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The therapeutic symphony of thyme: A natural elixir and its crucial role in aromatherapy

P. M. Usha Nandhini*, K. Kalpana◆, J. Rajangam***, A. Beaulah*, S. Jaya Prabhavathi**** and Medari Sagarika*******

* *Department of Postharvest Technology, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, Theni -625 604, Tamil Nadu, India*

** *Department of Plant Protection, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, Theni-625 604, Tamil Nadu, India*

*** *Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, Theni-625 604, Tamil Nadu, India*

**** *Tapioca and Castor Research Station, Tamil Nadu Agricultural University, Yethapur-636 119, Tamil Nadu, India*

***** *Department of Plant pathology, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai-625 104, Tamil Nadu, India*

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Abstract

In an era marked by rising stress, chronic illnesses, and a growing demand for natural remedies, the exploration of plant-based therapeutics has gained significant momentum. Among these, thyme (*Thymus vulgaris* L.) emerges as a powerful botanical with a diverse range of therapeutic properties, making it especially valuable in the realm of aromatherapy. As the world shifts towards holistic wellness, thyme stands at the intersection of tradition and science, offering a harmonious and evidence-based approach to enhancing physical, mental, and emotional well-being through aromatherapy. The synergistic effects of its bioactive compounds are explored, alongside their mechanisms of action within the human body. By connecting ancestral plant knowledge with modern scientific methodology, thyme represents an important botanical resource bridging conventional aromatherapy practices and evidence-supported healthcare approaches, deserving further clinical exploration. This review highlights thyme essential oil which is rich in thymol, carvacrol, and linalool, their scientifically supported roles in promoting mental clarity, reducing anxiety, alleviating respiratory conditions, supporting immune function and against plant pathogens.

1. Introduction

Consumer demands are rising these days for foods that have herbal ingredients and other components that may offer health advantages beyond simple nourishment. They serve as a practical means of consumption in addition to being an appropriate medium for the dissolution of functional components (Nanasombat *et al*., 2015). Originally from Europe, North Africa, and Asia, thymus is an evergreen perennial herb that belongs to Lamiaceae family commonly referred to the mint family, comprises approximately 350 species and 36 subspecies. Wild thyme (*T. serphyllum*) is a native related to each cultivated plant species (Jalas, 1971) and the most common and widely utilized plant for thyme essential oil is garden thyme, or *T. vulgaris*. One of the characteristics that distinguishes the genus thymus apart is its leaf shape. Usually small (less than 1/8 inch long and 1/16 inch wide), the leaves are elliptic and narrow, with a greenish-gray hue, and they are arranged in whorled phyllotaxy. The whorls of thyme flowers, which end branches, can be white, yellow, or purple. The following are among the commonly used thyme cultivars for extraction of essential oil such as *T. zygis*, *T. rumidicus hispánicos*, *T. hyemalis*, *T. citríodotus*, *T. vulgaris*, *T. mastichina*, *T. loscossi*, *T. communis*, *T. corydothymus* and *T. pipirella*.

Thyme, an herbaceous plant of the platoon species, grows in mountainous areas and is commonly used in folk medicine to treat mouth infections, stomach, intestine, and airways, coughing, gastroenteritis, and intestinal worms. It is also used to strengthen the heart through its ability to lower cholesterol, regulate blood pressure, and reduce inflammation, all of which can contribute to heart health (Mohamed *et al*., 2013). Thyme extracts have been used in traditional medicine to treat a range of respiratory conditions, including bronchitis and asthma, as well as other illnesses because of their antiviral, antiseptic, antispasmodic, antitussive, antimicrobial, antifungal, and antioxidant qualities (Ocana and Reglero, 2012). There are at least 70 distinct species that make up thyme oil (Pandur *et al*., 2022). Thymol constitutes one of the many prevalent molecular species among thyme oil in species including *T. vulgaris* and *T. magnus* Nakai. It is also the most investigated and has been demonstrated to have a variety of medicinal effects, including antibacterial, antitumor, antifungal, antiparasitic, antioxidant, and anti-inflammatory properties. P-cymene, another chemical contained in thyme oil at rather high concentrations, has antiviral, antioxidant, and antitumoral effects, particularly when conjugated to Ruthenium (Salimi *et al*., 2022). As a component of Australian tea tree oil, γ-terpinene, another common component of thyme oil, is a member of chemical class and

Corresponding author: Dr. K. Kalpana
Associate Professor, Department of Plant Protection, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, Theni-625 604, Tamil Nadu, India
E-mail: kalpana.k@tnau.ac.in
Tel.: +91-9994387816

has been demonstrated to prevent the growth of helminthic and protozoan infections (Lam *et al.*, 2022). In addition to thyme oil, essential oils from pepperwort, wild bergamot, and oregano contain carvacrol. The relative abundance of this species might vary significantly depending on its origin. Additionally, thyme oil contain (E)-β caryophellene, which has anti-inflammatory and proapoptotic effects on tumor cells (Dahham *et al.*, 2021). Together with thymol and carvacrol, (E)-β caryophellene exhibits antibacterial growth characteristics. Another component of thyme oil is linalool, a terpene alcohol that is also present in flowers and spices. Linalool displays antioxidant effects and reverses oxidation.

