxidative stress: When exposed to thyme white essential oil, thymol, or carvacrol, Agrobacterium tumefaciens undergoes oxidative stress together with disruption of its membrane structure; imaging reveals higher levels of reactive oxygen species inside cells along with clear signs of membrane harm. Gene expression analysis shows reduced activity in manganese transporter systems - specifically sitABCD and mntH - which are required for proper superoxide dismutase performance. Because superoxide dismutase functions poorly under such conditions, the bacterium struggles to neutralize free radicals, resulting in an overload of ROS that harms internal structures, especially the inner membrane, ultimately triggering cell demise (Fig. 1.3).[21]

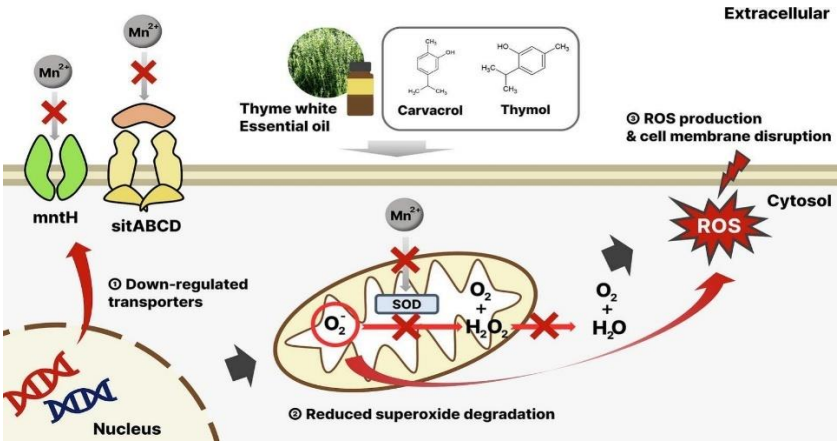


Figure 1.3: ROS-Mediated Oxidative Stress.[21]

***Salvia officinalis* L**

2.1 Introduction

Found across the globe, roughly 900 types of Salvia grow where people value them for kitchen and remedy uses.[22] Because it comes from the Latin word "salvere," meaning "to heal," the plant has carried a reputation tied to recovery since ancient times.[23]

Sage, scientifically named *Salvia officinalis* L., grows commonly around the world today despite originating in Mediterranean regions. This fragrant herb belongs to the Lamiaceae group, valued across cultures for healing, cooking, and decoration alike. Within Iran's long-standing medical practices, leaf applications address stomach troubles, gas relief, pain reduction, muscle relaxation, sleep support, bodily stimulation, urine flow increase - also applied externally to stop bleeding or assist reproductive function. Research from past

records up to recent years highlights diverse biological actions: scavenging free radicals, fighting microbes, slowing tumour growth, calming swelling, easing anxiety, lifting mood, reducing stress markers. Some evidence even points toward improved brain performance, heart protection, alertness gains, rest quality enhancement, alongside influence on conditions like Alzheimer's disease.[24]

Though rooted in Asia and Latin America, sage found purpose beyond borders - treating gout, convulsions, vertigo, joint pain, swelling, sores, shaking limbs, loss of movement, loose bowels, and high blood sugar. In Europe, healers turned to it for irritated skin and sore throats, night sweats, fading memory with age, plus indigestion marked by acid reflux or fullness - roles later echoed in Germany's official herbal guidelines on inflammation and poor digestion. Research now backs several long-standing applications, at the same time revealing new biological actions, which helps explain why S. officinalis remains visible across ancestral practices and current studies alike.[25]

Found across wild habitats, Dalmatian sage stands as one of the key economic plants within the Lamiaceae family. During the Carolingian period, monks first grew it in garden plots tied to religious sites - later spreading into broader monastic use. Its journey reached North America by the 1600s, carried along trade and migration routes. While long used for healing purposes, cooks also prize the plant for seasoning meats, thanks to its sharp scent and bold taste. On a cellular level, the species carries two sets of chromosomes (2n = 14), allowing matched pairs to align correctly - a process critical for healthy life cycles and seed production.[25]

2.2 Botanical Description

Standing up to sixty centimeters tall, *Salvia officinalis* L. grows as a long-lived shrubby plant that typically spreads through cross-pollination. Its stems rise upright, though now and then they sprawl along the ground, carrying many slender, dark green limbs clothed in soft hair. Leaves attach in pairs opposite each other on the stem, connected by short stalks. Elongated in shape most of the time, their edges come with small teeth, and the texture appears bumpy or puckered - especially noticeable when young, where tiny side lobes may appear near the base. Underneath, a thick mat of pale fuzz gives them a light-colored look; above, color shifts between deep green and tones mixed with gray.

Perched on stalks measuring 2–4 mm, blooms cluster in whorl-like groups of five to ten, shaping an elongated floral tip. About 10 to 14 millimeters in length, the calyx bristles with fine hairs and shows five clear lobes. Reaching up to nearly 35 millimeters, the petal tube most often displays hues ranging from pinkish to bluish-purple - rarely white forms appear. Blooming unfolds between March and July, timing shifting slightly with climate cues.

