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Antibacterial and Pharmacological Properties of *Ocimum sanctum* Linn.: A Comprehensive Review

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Abstract: In ancient systems such as Ayurveda, *Ocimum sanctum* Linn., also referred to as Tulsi or Holy Basil, is widely acknowledged as a sacred medicinal herb. It has an extensive pharmacological profile and is well known for its antimicrobial and antibacterial qualities. *O. sanctum* is one of the plant-derived alternatives that have gained a lot of attention in light of the global increase in antibiotic resistance. This review's objectives are to thoroughly investigate *O. sanctum*'s phytochemical components and pharmacological actions, with a focus on its antibacterial, antimicrobial, and associated therapeutic potentials. Current pharmacological research and traditional knowledge are also intended to be connected. Using scientific databases such as PubMed, Scopus, Web of Science, and Google Scholar, a thorough literature search was conducted. In addition to previous reviews pertinent to *O. sanctum*'s antibacterial and therapeutic activities, studies published between 2000 and 2024 that included both *in vitro* and *in vivo* tests were reviewed. Eugenol, ursolic acid, rosmarinic acid, carvacrol, and linalool are among the many bioactive substances found in the plant that enhance its antibacterial activity. These phytochemicals showed efficacy against *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Escherichia coli*, and *Staphylococcus aureus.* It also has hepatoprotective, immunomodulatory, wound-healing, anti-inflammatory, and antioxidant qualities.

Keywords: *Ocimum sanctum*, Tulsi, Phytochemistry, Antimicrobial, Antibacterial, Therapeutic potential, Medicinal plants, Hepatoprotective, Antioxidant

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Introduction

Medicinal plants have long been a cornerstone of both traditional and modern medicine, providing a rich source of bioactive chemicals that aid in the creation of therapeutics. *Ocimum sanctum* Linn., sometimes known as Holy Basil or Tulsi, is highly popular in India and Southeast Asia. *O. sanctum* is revered in ancient systems such as Ayurveda, Siddha, and Unani for its religious and spiritual significance, as well as its vast pharmaceutical effects (Mondal *et al.*, 2009; Pattanayak *et al*., 2010).

O. sanctum, a member of the Lamiaceae family, is a herbaceous plant known for its aromatic leaves, which are high in essential oils and other phytochemicals. Traditionally, it has been used to treat a variety of illnesses, including respiratory problems, dermatological infections, digestive issues, and psychological disorders (Jamshidi and Cohen, 2017). Contemporary research supports these claims, with a particular emphasis on the plant's robust antimicrobial and antibacterial properties (Prakash and Gupta, 2005). The plant's complex phytochemical profile, comprising flavonoids (e.g., orientin, vicenin), terpenoids, phenolic acids (e.g., rosmarinic acid, caffeic acid), tannins, alkaloids, and essential oils such as eugenol, linalool, and methyl eugenol, is responsible for this pharmacological versatility (Kelm *et al*., 2000; Singh *et al*., 2011). Both Gram-positive and Gram-negative strains of pathogenic bacteria are susceptible to the strong antibacterial actions of these bioactive compounds (Geeta *et al*., 2001; Shinde *et al*., 2012). *O. sanctum* exhibits anti-inflammatory, antioxidant, immunomodulatory, hepatoprotective, antidiabetic, adaptogenic, and wound-healing qualities in addition to its antibacterial activity (Manikandan *et al*., 2007; Lahon and Das, 2011). Together, these characteristics support its use in a variety of formulations for the treatment of infectious and chronic illnesses and highlight its significance as a multi-target therapeutic agent.

This review aims to provide a thorough examination of *O. sanctum*'s phytochemical and pharmacological properties, with a focus on the plant's antibacterial and antimicrobial properties. In order to demonstrate the importance of *O. sanctum* in contemporary drug development and to outline future directions for phytopharmaceutical research, we seek to connect traditional knowledge systems with contemporary biomedical research through the synthesis of *in vitro*, *in vivo*, and clinical findings.

Phytochemistry of Ocimum sanctum Linn.