Understanding the therapeutic potential of thyme in aromatherapy is vital as it bridges ancient herbal wisdom with modern holistic wellness. Thyme's essential oil, rich in bioactive compounds, plays a crucial role in enhancing physical and emotional health through natural means. Its antibacterial, antifungal, and mood-boosting properties make it a versatile tool in stress relief, immune support, and respiratory care. As people increasingly seek alternatives to synthetic treatments, exploring thyme's benefits provides insight into sustainable, plant-based healing. Highlighting its importance helps promote natural remedies that align with the body's rhythms, offering a gentle yet effective path to overall well-being and balance.

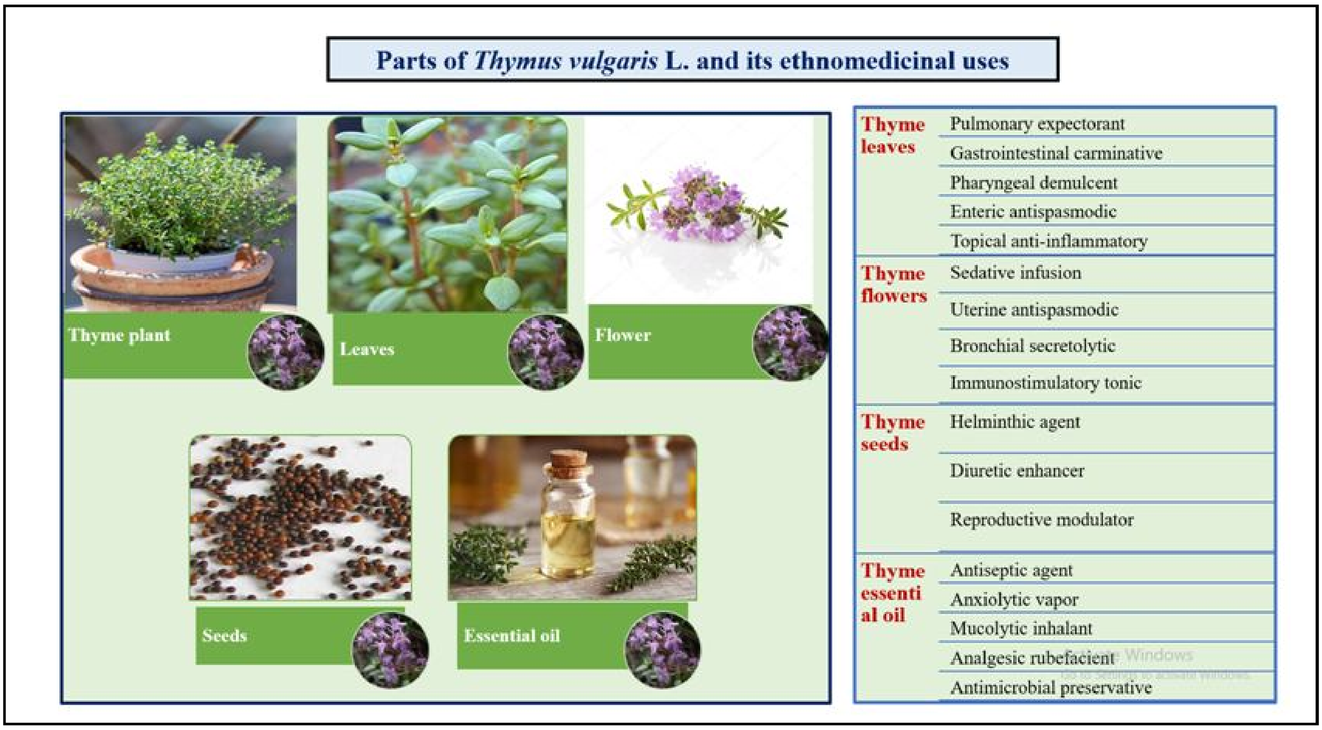

Figure 1: Overview of thyme and its ethnomedicinal uses.

2. Authentication of plant material

Botanists from Gandhigram Rural Institute, Gandhigram, Dindigul, conducted the entire botanical authentication and identified the plant specimen as *Thymus vulgaris* L. The Voucher Specimen is Catalogued and stored at the GUD Herbarium.

3. Phytochemical profile and essential oils of thyme

Extensive research has been carried out on different thyme species to analyze their chemical composition. Thyme is rich in various chemical constituents (Table.1) and essential oils, with its composition influenced by environmental factors such as climate and geographic location. Studies have shown that thyme is composed predominantly of monoterpenes (56.53%), followed by monoterpene hydrocarbons (28.69%), sesquiterpene hydrocarbons (5.04%), and a smaller proportion of oxygenated sesquiterpenes (1.84%) (Almanea *et al.*, 2019). Thyme is a valuable source of various flavonoids and phenolic antioxidants, including zeaxanthin, lutein, apigenin, naringenin, luteolin, and thymonin (Dauqan and Abdullah, 2017). Fresh thyme is recognized for its remarkably high antioxidant capacity and is also abundant in essential vitamins and minerals that contribute to overall health. The leaves are particularly rich in elements such as potassium, iron, calcium, manganese, magnesium, and selenium. Thymol, the predominant compound in thyme essential oil, is a significant phenolic molecule primarily responsible for its antioxidant properties. Furthermore, the flowering stems of thyme contain flavonoid derivatives like apigenol and luteolol, along with phenolic acids such as caffeic and rosmarinic acids, as well as tannins (Jaafari *et al.*, 2007).

Capillary electrochromatography coupled with diode array detection (CEC-DAD) and liquid chromatography-tandem mass spectrometry (LC-MS/MS) have identified thymol and carvacrol as predominant constituents in thyme (Micucci *et al.*, 2020). Regardless of the analytical method employed, certain chemical constituents are consistently detected across various *thymus* species, albeit in differing concentrations. Modern analytical investigations into thyme's volatile profile have identified specific chemotypes with varying therapeutic applications in aromatherapy, suggesting personalized approaches based on individual constituent ratio (Rajput *et al.*, 2018).