Apart from simple ones, glandular trichomes appear in five known forms. Small mericarps, dark brown and roundish to egg-shaped, measure roughly 2–3 millimeters. Mainly dropping near the parent plant, they spread through gravity; yet wind and rain contribute too. Their size and shape support these varied movement methods.[25]

One way to look at *Salvia officinalis* is through its genetic differences - five types were studied (108-14, 109-14, 108-14-1, 108-14-2, and 113-16) (Fig. 2.1), showing variation in shape and chemical makeup. Although most shared similar features, their internal chemistry set them apart. The type labeled 109-14 produced more essential oil than the others, whereas 113-16 fell behind. Because these plants differ so much inside and out, picking the right one matters - for growth form, overall mass, and how much oil they give.[26]

2.3. Chemical Composition of *Salvia officinalis* L

The essential oil of *Salvia officinalis* has a highly complex chemical profile dominated by volatile terpenoids, mainly monoterpenes and sesquiterpenes, which together shape its aroma, pharmacology, and biological activity. While composition varies with geographic origin, climate, harvest stage, and extraction method, certain constituents consistently dominate.

Monoterpene hydrocarbons: this fraction, primarily α-pinene and β-pinene, contributes the fresh, resinous, herbal and woody aroma characteristic of sage and is linked to its biological activities.

Oxygenated monoterpenes: the most abundant and bioactive fraction, including α-thujone, β-thujone, camphor, borneol, and 1,8-cineole, gives the oil its characteristic camphoraceous odor and is widely associated with antimicrobial, antioxidant, anti-inflammatory, and therapeutic properties. Camphor and thujone derivatives serve as key marker compounds, 1,8-cineole adds a fresh, penetrating aroma, and borneol contributes to both fragrance and pharmacological value.

Sesquiterpene hydrocarbons: constituents such as β-caryophyllene, α-humulene, elemene, humulene, ledene, and allo-aromadendrene add woody, spicy notes and depth to the oil's composition, with reported anti-inflammatory and other beneficial activities.

Oxygenated sesquiterpenes: present in smaller amounts, this group includes viridiflorol, notable for its aromatic contribution and potential biological activity.

Overall, the high proportion of oxygenated monoterpenes alongside diverse sesquiterpenes gives *Salvia officinalis* essential oil its significant medicinal, aromatic, and antimicrobial properties.[27,28,29]

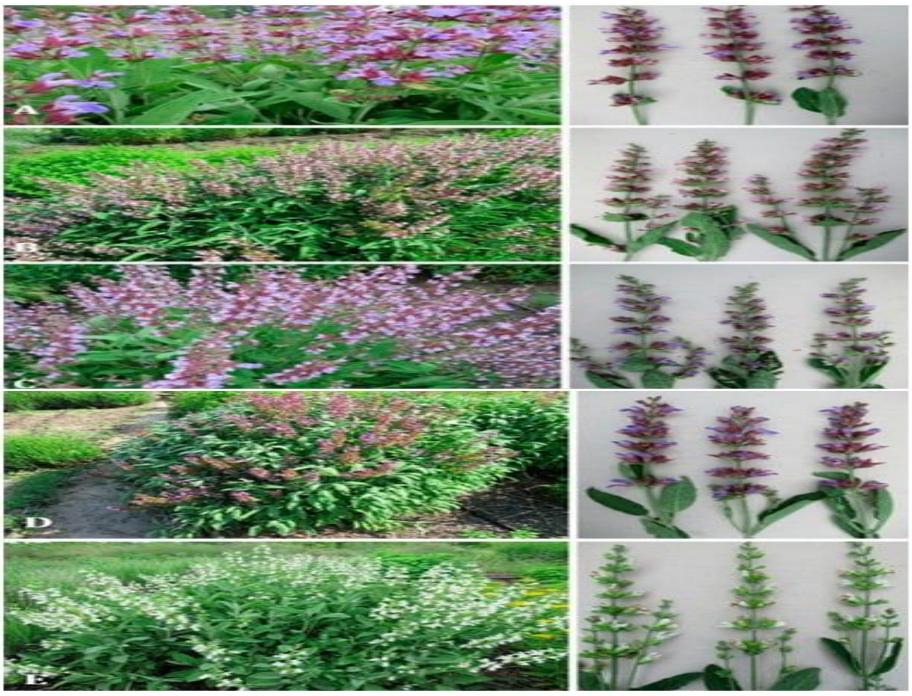


Fig 2:1 selected genotype of *Salvia officinalis* L A -108-14, B- 108-14-1, C- 108-14-2, D-109-14, E-113-16.[29]