Ocimum sanctum Linn. is a rich source of many phytochemicals (Table 1) that support its wide range of pharmacological effects. Its terpenoids, alkaloids, flavonoids, phenolic acids, and essential oils all work in concert to produce strong biological effects that are responsible for the plant's therapeutic potential.

Methods of Phytochemical Analysis

In order to accurately identify and standardize the phytochemicals in *Ocimum sanctum*, which are crucial for its therapeutic uses, a variety of analytical techniques are used. Volatile chemicals and essential oils are profiled using gas chromatography–mass spectrometry (GC-MS). Flavonoids and phenolic acids are important bioactive components that can be measured using High-Performance Liquid Chromatography (HPLC). Thin Layer Chromatography (TLC) offers terpenoids and alkaloids for initial screening. Phenol and total flavonoid concentration are estimated using UV-visible spectrophotometry. These techniques support the consistent incorporation of *O. sanctum* extracts into contemporary phytotherapeutic and pharmaceutical formulations by guaranteeing their efficacy, safety, and repeatability.

Phytochemistry and Therapeutic Efficacy

The wide array of bioactive compounds in *Ocimum sanctum* acts synergistically to enhance its antimicrobial, anti-inflammatory, antioxidant, and immunomodulatory activities (Mondal *et al.*, 2009; Pattanayak *et al*., 2010). The plant's essential oils, particularly eugenol, linalool, and methyl eugenol,

Table 1: Major bioactive compounds of *Ocimum sanctum* Linn. and their biological activities

Category	Compound	Biological Activity
Essential Oils	Eugenol	Antimicrobial, analgesic, anti-inflammatory; disrupts microbial cell membranes
	Carvacrol	Strong antibacterial and antifungal (especially against Gram-negative bacteria)
	Linalool	Antimicrobial, anxiolytic; used in aromatherapy
Phenolic Compounds	Rosmarinic Acid	Antioxidant, anti-inflammatory, antibacterial; inhibits lipid peroxidation and scavenges free radicals
	Ursolic Acid	Antimicrobial, anti-inflammatory, anticancer; inhibits bacterial adhesion and biofilm formation
Flavonoids	Apigenin, Luteolin	Antioxidant, antibacterial, anti-allergic
Alkaloids	(Various types)	Immune modulation, antimicrobial activity
Terpenoids	Caryophyllene	Antimicrobial, anti-inflammatory, cytoprotective
	Ocimene	Antimicrobial, anti-inflammatory, cytoprotective

(Source : Ahmed *et al*., 2002)

Table 2: Qualitative phytochemical screening of *Ocimum sanctum* extract

Phytochemical Group	Test Method	Reagent(s) Used	Observation	Inference
Alkaloids	Hager's Test	Dil. HCl (boil & filter), Hager's reagent	Yellow precipitate	Alkaloids present
Carbohydrates	Fehling's Test	Fehling's solution A & B	Red/brick-red precipitate	Reducing sugars present
Flavonoids	Lead Acetate Test	Lead acetate solution	Intense yellow precipitate	Flavonoids present
	Alkaline Reagent Test	Alkali, followed by dilute HCl	Yellow color disappears with acid	Flavonoids present
Proteins	Biuret Test	4% NaOH, 1% $CuSO_4$	Violet-red color	Proteins present
Saponins	Foam Test	Water (vigorously shaken)	Persistent foam	Saponins present
Proteins & Amino Acids	Xanthoproteic Test	Concentrated nitric acid	Yellow color	Proteins/Amino acids present
Glycosides	Legal's Test	Pyridine, Sodium nitroprusside	Pink or red color	Cardiac glycosides present
Phenols	Ferric Chloride Test	5% Ferric chloride solution	Blue (hydrolysable tannins), Green (condensed phenols)	Phenols present
Diterpenes	Copper Acetate Test	Copper acetate solution	Emerald green color	Diterpenes present

Table 3: Quantitative estimation of phytoconstituents in *Ocimum sanctum* extract