Table 1: Nutritional profile of *T. vulgaris*

Proximate composition		Phytochemical constituents	
Moisture	65.11 g/100 g	Total phenolics	1123.5 mg GAE/100 g
Total protein	9.11 g/100 g	Total flavonoids	432.6 mg QE/100 g
Total lipids	7.43 g/100 g	Thymol	38.54 mg/g dry weight
Carbohydrates	24.45 g/100 g	Carvacrol	15.72 mg/g dry weight
Dietary fiber	14.05 g/100 g	Rosmarinic acid	22.36 mg/g dry weight
Ash	3.91 g/100 g		
Energy	276 kcal/100 g		
Mineral composition		**Vitamin content**	
Calcium (Ca)	405.87 mg/100 g	Vitamin C	160.15 mg/100 g
Potassium (K)	814.54 mg/100 g	Vitamin A	238.10 ìg/100 g
Phosphorus (P)	106.25 mg/100 g	Vitamin E	7.48 mg/100 g
Magnesium (Mg)	160.54 mg/100 g	Thiamin (B1)	0.08 mg/100 g
Iron (Fe)	17.45 mg/100 g	Riboflavin (B2)	0.40 mg/100 g
Zinc (Zn)	6.18 mg/100 g	Niacin (B3)	1.82 mg/100 g
Manganese (Mn)	4.70 mg/100 g		
Copper (Cu)	0.86 mg/100 g		
Sodium (Na)	55.13 mg/100g		

Source: Halat *et al*., 2022; Reddy *et al*., 2014; Satyal *et al*., 2016.

4. Therapeutic insights

The following review provides an overview of the key biological and therapeutic effects of thyme and its primary bioactive constituents, emphasizing its anticancer, antioxidant, anti-inflammatory and antimicrobial activities.

4.1 Antioxidant activity

Oxidation is a chemical process where electrons or hydrogen atoms are transferred from a substance to an oxidizing agent. Lipid oxidation is a significant challenge encountered during food processing, storage, and consumption, leading to the formation of reactive oxygen species (ROS) and free radicals that initiate chain reactions (Zaborowska *et al*., 2014). The antioxidant properties of thyme extracts are largely attributed to their high content of phenolic compounds, which act as free radical scavengers, metal ion chelators, and inhibitors of oxidative enzymes (Yanishlieva *et al*., 1999). Numerous *in vitro* and *in vivo* studies have demonstrated the antioxidant activity of thyme. For example, research on *T. vulgaris* revealed its significant antioxidant potential, likely due to elevated levels of total phenols and flavonoids. The phenolic compounds in thyme are primarily responsible for these effects due to their redox properties, which neutralize free radicals, quench singlet and triplet oxygen, and decompose peroxides. Furthermore, research by Tohidi *et al*. (2017) evaluated thyme species collected from different regions of Iran and found *T. vulgaris* to exhibit superior antioxidant activity compared to other species, as confirmed by DPPH and reducing power assays. Roby *et al*. (2013) also demonstrated that thyme methanol extract exhibited the highest antioxidant activity among several plants, outperforming sage, marjoram, α-tocopherol, and BHA.

Zaborowska *et al*. (2014) found that ethanol extracts of thyme could significantly prolong the stability of sunflower oil, suggesting its potential as a stabilizing antioxidant. Similarly, El-Guendouz *et al*. (2019) assessed thyme waste extract in oil in water emulsions and revealed that it prevented both primary and secondary lipid oxidation products over a 10 week period, maintaining viscosity without interfering with the emulsion's properties. Optimal protection was achieved with higher concentrations of thyme extract (0.02% - 0.04%) combined with almond oil ($\leq$50%). El-Nekeety *et al*. (2011) investigated the antioxidant effects of *T. vulgaris* oil in rats exposed to aflatoxin-induced oxidative stress and found that the oil treatment significantly improved various oxidative stress markers, with greater effects observed at higher doses.

Recent studies by Gursul *et al*. (2019) explored the use of thymol and carvacrol as antioxidants in microencapsulated walnut oil, showing that these compounds reduced oxidation and improved oil storability by stabilizing lipid radicals. Lukic *et al*. (2020) assessed the antioxidant activity of films impregnated with thymol (27.5%), carvacrol (21.2%), and their combination (21.5%) using a DPPH assay, finding that the combined thymol-carvacrol films exhibited superior antioxidant activity, likely due to synergistic interactions and enhanced reducing power, ensuring good storage stability. Additionally, research by Güvenç *et al*. (2019) investigated the impact of thymol and carvacrol on oxidative stress and antioxidant systems in rats and found that these compounds decreased oxidative damage and enhanced sperm quality.

4.2 Anti-inflammatory activity

Inflammation is a complex physiological response aimed at protecting body tissues from harmful stimuli such as pathogens and cellular injury. Traditionally, thyme and its derivatives have been utilized globally for managing inflammatory conditions, several studies also evaluated the molecular mechanisms underlying thyme's anti-inflammatory activity and numerous scientific investigations have confirmed the anti-inflammatory efficacy (Lorenzo *et al*., 2019).