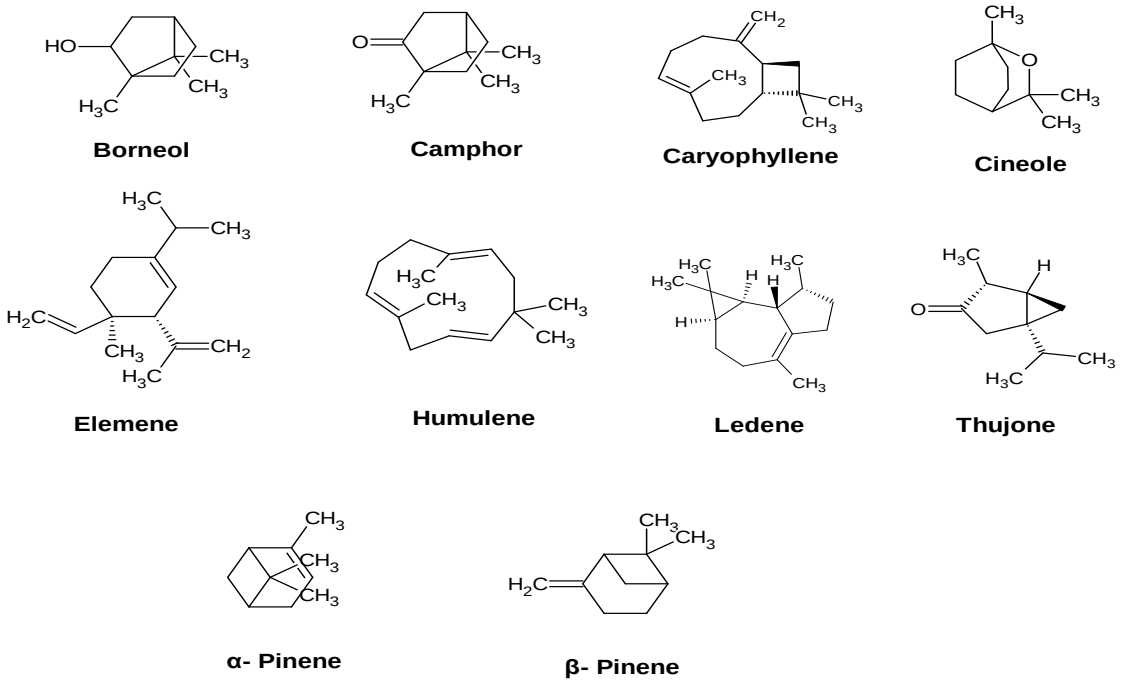


Fig 2:2: Structure of Major Volatile compounds of *Salvia officinalis* L.

2.4. Safety and Toxicity profile

Most people tolerate *Salvia officinalis* well when used moderately, though high intake brings risks. Beginning with symptoms like nausea, too much can trigger drooling or a racing heart. When consumption extends over weeks, especially using strong forms such as alcohol-based extracts, problems grow likely. Doses surpassing leaf equivalents of 15 grams may spark dizziness alongside sudden skin warmth. In rare cases, breathing slows due to bluish tinted lips or swollen mouth tissue. Despite general safety, misuse shifts outcomes toward harm rather quickly.[26]

Though generally avoided in pregnancy and breastfeeding, it may harm developing fetuses or newborns. Exposure in early childhood has led to seizure activity, even full tonic-clonic episodes. These neurological reactions often follow unintended contact with the oil. Main culprits appear to be thujone, camphor, and 1,8-cineole. Such compounds interfere with normal ion flow in nerve cells. This disruption can elevate brain cell responsiveness. Risk remains highest when oils are accessible to small hands.[30]

Starting at lower levels, exposure under 200 nl EO/ml did not trigger notable harm in newly harvested rat liver cells. In contrast, when concentration rose tenfold - to 2000 nl EO/ml - clear signs of cell injury appeared. These included greater release of LDH, pointing to compromised membranes. Alongside that, glutathione dropped sharply, signaling oxidative

strain and weakened protection systems. Overall, the pattern suggests limited risk at minimal amounts. Yet high intake may threaten liver function. Safety thus depends heavily on dosage level.[31]

Most participants using minimal amounts of essential oils near their pillows reported no troubling reactions. Though exposure lasted half an hour or more across multiple days, bodily systems like liver function and skin health remained stable. Breathing in small quantities appeared well tolerated among adult subjects. Safety signals were favorable when use stayed within defined limits. Outcomes point toward manageable risk in structured settings without intense concentration levels.[32]

2.5 Antibacterial action of *Salvia officinalis* essential oil

Assaggaf et al. (2022) found that Though antibacterial effects of *Salvia officinalis* essential oil remain strong throughout its life cycle, slight shifts appear depending on growth phase. During vegetative, early-flower, and full-flower periods, oils inhibit bacteria well - yet peak performance emerges when plants reach full bloom, seen through reduced MIC and MBC levels. Lower concentration thresholds for killing microbes mark this phase as particularly potent. Despite such trends, measured variation between stages fails to cross the threshold of statistical significance ($p \leq 0.05$). Activity stays consistent enough across development to suggest harvest timing has limited impact. Full flowering still stands out slightly, offering optimal strength where minimal dosage matters most. Because results do not differ strongly overall, usable oil comes from any point in the plant's growth. Still, maximal effect with less material occurs during complete floral expansion.[33]