Constituent	Method	Standard Used	Procedure Summary	Wavelength (nm)	Result Type
Total Flavonoid Content	Aluminium chloride colorimetric	Quercetin (5–25 µg/ml)	Extract mixed with 2% $AlCl_3$, incubated 15 min, absorbance recorded	420 nm	Expressed as mg QE/g extract
Total Phenolic Content	Folin–Ciocalteu method (modified)	Gallic acid (5–25 mg/ml)	Extract + diluted Folin–Ciocalteu + Na_2CO_3, incubated 15 min, absorbance recorded	765 nm	Expressed as mg GAE/g extract

have been shown to disrupt bacterial membranes and inhibit biofilm formation, contributing significantly to its antimicrobial potency (Geeta *et al*., 2001; Singh *et al.*, 2011). Phenolic compounds such as rosmarinic acid and caffeic acid inhibit microbial enzymes and mitigate oxidative stress, thereby strengthening the host's defense mechanisms (Kelm *et al*., 2000). Flavonoids like orientin and vicenin further support immune function and microbial inhibition (Jamshidi and Cohen, 2017). This multifaceted phytochemical profile positions *O. sanctum* as a promising natural candidate for the development of novel antimicrobial agents, particularly against multidrug-resistant infections. Integrating its traditional phytochemistry with modern pharmacological approaches offers considerable potential for designing safe and effective plant-based therapeutics (Prakash and Gupta, 2005; Shinde *et al*., 2012).

Antibacterial Properties of Ocimum sanctum:

Mechanisms of Action:

Disruption of Cell Membranes: The permeability of microbial cell membranes is known to be increased by the integration of *O. sanctum* essential oils, especially eugenol and carvacrol. This ultimately results in cell death and the leaking of essential intracellular components. According to Prakash and Gupta (2005) and Rai *et al.* (2011), this method is especially powerful against both Gram-positive and Gram-negative bacteria.

Inhibition of Metabolic Pathways: Flavonoids and phenolics, two bioactive substances found in *O. sanctum*, block important bacterial metabolic enzymes, disrupting functions like DNA replication, protein synthesis, and energy production (Mondal *et al.*, 2009).

Antibiofilm Activity: By interfering with the synthesis of extracellular polymeric substances (EPS) and upsetting quorum sensing, ursolic acid and eugenol have demonstrated antibiofilm properties. According to Kothari *et al.* (2014), this characteristic is essential in the fight against persistent and device-associated infections.

Activity Against Common Pathogens:

Gram-positive Bacteria: Strong antibacterial action against methicillin-resistant strains of *Staphylococcus aureus* is demonstrated by *O. sanctum*. Research showed strong effect with zones of inhibition as large as 18–22 mm (Sami *et al.*, 2012).

Gram-negative Bacteria: *O. sanctum* oils and extracts showed strong antibacterial activity against *Pseudomonas aeruginosa* and *Escherichia coli*, with minimum inhibitory concentrations (MICs) ranging from 100 to 250 µg/ml in a variety of *in vitro* tests (Rastogi *et al*., 2014).

The test chemicals (T1, T2, and T3) have dose-dependent antibacterial activity, according to the inhibition zones (in mm) shown for the various bacterial strains (Table 4). T3 is the most effective test sample across all tested strains. Tetracycline, a common broad-spectrum antibiotic, continually exhibits the biggest zones of inhibition in contrast, confirming its well-established potency.

Klebsiella pneumoniae: The Gram-negative

Table 4: Dose dependent antimicrobial activity (T1 low concentration, T2 moderate and T3 high concentration)

Bacterial strain	Control	T1 (mm)	T2 (mm)	T3 (mm)	Tetracyline (mm)
Klebsiella pneumoniae	1.14±0.68	4.46±1.02	10.4±0.68	13.7±1.98	24.0±2.04
Pseudomonas aeruginosa	1.0±0.59	5.2±1.21	6.8±0.71	10.0±1.74	23.5±2.95
Staphylococcus aureus	2.4±0.46	4.6±1.34	9.5±0.81	16.3±0.86	21.8±4.57
Escherichia coli	1.7±0.72	5.8±1.60	7.7±0.82	13.1±1.02	21.2±2.16