Thyme extracts were shown to exert a dose-dependent inhibitory effect on the production and gene expression of key proinflammatory cytokines-TNF-α, IL-1β, and IL-6-in oxidized LDL-stimulated THP-1 macrophages, while simultaneously enhancing the secretion of the anti-inflammatory cytokine IL-10. In an *in vivo* model of rheumatoid arthritis in rats, Golbahari *et al*. (2019) examined the effects of thymol and nicotine, individually and in combination. Both compounds reduced proinflammatory cytokines (TNF-α, IL-6, IFN-γ, IL-1β, IL-17), while their combination achieved a more substantial decrease in IL-1β, IL-17, C-reactive protein, and myeloperoxidase levels. Further investigations using a murine pleurisy model found that thyme essential oil significantly reduced exudate accumulation and leukocyte migration following carrageenan injection, particularly at higher doses. In contrast, standard anti-inflammatory drugs such as indomethacin and celecoxib decreased exudate volume but not leukocyte infiltration. Additionally, thyme essential oil demonstrated effectiveness in reducing paw edema and neutrophil infiltration in zebra fish, further confirming its anti-inflammatory potential (Abdelli *et al*., 2017).

The aqueous extract of *T. vulgaris* was also found to significantly inhibit nitric oxide production induced by LPS and IFN-β in the J774A.1 murine macrophage cell line. This effect was mediated through the downregulation of iNOS mRNA expression and direct scavenging of NO radicals, suggesting both transcriptional and antioxidant mechanisms. Moreover, in U937 human macrophage-like cells, carvacrol a major constituent of thyme oil exhibited anti-inflammatory activity by suppressing LPS-induced COX-2 mRNA and protein levels, an effect attributed to its activation of the PPARγ signaling pathway (Vigo *et al*., 2004). Collectively, these findings highlight thyme's robust anti-inflammatory properties, mediated through multiple pathways including cytokine modulation, enzyme inhibition, and oxidative stress reduction.

4.3 Antineoplastic activity

Cancer is recognized as a primary contributor to mortality following cardiovascular diseases. Mutations or alterations in the DNA sequence can disrupt the normal functioning of cells, triggering their transformation and the onset of malignant growth (Usha nandhini *et al*., 2024). Current anticancer treatments like chemotherapy, while effective, often damage healthy tissues due to their high toxicity. One such medicinal plant, thyme, contains potent bioactive substances, especially carvacrol and thymol. These molecules have shown significant potential to combat various malignancies (Salehi *et al*., 2018). Their biological effects include promoting programmed cell death, halting tumor cell multiplication, disrupting mitochondrial function, raising reactive oxygen species levels, and inhibiting new blood vessel formation necessary for tumor growth. Animal and laboratory studies involving thyme showed marked tumor reduction in breast cancer models, alongside lowered activity of cancer-related markers like VEGFR-2, CD44, and ALDH1A1. It also decreased oxidative stress markers and increased pro-apoptotic proteins such as Bax (Kubatka *et al*., 2019). The plant's extracts showed effectiveness against colon, lung, and blood cancers, and also regulated key molecular processes like interferon and ERK5 signaling (Sertel *et al*., 2011).

Thymol, one of the active components, demonstrated strong cell-killing abilities in multiple cancer types affecting breast, lung, prostate, brain, and gastric cancers. Interestingly, it protected healthy cells at low concentrations while selectively targeting cancer cells. It activated cell death processes *via* oxidative stress and mitochondrial dysfunction. In bladder cancer models, it blocked the cell cycle at a specific stage and initiated apoptosis through mechanisms involving caspases and stress-related pathways. Carvacrol displayed even stronger anticancer effects, surpassing thymol in potency (Jamali *et al*., 2018). It effectively reduced the survival and spread of cancer cells across several tumor types including gastric, colon, breast, lung, and prostate. It works by disrupting mitochondrial balance, modifying key proteins involved in survival and apoptosis, and interfering with pathways like TRPM7 and AXL (Li *et al*., 2021).

4.4 Immunomodulatory activity

Thymol, a naturally occurring monoterpenoid extracted from thyme, has been identified to have substantial effects on the immune system, influencing both its innate and adaptive components. Investigations have demonstrated that this compound enhances early immune responses by activating phagocytic cells, especially macrophages, largely through increasing the fluid nature of cell membranes, which subsequently supports this activity (Gierlikowska *et al*., 2021). With regard to its impact on the adaptive immune arm, thymol appears to interfere with the overexpression of T-helper type 2 cytokines, particularly in experimental models of allergic airway disease. This modulation leads to decreased airway reactivity and inflammation, underscoring its role in balancing immune responses in conditions like asthma (Mousa *et al*., 2021). Further mechanisms of action include suppression of the MAP kinase cascade and NF-κB transcriptional activation two critical routes in propagating inflammatory signals. These effects not only help in reducing overactive immune responses but also suggest a role for thymol in managing conditions associated with immune system imbalances. As highlighted by Kowalczyk *et al*. (2020), the compound's influence on immune regulation presents a promising approach for addressing both immune deficiencies and autoimmune pathologies. Continued research is needed to confirm these effects in clinical practice and assess long-term safety and efficacy.

4.5 Antitussive activity

The muscle-calming and cough-suppressing characteristics of *T. vulgaris* have been chiefly linked to its core chemical agents, carvacrol and thymol, as highlighted by Basch *et al*. (2004). Furthermore, controlled laboratory testing has revealed that both essential oil and extract forms of thyme exhibit inhibitory actions on contractions within isolated muscle tissues from the ileum and trachea. Such relaxation effects point to the potential role of flavone aglycones, non-sugar flavonoid derivatives as key players in these pharmacodynamic processes, as indicated in the findings of Gairola *et al*. (2010). Overall, these studies support the long standing herbal use of thyme for conditions involving respiratory or digestive tract spasms. The plant's unique combination of volatile oils and secondary metabolites appears to influence biochemical pathways involved in smooth muscle tone regulation. This supports its application in traditional medicine as a natural agent for easing cough and reducing involuntary muscular contractions.