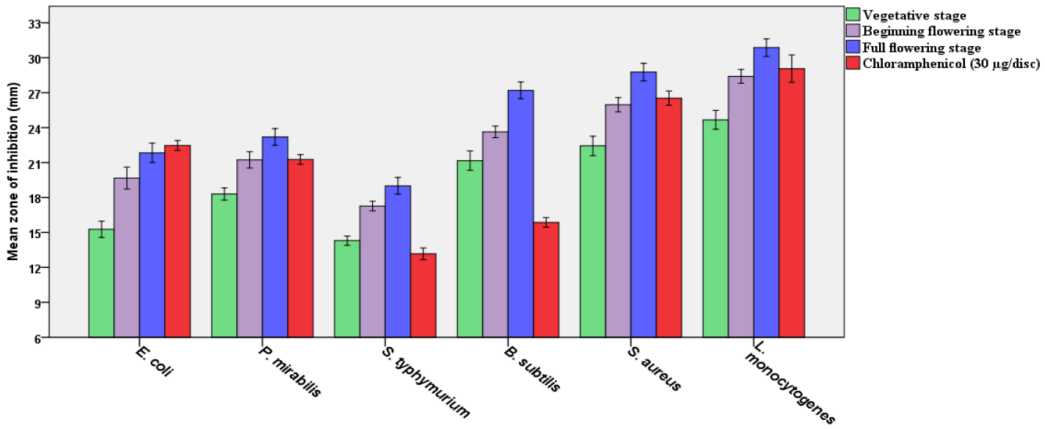


Fig 2.3: Influence of Phenological Stages on the Antibacterial Activity of *Salvia officinalis* Essential Oil.[33]

Though chemically similar through high terpene content, *Salvia officinalis* and Salvia sclarea produce distinct essential oils - camphor makes up nearly one fifth of the first, whereas linalyl acetate accounts for close to three fifths in the second. Because their chemical profiles vary so much, their effects on living systems differ too. Despite these contrasts, each shows notable ability to inhibit bacterial growth, especially where Gram-positive strains are concerned. Resistance tends to be higher among Gram-negative types. Notably, both interfere with Listeria monocytogenes, a microbe linked to contaminated foods, hinting at usefulness within food protection strategies.[34]

Milenković et al. found that leaf maturity significantly affects S. officinalis essential oil's antimicrobial activity: oils from young leaves, rich in cis-thujone, camphor, 1,8-cineole, α-humulene, and manool, showed strong inhibition of methicillin-resistant Staphylococcus aureus (MRSA), with MIC values around 25 µg/ml across most strains. Oils from older leaves showed no measurable antimicrobial activity despite higher levels of cis-thujone and camphor. Combinations with ceftriaxone and ciprofloxacin produced synergistic effects against all tested strains, while gentamicin interactions varied between synergistic and antagonistic depending on the strain.[35]

Aćimović et al. (2022) reported Steam-distilled S. officinalis essential oil mainly consists of cis-thujone, camphor, trans-thujone, along with 1,8-cineole; in contrast, its hydrolate features camphor most prominently, then cis-thujone and 1,8-cineole. Antibacterial effects were far stronger in the essential oil when compared to the hydrolate.[36]

Essential oil from S. officinalis displays clear effects on drug-resistant Klebsiella pneumoniae, yet fails against Pseudomonas aeruginosa. When paired with ceftriaxone or aztreonam, its power grows - particularly where resistance is present - pointing to joint action. That shift in performance emerges only under combination, revealing a pattern not seen alone.[37]

Among tested essential oils, S. officinalis stood out through stronger interference with microbial colonies formed by tough strains of Pseudomonas aeruginosa. Unlike Ocimum basilicum, sage-derived oil cut down biofilm development across many stubborn clinical samples. Results emerge from side-by-side analysis of plant extracts facing drug-evading bacteria isolated in medical settings. Though both oils showed some effect, reduction linked to sage was more consistent and pronounced. This pattern suggests usefulness where standard

treatments struggle - particularly in cases involving clinging bacterial layers. Because these microbes resist multiple drugs, alternatives that disrupt their protective films matter. Observations support further exploration of sage oil, not as replacement, but as complement under specific conditions.[38]

Mechanisms of Antimicrobial Action of *Salvia officinalis*

Salvia officinalis essential oil exerts antibacterial effects through several mechanisms.

Cytoplasmic membrane disruption: Because it contains fat-soluble terpenes, the substance interferes with the inner membrane of bacteria. Such interference makes the membrane more porous, allowing vital materials like genetic material to escape. As a result, cells suffer permanent harm. The weakening of membrane integrity might also boost the effects of certain antibiotics, such as oxacillin. Changes triggered by this process can influence how resistant strains handle penicillin-binding protein 2a. Together, these actions strengthen the response toward drug-resistant forms of Staphylococcus epidermidis.[39]

Enzyme inhibition: By blocking type IV topoisomerase, DNA gyrase B, dihydropteroate synthase, dihydrofolate reductase, and penicillin-binding protein 1a, the oil interferes with bacterial DNA replication. Folate pathways face disruption alongside impaired cell wall formation. As a result, bacteria struggle to grow or survive. Through these combined effects on essential enzymes, microbial viability declines.[40]

Anti-biofilm activity: The presence of oil affects how biofilms develop while also breaking down existing structures in microbes like Streptococcus pyogenes, which contributes to stronger activity toward long-lasting infections.[41]

It begins with complexity - S. officinalis fights microbes through many plant-based compounds at once, targeting several cell parts and processes. This wide reach stems not from one single agent but rather a collection working in parallel. Because of varied components interfering across different systems, effects span numerous microbe types. Efficacy spreads far due to simultaneous interactions within cells. Multiple substances contribute, each engaging distinct biological routes. Broad results emerge when natural elements act together yet independently. One compound alone does not explain strength; it comes instead from combined influence spread throughout cellular functions.