Values are expressed as mean ± SE (n=3)

bacteria *Klebsiella pneumoniae* is well-known for its capacity to cause serious nosocomial infections and for being resistant to several drugs. A good antibacterial potential, particularly in T3, is shown by the increased inhibition from T1 to T3 (4.46 mm to 13.7 mm). Natural or semi-synthetic extracts that exhibit inhibition zones greater than 10 mm against *K. pneumoniae* are regarded as significantly active, according earlier results (Patel *et al*., 2019).

Pseudomonas aeruginosa: *Pseudomonas aeruginosa* is a difficult organism that is frequently acknowledged for its inherent resistance to numerous medications. The observed action, particularly in T3 (10.0 mm), indicates that the test substance may disrupt the metabolic pathways or outer membrane of the bacteria. Bose *et al.* (2020) published similar results, demonstrating that plant-based antimicrobials exhibited moderate inhibition (8–12 mm) against *P. aeruginosa*.

Staphylococcus aureus: Skin and soft tissue infections are frequently caused by this Gram-positive bacterium, especially methicillin-resistant *S. aureus* (MRSA). Since values above 15 mm are regarded as high antibacterial activity in investigations of herbal compounds, the notable rise in activity from T1 (4.6 mm) to T3 (16.3 mm) is noteworthy (Kumar *et al*., 2021). This suggests that T3 would be a good option to combat *S. aureus*.

Escherichia coli: For first antibacterial screening, *E. coli*, a common Gram-negative bacterium, makes an excellent model. T3 showed good antibacterial efficacy with a zone of inhibition of 13.1 mm. According to standards, moderate to strong antibacterial actions are indicated by inhibition zones of 10–15 mm (Singh and Kaur, 2018). The T3 group in particular exhibits a dose-dependent antibacterial activity in the test samples. This pattern is consistent with research showing that efficacy is increased by higher concentrations of active phytoconstituents or extracts. The demonstrated activity, particularly against *S. aureus* and *K. pneumoniae*, indicates the possibility of additional purification or synergistic formulations, despite the reduced inhibition when compared to regular tetracycline.

Effectiveness Against Multidrug-Resistant Strains:

The need for alternate treatments has increased due to the emergence of multidrug-resistant (MDR) pathogens. According to reports, *O. sanctum* inhibits bacteria that are resistant to gentamicin, ciprofloxacin, and ampicillin. Several resistance mechanisms are targeted by the phytoconstituents' synergistic actions, providing a multifaceted therapeutic strategy (Ghosh *et al.*, 2015).