4.6 Antinociceptive activity

The pain-relieving and numbing effects of thyme-derived substances have been evaluated in both laboratory and live-animal studies. A clinical investigation focused on women with primary menstrual cramps explored the effectiveness of herbal interventions compared to standard medication (Moghadam and Khosravi, 2012). Pain levels were assessed using a visual scoring system that quantifies discomfort. Findings indicated that both treatment approaches, herbal and pharmaceutical produced similar reductions in menstrual discomfort, showing no significant difference in efficacy between the two groups (Sajed *et al*., 2013). The herbal formula's impact is likely linked to two primary mechanisms. First, its anti-inflammatory potential may result from the suppression of prostaglandin biosynthesis. Second, it may relax smooth muscle tissues, thus limiting uterine cramping, as supported by Iravani (2009). These actions reflect its antispasmodic and prostaglandin-inhibitory properties.

4.7 Antimicrobial activity

4.7.1 Antibacterial activity

T. vulgaris, commonly recognized for its aromatic and medicinal properties, is increasingly being studied as a renewable reservoir of natural antibacterial agents. The species is especially relevant in the context of escalating antimicrobial resistance (AMR), which has emerged as a critical health issue worldwide. In 2019 alone, resistant bacterial infections were linked to approximately five million deaths, most severely affecting under-resourced areas. The primary pathogens implicated in resistance-related fatalities include *E. coli*, *S. aureus*, *K. pneumoniae*, *S. pneumoniae*, *A. baumannii*, and *P. aeruginosa* (Salehi *et al*., 2022). Progress in creating new antimicrobial treatments has been slow, leaving a significant void in the fight against resistance. Therefore, plant-derived compounds, particularly those with historical medicinal use, are being explored as potential alternatives. Thyme, used since ancient times and documented in traditional remedies for infections like malaria and bronchitis, has shown strong antibacterial properties. The British Herbal Pharmacopoeia notes its application for ailments such as whooping cough and sore throats, often in combination with other botanicals.

The key to thyme's effectiveness lies in its volatile oils particularly thymol and carvacrol. These phenolic substances contribute substantially to its antimicrobial strength. Historical interest in these oils dates back over a century. In one recent investigation, researchers tested *T. vulgaris* oil against reference bacterial strains, observing high effectiveness against *S. aureus* and *K. pneumoniae*, with other strains showing dose-responsive inhibition. This confirms its promise for both therapeutic and food safety use. Studies targeting *E. coli* O157:H7 found thyme essential oil to be active across a range of conditions, particularly when used with stabilizers like agar (Burt and Reinders, 2003). Enhanced forms, such as nanoemulsions, have successfully been employed to cleanse vegetables of bacterial contaminants. A combination of thyme oil with the natural bacteriocin enterocin A resulted in a synergistic antimicrobial action, effective against *L. monocytogenes* and *E. coli* O157:H7 (Ghrairi and Hani, 2015). This approach may not only improve safety but also limit resistance development and maintain flavor in foods. Applications of thyme oil have expanded to meats and cheeses, providing protection against bacterial threats including vancomycin-resistant *Enterococcus* (Selim *et al*., 2011). Among multiple essential oils analyzed, thyme, cinnamon, and oregano oils displayed top efficacy against spoilage and foodborne pathogens. Beyond the food industry, thyme oil has been tested against hospital-acquired bacterial infections. It inhibited the growth of clinical isolates from diverse infections, showing broad-spectrum activity against both Gram-negative and Gram-positive bacteria. Its efficacy even surpassed other plant oils when tested on clinical *E. coli* strains.

Thyme oil interaction with traditional antibiotics is also of interest. It significantly reduced the effective dose of colistin against both resistant and susceptible strains of *A. baumannii* and *K. pneumonia* (Ucha *et al*., 2020). In combination with tea tree oil, it increased the potency of urinary tract medications like fosfomycin, suggesting a role in multidrug regimens (Loose *et al*., 2020). A thyme and clove-based nano-emulgel formulation showed potential as a treatment for acne and skin infections, demonstrating antibiofilm properties and improving skin health in animal trials.In the agricultural sector, a recent application involved the use of thyme oil microemulsion to combat *Salmonella enteritidis* in poultry (Hamed *et al*., 2022). The intervention significantly lowered infection rates and bird mortality, showcasing its utility as a cost-effective farming aid.

4.7.2 Antifungal activity

Thyme possesses strong antifungal capabilities, largely attributed to the presence of phenolic elements like thymol and carvacrol (Arras and Usai, 2001). Thymol, in particular, has been known for over twenty years as an effective compound in preventing fungal development in fruit. A notable fungal threat in healthcare is *Candida*, especially *C. albicans*, which can cause both non-invasive and systemic infections, with the latter posing significant health risks (Pristov and Ghannoum, 2019). As drug resistance to commonly used antifungals such as azoles and echinocandins grows, alternative solutions like thyme are gaining attention. Research shows that thyme oil can suppress growth and reproductive structures in resistant *C. albicans* strains and even performs better than fluconazole in certain cases (Pereira *et al*., 2021). Its effects also include inhibition of germ tube formation, changes in cell structure, and disruption of biofilm generation key elements in fungal pathogenicity. Additionally, thymol has demonstrated the ability to work in conjunction with antifungal drugs to improve their effectiveness, while also directly altering fungal metabolism and reducing energy-producing processes within cells. According to research conducted by Ben Jabeur *et al*. (2015), the application of thyme oil resulted in a 64% reduction in *Botrytis cinerea* infection on tomato foliage and a 30.76% decrease in the severity of Fusarium wilt. Their experiments indicated that the oil stimulated greater peroxidase enzyme activity, hinting at the activation of the plant's defensive mechanisms, commonly known as systemic acquired resistance. The investigators concluded that thyme oil holds promise as a biological means of plant disease control.