Minimum Inhibitory Concentration (MIC) of *Salvia officinalis* Essential Oil Against Selected bacteria

s.no	Part of the plant used/ brand from which the essential oil was purchased	Extraction procedure	Micro organism	Organism type	MIC (mean ± SD)	Reference
1	Leaves	Hydrodistillation	Enterococcus faecalis ATCC 29212	Bacteria (Gram-positive)	658.6 µg/mL ± 37.2	[42]
2	Leaves	Hydrodistillation	Micrococcus luteus ATCC 4698	Bacteria (Gram-positive)	128.3 µg/mL ± 9.7	[42]
3	Leaves	Hydrodistillation	Bacillus subtilis ATCC 6633	Bacteria (Gram-positive)	62.2 µg/mL ± 3.9	[42]
4	Leaves	Hydrodistillation	Streptococcus aureus ATCC 29213	Bacteria (Gram-positive)	123.5 µg/mL ± 5.7	[42]
5	Leaves	Hydrodistillation	Escherichia coli ATCC 8739	Bacteria (Gram-negative)	350.2 µg/mL ± 6.4	[42]
6	Leaves	Hydrodistillation	Klebsiella pneumoniae ATCC 10031	Bacteria (Gram-negative)	450.3 µg/mL ± 56.6	[42]
7	Leaves	Hydrodistillation	Shigella sonnei ATCC 29930	Bacteria (Gram-negative)	968.4 µg/mL ± 120.6	[42]
8	Leaves	Hydrodistillation	Agrobacterium tumefaciens ATCC 23308	Bacteria (Gram-negative)	650.7 µg/mL ± 40.8	[42]
9	Leaves	Hydrodistillation	Pseudomonas aeruginosa ATCC 9027	Bacteria (Gram-negative)	323.4 µg/mL ± 69.5	[42]
10	Leaves	Hydrodistillation	Salmonella enterica ATCC 35664	Bacteria (Gram-negative)	1,398.1 µg/mL ± 50.7	[42]
11	leaves	provided by “èssenziale – (obtained by steam distillation)	Bacillus cereus ATCC 14579	Bacteria (Gram-positive)	5.6 µg/mL ± 0.68	[43]
12	leaves	provided by “èssenziale – (obtained by steam distillation)	Staphylococcus aureus ATCC 25923	Bacteria (Gram-positive)	5.6 µg/mL ± 0.68	[43]
13	leaves	provided by “èssenziale – (obtained by steam distillation)	Enterococcus faecalis ATCC 29212	Bacteria (Gram-positive)	5.6 µg/mL ± 0.68	[43]

14	leaves	provided by “èssenziale – (obtained by steam distillation)	Micrococcus luteus ATCC 1880	Bacteria (Gram-positive)	4.6 µg/mL ± 0.03	[43]
15	leaves	provided by “èssenziale – (obtained by steam distillation)	Listeria monocytogenes ATCC 1911	Bacteria (Gram-positive)	4.6 µg/mL ± 0.03	[43]
16	leaves	provided by “èssenziale” – (obtained by steam distillation)	Pseudomonas aeruginosa ATCC 9027	Bacteria (Gram-negative)	7.5 µg/mL ± 0.00	[43]
17	leaves	provided by “èssenziale – (obtained by steam distillation)	Escherichia coli ATCC 25922	Bacteria (Gram-negative)	7.5 µg/mL ± 0.31	[43]
18	leaves	provided by “èssenziale – (obtained by steam distillation)	Salmonella enterica ATCC 43972	Bacteria (Gram-negative)	4.6 µg/mL ± 0.03	[43]

Lemon grass (*Cymbopogon citratus*)

3.1 Introduction

Lemongrass, known scientifically as *Cymbopogon citratus*, forms part of the Poaceae family - sometimes labeled Gramineae. Of nearly 180 types within its genus, this one sees more research attention than others. Its habitat spans warm zones worldwide, thriving where climate allows. From ancient Greek words comes the genus title, tied to how the blooms align along the stem.

Originating possibly in India or Sri Lanka, C. citratus grows today throughout tropical and subtropical zones around the globe - parts of the Indian subcontinent, Australia, North Africa, Europe, and the Americas - carrying different local names along the way. Used commonly in cooking to add taste to soups, curries, fish dishes, and drinks, it also appears frequently in cosmetics and industrial products.

From C. citratus, aqueous extracts along with essential oils emerge through processing of leaves, stems, and rhizomes. Despite limited focus elsewhere, research into this plant reveals activity against bacteria, fungi, protozoa - backed by observable antioxidant traits. Its compounds display properties reducing inflammation; certain ones interfere with carcinogen pathways. Notably, structural components lend themselves beyond medicine: fibers suit paper

manufacture, while residual matter feeds bioenergy systems. Silica recovery, composite development, and adsorption materials form additional outcomes. Such versatility arises not from novelty but consistent biochemical patterns across studies.[44]

Although leaves dominate usage, roots or entire plants appear less frequently within traditional medicine practices. Documentation of regional applications proceeds by focusing on how parts are prepared, which sections get selected, and whether taken orally or applied externally.