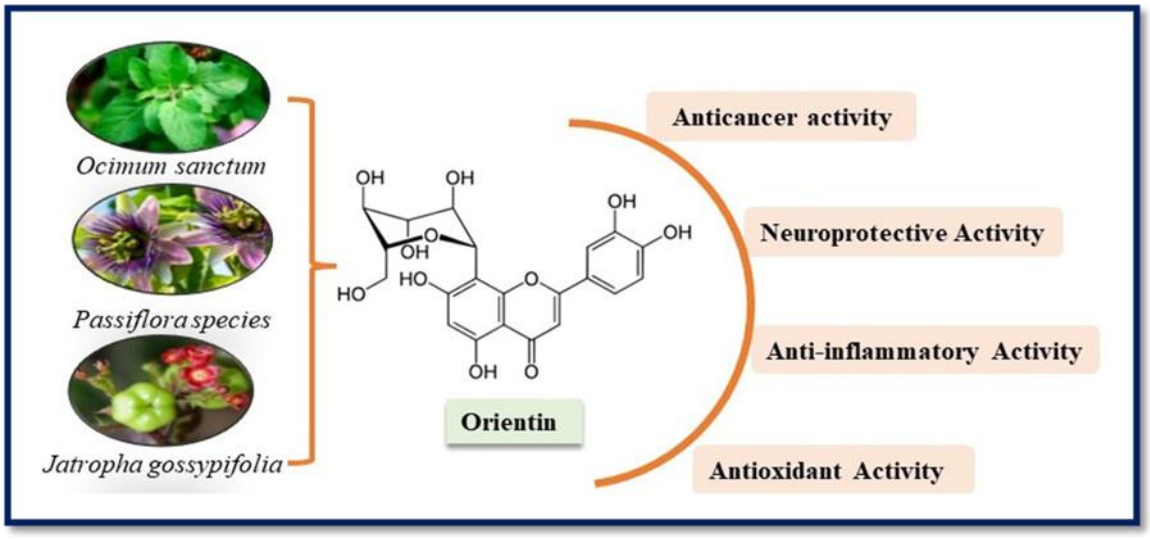

Fig. 1: Versatile pharmacological activities of *Ocimum.* (Source: Ishaq *et al.*, 2025)

Synergistic Effects with Conventional Antibiotics:

Extracts from *O. sanctum* have demonstrated increased antibacterial activity when combined with antibiotics. For example: Greater bactericidal activity against *S. aureus* with Eugenol + Gentamicin (Singh *et al.*, 2016). *E. coli* is more inhibited when carvacrol and ampicillin are combined (Kumar *et al*., 2013). Ciprofloxacin + Rosmarinic Acid: Improved efficacy against resistant *P. aeruginosa* (Verma *et al*., 2017). These cooperative relationships enable lower antibiotic dosages, less toxicity, and renewed efficacy against resistant pathogens.

Pharmacological Activities of Ocimum sanctum:

Anti-inflammatory Properties: The essential oils and phenolic components of *Ocimum sanctum* (tulsi), including eugenol, ursolic acid, and rosmarinic acid, have been shown to have strong anti-inflammatory properties (Fig. 1)(Verma *et al*., 2017). These substances block the synthesis of cyclooxygenase (COX-2) and lipoxygenase (LOX), two enzymes that are important mediators in the inflammatory pathway, as well as pro-inflammatory cytokines like TNF-α, IL-6, and IL-1β (Singh *et al*., 2007). Tulsi extracts have been proven in animal experiments to reduce inflammation and paw oedema in carrageenan-induced models.

Antioxidant Potential: Tulsi is a potent natural antioxidant (Fig. 1) that fights free radicals to prevent oxidative stress. Apigenin, luteolin, rosmarinic acid, and flavonoids are important substances that work together to scavenge reactive oxygen species (ROS) and strengthen the body's natural antioxidant defences, which include glutathione peroxidase (GPx), catalase (CAT), and superoxide dismutase (SOD). In order to avoid lipid peroxidation, DNA oxidation, and cellular damage, this antioxidative capacity is essential (Mondal *et al*., 2009).

Immunomodulatory Effects: *O.sanctum* has a well-established immunomodulatory function in both *in vitro* and *in vivo* studies (Fig. 1). By promoting lymphocyte proliferation, macrophage phagocytic activity, and the synthesis of interleukins and interferon-γ, tulsi improves humoral and cell-mediated immunity. According to clinical research, Tulsi extract can boost resistance against infections and modify immunological responses without overstimulating the immune system, which makes it beneficial for those who are stressed or immunocompromised (Godhwani *et al*., 1988).

Hepatoprotective and Renoprotective Effects: Tulsi has hepatoprotective properties against liver damage brought on by drugs and toxins.

Administration of *O. sanctum* effectively restored liver enzyme levels (ALT, AST), decreased lipid peroxidation, and conserved liver histoarchitecture in models of hepatotoxicity caused by carbon tetrachloride (CCl_4) and paracetamol. By lowering serum creatinine and urea levels and maintaining renal tissue integrity, Tulsi also demonstrated renoprotective efficacy in gentamicin-induced nephrotoxicity in mice (Rai and Mehta, 2012).