Beyond *Candida*, thyme has shown potential against other fungal species, particularly those in the *Aspergillus* genus, which are known not only for infections but also for creating harmful toxins like aflatoxins (Schubert *et al*., 2021). In laboratory studies, thyme oil triggered programmed cell death, damaged cellular membranes, and lowered the production of these toxins by *A. flavus*, also reducing the expression of key virulence genes. In tests against indoor fungal species, a combination of thyme and lemongrass oils was the most powerful pairing, especially in suppressing *A. fumigatus* (Hlebova *et al*., 2021). Compared to the full essential oil, thymol alone was three times more effective in preventing mold growth, with lasting suppression observed in various household mold types, including *Penicillium*, *Rhizopus*, and *Cladosporium*. This supports its usefulness in mold control, especially in moisture-prone indoor spaces. Thyme also aided in treating *Cryptococcus neoformans*, a yeast that affects the respiratory and nervous systems in vulnerable individuals (Scalas *et al*., 2018). This evidence (Table 2) supports thyme's adaptability and low-cost potential as a treatment for both human infections and environmental decontamination. Considering the increase in resistance to synthetic antifungal drugs, the growing body of research underscores thyme's value as a natural and flexible antifungal option with wide-reaching implications in healthcare and agriculture.

4.7.3 Antiviral activity

Extracts derived from thyme, particularly those from the *Lamiaceae* family, have been studied for their virus-fighting capabilities. Aqueous form of thyme extract could hinder both HSV-1 and HSV-2 activity in cultured cells (Nolkemper *et al*., 2006). The extract's effectiveness was limited to early stages of viral invasion, specifically before the virus adhered to host cells, with no noticeable effect once the virus entered the cells. These findings suggest possible benefits of thyme for topical treatment against recurring herpes outbreaks. More recently, Toujani *et al*. (2018) confirmed these results, noting that an ethanol-based extract of thyme exhibited even greater antiviral strength. This form directly neutralized HSV-2 particles outside of host cells, preventing the virus from spreading further. In studies involving respiratory illnesses, thyme extracts were evaluated against viruses like rhinoviruses and influenza. While the extract showed little impact on rhinoviruses, it effectively reduced influenza-induced cellular damage in a concentration-dependent way without harming healthy cells (Walther *et al*., 2020). Additionally, some investigations suggest that thyme may also affect HIV-1 by targeting its critical biological pathways, indicating broader antiviral potential.

With the emergence of COVID-19, natural substances gained attention as possible alternatives or complementary treatments for SARS-CoV-2. The U.S. Environmental Protection Agency (EPA) included thymol, a primary compound found in thyme, on its official list of disinfectants proven to help manage the spread of COVID-19 on hard surfaces and skin. These possibilities underline the role thyme may play in future antiviral strategies, both as a preventative and a treatment. The consistent efficacy of thymol in interfering with viral function emphasizes its value in the fight against contagious diseases like COVID-19 (Catella *et al*., 2021). Carvacrol, another key element present in thyme oil, has also attracted interest for its possible role in managing COVID-19. It is known for its antioxidant strength and capacity to support immune system responses mentioned in Table.2. These traits may help the body to resist viral infection by interfering with the angiotensin-converting enzyme 2 (ACE2) receptors, which SARS-CoV-2 uses to enter human cells (Javed *et al*., 2021). Carvacrol has also shown potential to bind directly to viral enzymes and the spike protein, disrupting the virus's ability to attach and infect. Meanwhile, computer-based modeling has supported thymol's ability to interact with the spike protein's receptor-binding domain, an important target in antiviral drug development (Kulkarni *et al*., 2020). These molecular interactions suggest that thymol could act as a natural blocker, preventing viral particles from binding to host cells. Altogether, compounds from thyme, including thymol and carvacrol, demonstrate promising antiviral action and could be considered in the design of future plant-based antiviral medications.

Table 2: Antimicrobial efficacy of thyme-target pathogens, mechanisms of action, and therapeutic performance

Antimicrobial class	Active substances	Affected microorganisms	Action pathways	Performance characteristics	References
Bacterial control	Thymol and carvacrol	**Gram+**: *Staphylococcus aureus*, *Streptococcus species*, Enterococcus with vancomycin resistance **Gram-**: *E. coli* O157:H7, *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, *Listeria monocytogenes*, *Salmonella enteritidis*	Cell wall structural compromise, Growth inhibitory effects, Prevention of biofilm development	Effectiveness varies with concentration, better results in nano-emulsified preparations, works cooperatively with enterocin A lowers necessary amounts of traditional antibiotics including colistin and fosfomycin	Salehi *et al.* (2019); Khan *et al.* (2021)
Fungal inhibition	Thymol and carvacrol	**Yeasts**: Various *Candida* species (including resistant *C. albicans* strains), *Cryptococcus neoformans* **Molds**: *Aspergillus flavus, Aspergillus fumigatus, Penicillium species, Rhizopus species, Cladosporium species* **Dermatophytes**: *Trichophyton* species, *Microsporum* species	Blocks germination tube creation, Modifies cellular organization, Destroys existing biofilms, Promotes cell death pathways, Damages membrane structure, Affects calcineurin pathway function, Decreases ergosterol synthesis, Limits virulence factor expression	Outperforms fluconazole against certain resistant *Candida* variants, enhances conventional antifungal medication effects, maintains long-term suppression of household fungi, decreases aflatoxin production levels,higher potency when nano-emulsified	Tullio *et al.* (2007); Khan *et al.* (2018)