Country	Plant Part Used	Preparation / Form	Route of Administration	Use
Brazil	Leaf	Decoction	Oral	Used for the management of anxiety and epilepsy; exhibits sedative, analgesic, anti-inflammatory, antispasmodic, antipyretic, and diuretic properties.
Argentina	Leaf	Decoction	Oral	Used for sore throat, empacho, and as an emetic
India	Leaf	Infusion	Oral	Used for gastrointestinal problems
Costa Rica	Leaf	Decoction / Tea	Oral	Used to relieve cough, expectorant and depurative. It also acts as acts as carminative.
Colombia	Rhizome / Root	Chewed	Oral	Used for oral hygiene (as a toothbrush) and pest control
Ethiopia	Root	Not specified	Oral	Used for stomach-ache
Pakistan	Aerial parts	Not specified	Oral	Used as antiseptic and stomachic; also used in diuresis, rheumatism, and malaria
Indonesia	Whole plant	Hot water extract	Oral	Used as an emmenagogue
Cuba	Dried leaves	Hot water extract	Oral	Used in rheumatism and as a hypotensive agent
Egypt	Dried leaves	Hot water extract	Oral	Used as antispasmodic and diuretic
USA	Whole plant	Hot water extract	Topical	Used for wound healing and bone fractures
Thailand	Whole plant (dried)	Hot water extract	Oral	Used as an antidiabetic agent
China	Dried leaves	Infusion	Oral	Used as an anxiolytic agent

[45]

3.2 Botanical Description

Standing quite high, *Cymbopogon citratus* grows back each year without fail, forming tight clusters of pale green foliage marked by a distinct citrus aroma. From spreading underground stems, fresh shoots emerge steadily, building plant matter over time while reaching beyond two full meters upward, occupying nearly one meter across. Its slender blades, generally

between five and fifteen millimeters broad, rise sharply from base to tip. Seed formation never occurs in this type; reproduction happens only through living fragments carried forward season after season.[44]

3.3 Chemical Composition of *Cymbopogon citratus* Essential Oil

The chemical profile of *Cymbopogon citratus* (lemongrass) consists of a complex mix of volatile essential oils and non-volatile phytoconstituents. Essential oil yield from the leaves typically ranges from 0.28% to 1.4%, although yields as high as 3.0% have been reported in dried leaves subjected to hydrodistillation.

Main marker compound: Citral, comprising the isomeric aldehydes geranial and neral, is present in high concentrations ranging from 30% to 93.74%, with geranial generally dominant, and is chiefly responsible for the plant's characteristic lemon aroma and commercial value.

Terpenes and terpenoids: the essential oil contains a wide variety of terpene and terpenoid compounds, including myrcene, limonene, α- and β-ocimene, α-pinene, β-caryophyllene, phellandrene, and α-oxobisabolene, with myrcene showing notable variability (2%-25.3%), limonene occurring at 0.3%-5%, and α-oxobisabolene reaching up to 12%. Analysis of leaf wax identified two structurally related triterpenoids, cimbopogone and cimbopogonol, with cimbopogone possibly an isolation artefact while cimbopogonol is considered the true naturally occurring compound.

Alcohols: identified alcohols include volatile types such as linalool, citronellol, methylheptanol, 1,8-cineole, menthol, neomenthol, terpineol, nerol, and farnesol, along with long-chain alcohols like triacontanol, dotriacontanol, octacosanol, and hexacosanol that play structural and protective roles. Geraniol typically occurs at 1.5%-10.4%, though levels up to 40% have been reported in Ethiopian varieties, and plays a key role in both aroma and therapeutic properties.

Esters and ketones: identified esters include terpinyl acetate, geranyl formate, citronellyl acetate, linalyl formate, linalyl acetate, laurate, and geranyl acetate, with linalyl acetate present at about 2.3% contributing to fragrance and flavour; ketones such as methylheptenone (occasionally exceeding 25% depending on distillation time) and ionones (generally minor) are also present.

Flavonoids and glycosides: the plant contains flavonoids including luteolin, quercetin, kaempferol, and apigenin, with luteolin serving as a key bioactive marker with strong antioxidant properties; glycosidic derivatives such as luteolin glycosides, homoorientine, and 2-O-rhamnosyl-orientin (6-C and 7-O glycosides) also contribute to its pharmacological activities.

Phenolics and organic acids: the non-volatile fraction includes phenolic acids such as chlorogenic, caffeic, and p-coumaric acid that enhance antioxidant activity, plus elemicin, catechol, hydroquinone, and organic acids including nerolic, geranic, and valeric acid.

Other non-volatile constituents: the non-volatile fraction also contains the leaf-wax triterpenoids cimbopogone and cimbopogonol, structural sterols such as β-sitosterol, minor steroidal saponins related to fucosterol, alkaloids mainly in the rhizomes, and tannins, phosphates, nitrates, chlorides, and sugars—together contributing to the plant's overall chemical diversity and biological activity.[46]

Fig 3.1: *Cymbopogon citratus* plant.[44]