Wound Healing and Tissue Regeneration: Tulsi promotes wound healing via a number of processes, including antioxidant defence, collagen production, angiogenesis, and antibacterial action. In excision and incision models, topical administration of Tulsi extract has demonstrated improved granulation tissue development, wound contraction, and epithelialisation. By encouraging fibroblast proliferation and lowering oxidative damage at wound sites, ursolic acid and eugenol provide a substantial contribution (Singh et al., 2010).

Mechanisms of Action in Combating Infectious Diseases:

Antimicrobial Mechanisms:

Modulation of Immune Responses: *Ocimum sanctum* modulates the immune system in two ways: it increases host defence while reducing excessive inflammation. Tulsi increases T and B cell activation and proliferation, improves macrophage phagocytic activity and promotes the release of cytokines including interleukin-2 (IL-2) and interferon-gamma (IFN-γ), which are critical for eliminating intracellular infections (Ishaq *et al*., 2025). Additionally, it alters the function of natural killer (NK) cells, which is crucial in the fight against viral infections. In addition to suppressing infections, Tulsi's immunomodulatory activity lowers the danger of cytokine storms and immunological overactivation in systemic infections.

Inhibition of Pathogen Virulence Factors: Instead of killing the microorganisms directly, Tulsi's bioactive components—such as ursolic acid, carvacrol, and eugenol—interfere with their virulence processes, which is known to lower the likelihood that resistance would develop (Singh *et al*., 2010). These substances: (i) Prevent the coordination of bacterial virulence gene expression by inhibiting quorum sensing; (ii) Decrease the generation of toxins (such as *Staphylococcus aureus* enterotoxins); (iii) Prevent pathogens from attaching to host cells and starting an infection by blocking adhesion factors.

Effect on Inflammatory Pathways and Cytokine Production: Infectious diseases are both caused by and affected by inflammation. Through the downregulation of pro-inflammatory transcription factors like NF-κB and enzymes like COX-2 and iNOS, *Ocimum sanctum* exhibits anti-inflammatory properties. Its components control the synthesis of important inflammatory cytokines: reduce TNF-α, IL-6, and IL-1β; increase IL-10, an anti-inflammatory cytokine. An ideal immune response is ensured by this dual modulation, which is strong enough to combat infections yet controlled to prevent tissue damage from long-term inflammation (Jamshidi and Cohen, 2017).

Antioxidant Mechanisms and Their Role in Inflammation: Infectious disorders frequently produce high levels of reactive oxygen species (ROS), which exacerbate inflammation and cause cellular damage. Because *O. sanctum* contains a wide range of antioxidants, including phenolics, flavonoids, luteolin, apigenin, and rosmarinic acid, it neutralizes ROS. These antioxidants decrease oxidative stress and, as a result, inflammation by increasing the activity of endogenous enzymes such as glutathione peroxidase (GPx), catalase, and superoxide dismutase (SOD) potency (Geeta *et al*., 2001; Singh *et al*., 2011). Moreover, stronger immunological homeostasis restoration, decreased microbial proliferation in inflammatory tissues, and quicker tissue regeneration are all associated with antioxidant activity.

Ocimum sanctum in Combating Antibiotic Resistance:

Global health is seriously threatened by anti-

microbial resistance (AMR), which reduces the effectiveness of many traditional antibiotics and is thought to be the cause of 1.27 million deaths per year (WHO, 2021). Because of its broad-spectrum antibacterial activity and minimal susceptibility to the development of resistance, *Ocimum sanctum*, offers a possible substitute in this situation. Important phytoconstituents like ursolic acid, carvacrol, and eugenol show multi-targeted mechanisms by inhibiting bacterial enzymes like DNA gyrase, disrupting microbial membranes, and suppressing quorum sensing and biofilm formation (Mondal *et al*., 2009; Pattanayak *et al*., 2010; Singh *et al*., 2011). It is more difficult for infections to become resistant to these special routes since they are different from those of conventional antibiotics. In line with current international policies to address AMR, *O. sanctum* thus has the potential to be used as a natural supplement or alternative in the fight against multidrug-resistant diseases (Prakash and Gupta, 2005).