Viral suppression	Thymol, Carvacrol, Water-based extracts, Alcohol-based extracts	**DNA viruses:** Herpes simplex 1 and 2 RNA viruses: Influenza virus, Human coronavirus types, Feline coronavirus, Possible activity against SARS-CoV-2	Deactivates virus particles outside cells, Blocks viral attachment processes, Interacts with ACE2 binding sites, Forms complexes with viral enzymes, Connects to spike protein domains	Most beneficial during initial infection phases, shows reduced activity after cellular entry occurs, shows little impact on rhinovirus types, Environmental protection agency has approved thymol products for coronavirus surface decontamination	Astani *et al.* (2010); Koch *et al.* (2008); Pilau *et al.* (2011)

5. Recovery, quantitative assessment, and chemical profiling of thymol

Thymol, a principal active component in thyme oil, can be obtained using a variety of extraction processes. Standard methods like steam and water-based distillation remain common, while more refined options such as supercritical carbon dioxide extraction offer enhanced efficiency and preserve compound integrity. Among the most frequently used are gas chromatography combined with mass spectrometry, and liquid chromatography-based systems, including high performance liquid chromatography (HPLC) and liquid chromatography tandem mass spectrometry (LCTMS). These instruments provide sensitivity and specificity for detecting chemical constituents, even at trace concentrations (Mottaleb *et al*., 2019). The evaluation of thyme oil's molecular profile is achieved using spectroscopic and chromatographic tools such as HPLC coupled with UV detectors and GC-MS analysis. These allow scientists to identify major aromatic and bioactive constituents like carvacrol, p-cymene, thymol, linalool, and gamma-terpinene, all of which contribute to the oil's therapeutic efficacy and commercial value. This multidisciplinary approach is critical for ensuring quality control, therapeutic validation, and potential pharmaceutical application of thyme-based essential oils.

6. Specification development and quality regulation

Ensuring the therapeutic performance and reliability of thymol formulations requires comprehensive protocols for consistency and product oversight. Establishing uniform levels of bioactive compounds in each production batch is essential for minimizing deviations that could affect treatment outcomes. As outlined by Bhairam *et al*. (2013), adherence to these procedures also helps to reduce the presence of undesirable elements, such as metallic residues, microbial contaminants, and agricultural chemicals. Following internationally recognized regulatory benchmarks, including those defined by International Organisation for Standardisation (ISO), is crucial for maintaining product integrity and facilitating global distribution. These frameworks support manufacturers in meeting monitoring obligations while also boosting consumer confidence and long-term brand engagement. Products produced under standardized conditions are more likely to earn consumer trust, leading to sustained market presence and improved user satisfaction. According to Foudah *et al*. (2022), this technique enables efficient detection and quantification of thymol content, confirming its presence at desired therapeutic levels. Applying structured standardization practices along with reliable analytical verification is essential for producing thymol based products that are both effective and safe. Through the use of validated techniques like HPTLC and adherence to global quality norms, manufacturers can ensure their formulations meet safety expectations, comply with regulations, and consistently deliver intended health benefits.

7. Thyme based novel therapeutics

To fully utilize the pharmacological effects of thymol and similar bioactive agents, particularly those of botanical or synthetic origin, advanced delivery strategies are necessary. These compounds often face challenges such as enzymatic breakdown and potential mucosal irritation upon oral intake. Nanocarriers composed of lipids, glycerol derivatives, or glycols are being explored to shield these substances and optimize systemic uptake.

7.1 Use of natural polymers

Piombino *et al.* (2020) highlighted the suitability of lignin-based polymers specifically lignosulfonate as biocompatible encapsulating agents for thymol. These carriers not only facilitate gradual release due to their lipophilicity but also enhance therapeutic action through synergistic antioxidant effects. Moreover, cellulose acetate membranes embedded with thymol exhibited delayed release kinetics and demonstrated heightened antimicrobial performance, especially in porous configurations. Tests using bacterial strains like *S. aureus* and *E. coli* confirmed strong inhibitory effects, with maximum efficacy seen at 15% thymol concentration, suggesting potential use in wound care.

7.2 Role of semi-synthetic carriers

In further investigations, Pinna *et al.* (2019) explored how carrier structure influences the biological activity of thyme essential oil. While traditional liposomal systems showed limited impact, vesicles enriched with glycerol or propylene glycol (PG-PEVs) enhanced thymol's effect on *S. mutans* by altering cellular morphology and disrupting membrane integrity. Thymol's encapsulation in methylcellulose microspheres significantly increased its systemic availability despite a shortened half-life, while hydroxypropyl methylcellulose phthalate based formulations offered localized intestinal delivery. Adjusting the proportion of hydroxypropyl methylcellulose to ethylcellulose optimal at a 5:1 ratio improved encapsulation and targeted release.