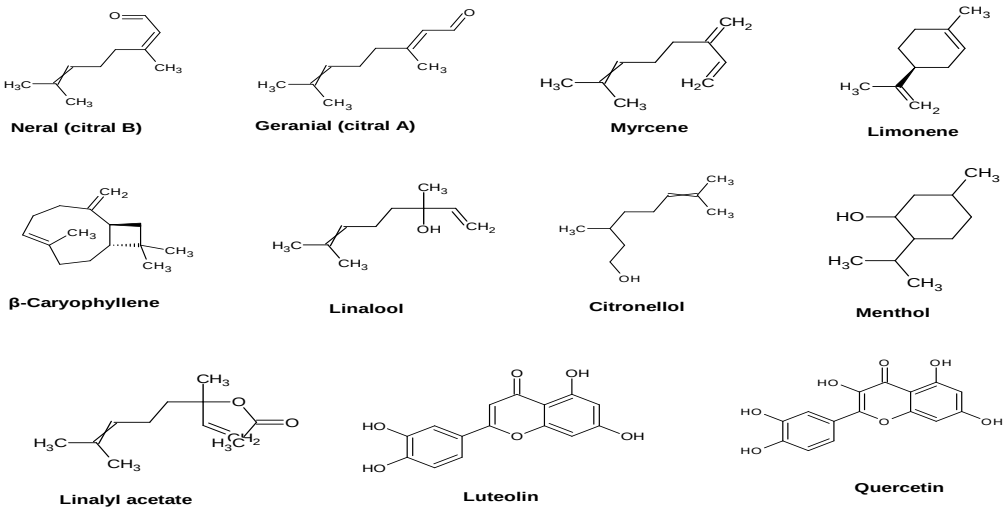


Fig 3.2: Chemical constituents of *Cymbopogon citratus.*[46]

3.4 Safety and Toxicity

Among plant-derived compounds, those from *Cymbopogon citratus* stand out when concentration increases. Higher levels bring measurable harm to cells, experiments confirm. Citral, making up between half and nearly nine-tenths of the oil, plays a central role here. As amounts rise, so does interference with normal cellular function. Evidence connects stronger doses to diminished survival rates in exposed tissues. Structural integrity of genetic material also comes under stress. Observations across trials consistently reflect these patterns.[47]

Unlike lab experiments, trials involving conventional water-based C. citratus extracts showed little shift in key health markers. Though slight rises in bilirubin and amylase occurred without symptoms, these shifts held no medical consequence. Such findings suggest typical lemongrass remedies in Brazil's traditional healing carry minimal risk when applied as usual.[48]

Moreover, analysis of DNA integrity in peripheral blood via comet assay revealed no signs of damage following exposure to C. citratus essential oil - suggesting that genotoxic activity was not present under the applied conditions.[49]

3.5 Antibacterial action of *Cymbopogon citratus* essential oil

From the range of tested preparations, *Cymbopogon citratus* essential oil demonstrated strongest antibacterial effects. Next came methanolic extracts, though their impact was less pronounced. Boiled extracts displayed no measurable activity at all. This variation arises because essential oil contains a denser level of active compounds. Extraction methods also differ: solvent-based processes preserve certain plant chemicals. Water-based boiling may degrade or fail to extract key components. Phytochemical composition thus shifts depending on preparation technique.[50]

Bassolé et al. found Essential oils from C. citratus and Cymbopogon giganteus show notable ability to inhibit microbes; together, they sometimes enhance each other, at times simply add up, or now and then make little difference when facing different bacterial strains. In a parallel case, pairing C. citratus oil with Allium cepa results in greater suppression of bacteria compared to individual applications - a result tied to varied active substances disrupting several points within microbial systems. Such mixtures may open paths toward reduced dosages, improved effectiveness, while offering one way to counter growing resistance among microorganisms.[51,52]

Valková et al. (2022) found that Despite promising results, sensory testing remains necessary to establish consumer tolerance levels. Strong antioxidant properties emerge from commercial C. citratus essential oil, primarily due to citral, geraniol, and 1,8-cineole. In practical applications, inhibition of microbial growth appears in bakery items and fresh produce when used within packaging systems. Activity extends across multiple biological pathways, including disruption of biofilm formation. Because extraction methods are straightforward, scalability presents fewer obstacles than with synthetic alternatives. Environmental impact tends to be lower compared to conventional preservatives. Broad effectiveness against various microorganisms supports its role in preservation strategies. Real-world performance in food models highlights utility for extending product freshness. While advantages exist, full integration into mainstream use requires additional study on taste thresholds.[53]

From every tested isolate, a clear pattern emerged: lemongrass oil inhibited growth more reliably than standard drugs. Resistance shaped the outcomes when typical antibiotics were applied - zones of inhibition ranged between 2 and 23 millimeters, signaling weak response. In contrast, *Cymbopogon citratus* delivered consistent results, showing effect sizes from 15 to 27 mm. Each sample reacted similarly under its influence. Where traditional treatments faltered, the essential oil maintained performance. One detail stood out - no isolate escaped its reach.[54]

From Sreepian and team comes evidence: C. citratus essential oil acts strongly on MRSA. The compound behind this effect? Citral, pinpointed as key. In various cases, isolated citral performed better than the full oil. Its dominance in action cannot be ignored.[55]

Beyond antimicrobial activity, C. citratus and its component citral modify ABC transporters and metabolic enzymes linked to drug resistance in cancer; because of this, combined application could align with established treatments. Originating from botanical sources, their influence reshapes cell behaviors that typically reduce pharmaceutical efficacy, suggesting routes uncommon in current oncology where resilience remains an issue. Rather than supplanting traditional protocols, disruption of energy-dependent efflux systems introduces a minor but notable shift - among limited options - through which plant-derived agents indirectly affect therapeutic results.[56]

Antibacterial Mechanisms of *Cymbopogon citratus* essential oil

The antibacterial mechanisms of these phytochemicals operate through several pathways.

Disruption of membrane integrity: quercetin increase flow across the inner barrier of bacteria - especially seen in Pseudomonas aeruginosa. This shift weakens electrical balance within cells, disrupting processes vital for life. As a result, stability fails, leading to functional decline.[50]

Inhibition of virulence factors: tannic acid suppresses bacterial virulence by reducing pyocyanin production and inhibiting acyl homoserine lactones (AHLs), key quorum-sensing signals involved in infection progression.[50]

Interference with protein synthesis: tannins and tannic acid precipitate proteolytic enzymes in Gram-positive bacteria, disrupting protein synthesis and inhibiting bacterial growth and proliferation.[50]

Disruption of structural stability: hydrophobic plant compounds, including various hydrocarbons, interfere with essential chemical interactions in bacterial cells, compromising structural stability and disrupting cellular organization and function.[57]

Membrane permeability disruption: lipophilic essential oil constituents interact with the bacterial membrane's lipid bilayer, increasing permeability and causing leakage of intracellular contents, leading to cellular dysfunction and death.[57]

Enzymatic system disruption: lipophilic oil components interfere with and damage bacterial enzymatic systems, impairing biochemical pathways essential for metabolism and survival.[57]

Metabolic interference: even minor structural changes to the cytoplasmic membrane caused by essential oil constituents can disrupt bacterial metabolism and macromolecule synthesis, inhibit growth and reduce cell viability.[57]

Minimum Inhibitory Concentration (MIC) of Lemon grass (*Cymbopogon citratus*) Essential Oil Against Selected bacteria

s.no	Part of the plant used/ brand from which the essential oil was purchased	Extraction procedure	Micro organism	Organism type	MIC: % (v/v)	Reference
1	Essential oil obtained from CIMAP, Lucknow	Not specified	Staphylococcus aureus	Gram-positive bacteria	0.06%	[58]
2	Essential oil obtained from CIMAP, Lucknow	Not specified	Bacillus cereus	Gram-positive bacteria	0.06%	[58]
3	Essential oil obtained from CIMAP, Lucknow	Not specified	Bacillus subtilis	Gram-positive bacteria	0.06%	[58]
4	Essential oil obtained from CIMAP, Lucknow	Not specified	Escherichia coli	Gram-negative bacteria	0.12%	[58]
5	Essential oil obtained from CIMAP, Lucknow	Not specified	Klebsiella pneumoniae	Gram-negative bacteria	0.50%	[58]
6	Essential oil obtained from CIMAP, Lucknow	Not specified	Pseudomonas aeruginosa	Gram-negative bacteria	ND (Not determined / resistant)	[58]
7	Sunspirit Oils Pty Ltd Byron Bay, NSW, Australia	Not specified	Acinetobacter baumannii	Gram-negative bacteria	0.03%	[59]
8	Sunspirit Oils Pty Ltd Byron Bay, NSW, Australia	Not specified	Aeromonas sobria	Gram-negative bacteria	0.12%	[59]
9	Sunspirit Oils Pty Ltd Byron Bay, NSW, Australia	Not specified	Enterococcus faecalis	Gram-positive bacteria	0.12%	[59]
10	Sunspirit Oils Pty Ltd Byron Bay, NSW, Australia	Not specified	Escherichia coli	Gram-negative bacteria	0.06%	[59]
11	Sunspirit Oils Pty Ltd Byron Bay, NSW, Australia	Not specified	Klebsiella pneumoniae	Gram-negative bacteria	0.25%	[59]
12	Sunspirit Oils Pty Ltd Byron Bay, NSW, Australia	Not specified	Pseudomonas aeruginosa	Gram-negative bacteria	1.00%	[59]
13	Sunspirit Oils Pty Ltd Byron Bay, NSW, Australia	Not specified	Salmonella typhimurium	Gram-negative bacteria	0.25%	[59]
14	Sunspirit Oils Pty Ltd Byron Bay, NSW, Australia	Not specified	Serratia marcescens	Gram-negative bacteria	0.25%	[59]
15	Sunspirit Oils Pty Ltd Byron Bay, NSW, Australia	Not specified	Staphylococcus aureus	Gram-positive bacteria	0.06%	[59]
16	Sunspirit Oils Pty Ltd Byron Bay, NSW, Australia	Not specified	Candidia albicans	Gram-positive bacteria	0.06%	[59]

CONCLUSION

Thymus vulgaris, *Salvia officinalis*, and *Cymbopogon citratus*, essential oils display strong antibacterial effects across many types of bacteria, both Gram-positive and Gram-negative, even those resistant to multiple drugs. Because these oils contain diverse plant-based

chemicals - especially phenolics and terpenoids - their impact arises via varied simultaneous actions on vital bacterial cell structures and processes.

These medicinal plants collectively serve as rich sources of natural antimicrobial compounds, offering potential substitutes for standard antibiotic treatments. Given the increasing worldwide prevalence of resistant microbes and stubborn infections that defy typical therapies, interest in such botanical resources has grown stronger. Essential oils extracted from them emerge prominently within current research efforts aimed at crafting new methods to combat pathogens, suggesting a shift toward innovative treatment designs rooted in plant chemistry.

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