7.3 Microfiber-based delivery

In wound management research, Gámez *et al.* (2020) developed thymol-loaded electrospun microfibers using polycaprolactone blended with mesoporous silica. This design improved the retention and delivery of thymol, reduced bacterial proliferation, and minimized inflammation. The use of controlled-release microfibers in dressings illustrates the potential for more effective chronic wound treatments. Collectively, these findings underscore the importance of delivery system selection spanning natural, semi-synthetic, and synthetic matrices to enhance the pharmacological profile and application range of thymol-based therapies. Continued development is essential to maximize therapeutic potential and ensure clinical success.

8. Importance of thyme oil in aromatherapy

Thyme essential oil has become a key ingredient in aromatherapy, with increasing scientific evidence supporting its therapeutic benefits. Nikolic *et al*. (2014) highlighted that thyme essential oil demonstrates significant biological activities, particularly antimicrobial and antioxidant properties, which make it effective in treating respiratory conditions. Clinical aromatherapy utilizing thyme oil reveals multifaceted therapeutic benefits, particularly in respiratory conditions where inhalation therapy produced statistically significant improvements in pulmonary function parameters (Verma *et al*., 2016). The study found a direct relationship between the chemical composition of thyme oil, specifically the thymol and carvacrol content, and its therapeutic efficacy. Thyme oil's anxiolytic effects have also been observed in clinical trials. Research by Komiya *et al*. (2006) showed that inhalation of thyme essential oil resulted in significant reductions in anxiety, with effects comparable to diazepam in behavioral models, indicating its potential for managing stress and anxiety in aromatherapy. The aromatherapeutic application of *T. vulgaris* essential oil demonstrates significant anxiolytic effects through olfactory pathway stimulation, with compounds like linalool directly modulating neurotransmitter systems associated with stress response (Padalia *et al*., 2015). Historical aroma therapeutic applications of thyme across Mediterranean traditions find substantial validation in contemporary research, particularly regarding its psychoactive properties and effects on cognitive performance (Chauhan and Kamboj, 2014).

Thyme oil has also shown promise in supporting immune function. Sienkiewicz *et al*. (2012) noted that the vapors of thyme essential oil exhibited notable inhibitory effects against respiratory pathogens, including antibiotic-resistant strains, positioning it as a valuable natural remedy in aromatherapy for boosting the immune system. Its anti-inflammatory properties further enhance its usefulness in pain management. According to Fachini-Queiroz *et al*. (2012), thyme oil and its key compounds effectively reduced markers of inflammation and pain in experimental models, reinforcing its role in traditional aromatherapy for treating inflammatory conditions. Beyond physical ailments, thyme essential oil has been linked to cognitive benefits. Moss *et al*. (2010) found that aromatherapy with thyme essential oil led to measurable improvements in memory and alertness, suggesting potential applications for cognitive enhancement. Regarding safety, thyme essential oil has been extensively studied and deemed safe when used correctly. Tisserand and Young (2014) emphasized that, when properly diluted, thyme oil has a favorable safety profile for use in aromatherapy, though precautions should be taken with specific chemotypes.

9. Conclusion

In conclusion, *T. vulgaris*, renowned for its bioactive compounds, especially thymol and carvacrol, has established itself as a highly effective natural therapeutic agent in the field of aromatherapy. Its diverse pharmacological properties ranging from antimicrobial to antioxidant, anti-inflammatory, and anxiolytic effects make thyme a valuable and potent remedy in both traditional and modern wellness treatments. As interest in natural, plant-based therapies increases, thyme's applications are expanding beyond culinary uses into clinical and therapeutic spheres, where its ability to support mood balance, immune function, and alleviate stress is gaining more attention. The integration of cutting-edge nanotechnology and encapsulation techniques is unlocking the full therapeutic potential of thyme, ensuring its active compounds remain stable, bioavailable, and targeted effectively. Additionally, the combination of thyme with other essential oils and phytochemicals in synergistic formulations can further amplify its therapeutic benefits. As research continues to integrate traditional wisdom with modern scientific discoveries, thyme is poised to become a key element in personalized medicine, offering innovative solutions for multi-faceted therapeutic approaches. With its natural roots and the support of emerging biotechnologies, thyme is set to be a powerful asset in future healthcare, firmly establishing itself not just in aromatherapy but as a scientifically validated, multifaceted agent in integrative medicine.

10. Future prospective

The expanding knowledge of *T. vulgaris* and its active compounds suggests a promising future in aromatherapy and integrative medicine. While thyme essential oil has long been recognized for its soothing aroma and broad range of therapeutic properties, future research will likely focus on creating standardized formulations, enhancing delivery techniques, and providing clinical evidence for its benefits. As the demand for holistic, natural therapies increases, thyme is well-positioned to address various health concerns, including stress, mood fluctuations, respiratory disorders, and immune system support through olfactory and topical use. Advancements in nanotechnology and encapsulation methods are anticipated to improve the stability, targeted delivery, and therapeutic effectiveness of thyme oil in aromatherapy practices. Furthermore, thyme's role is likely to evolve beyond traditional aromatherapy and contribute to multi-functional therapeutic systems. This could include the development of smart diffusers, wearable devices, and transdermal patches that would allow for more personalized and effective treatment options. Combining thyme with other essential oils and plant-based compounds may further enhance its therapeutic properties, enabling more targeted treatment strategies. Ongoing interdisciplinary research, merging phytochemistry, neuroscience, and pharmacology, will be vital to confirm thyme's full therapeutic potential. Through this integration of traditional and modern scientific methods, thyme is set to become a scientifically validated, multi-dimensional therapeutic tool in natural healthcare.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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