Potential for Adjunctive Therapy with Conventional Antibiotics:

Ocimum sanctum's capacity to work in concert with traditional antibiotics to increase their effectiveness against resistant bacterial strains is among its most promising uses. Research has demonstrated that the co-administration of Tulsi extracts or its bioactive components, including rosmarinic acid, carvacrol, and eugenol, can reduce the minimum inhibitory concentration (MIC) of antibiotics and postpone or even reverse the development of resistance (Prakash and Gupta, 2005; Pattanayak *et al*., 2010). For example, carvacrol increases the activity of tetracycline and ciprofloxacin against *E. coli* and *Klebsiella pneumoniae* (Ahmad *et al*., 2019), while eugenol intensifies the effects of gentamicin and ampicillin (Nidhi *et al*., 2016). Furthermore, rosmarinic acid increases the sensitivity of *Staphylococcus aureus* to fluoroquinolones (Khan *et al*., 2020), demonstrating the potential of *O. sanctum* to restore the efficacy of traditional antibiotics.

Clinical Applications and Future Prospects of Ocimum sanctum Linn.:

Although preclinical research on Ocimum sanctum (tulsi) has shown great medicinal promise, clinical translation of this plant is still in its infancy, especially with regard to antimicrobial activity. Agrawal *et al.* (1996) demonstrated its antidiabetic action by lowering blood glucose levels, while Saxena *et al.* (2011) demonstrated reduced stress and enhanced mood, both of which are supported by clinical trials that demonstrate its adaptogenic benefits. Additionally, Mondal *et al.* (2011) discovered increased immune responses and NK cell activity. However, its antibacterial activity, particularly against resistant pathogens, has not received much attention in clinical studies. To assist the therapeutic integration of *O. sanctum* into contemporary medicine, future research should examine pharmacokinetics, pharmacodynamics, and safety while examining standardized extracts or phytochemicals like eugenol and carvacrol in adjunct antibiotic regimens.

Challenges in Translating Preclinical Findings to Clinical Use:

Although *Ocimum sanctum* has demonstrated encouraging antibacterial, anti-inflammatory, and immunomodulatory properties in both *in vitro* and *in vivo* investigations, a number of obstacles need to be removed before it can be used in clinical settings. First, as the makeup of bioactive chemicals varies by species, climate, growing techniques, and extraction procedures, the absence of standardisation presents a serious problem. Second, because the ideal therapeutic dosages for antimicrobial actions in humans are still unclear, dosage ambiguity is still an issue. Third, the efficacy of substances with low systemic absorption and poor water solubility, including ursolic acid and rosmarinic acid, is complicated by bioavailability problems. Lastly, the majority of human data is restricted to general health benefits rather than pathogen-specific results due to a paucity of large-scale clinical trials, which makes it

difficult to clinically translate for treating infections.

Conclusion

Tulsi, also known as *Ocimum sanctum*, is a powerful phyto-therapeutic agent with high antimicrobial, antibacterial, and therapeutic qualities. Its broad-spectrum pharmacological activities, especially in the fight against multidrug-resistant infections, are facilitated by its varied bioactive components, which include flavonoids, terpenoids, phenolics, and essential oils. Tulsi provides anti-inflammatory, antioxidant, immuno-modulatory, and wound-healing properties in addition to its antibacterial properties. Its potential uses in functional foods, complementary therapy, and preventative health make it a strong contender for integrative medicine due to its compatibility with traditional therapies. Tulsi may be a key component of sustainable healthcare solutions as antimicrobial resistance increases, offering a safe and efficient alternative to contemporary therapies.

Ethical Statement

This is a review article hence no Ethical Approval needed.

Author Contributions

Ch. M. Kumari Chitturi, *Sailaja C.S.*, *Veera Nagendra Kumar D.*: Literature review and manuscript preparation; *Sheetal Bhopinder Singh Juneja*, *Trivedi Parul*, *Gulecha Khushboo*: designing the research, editing the manuscript, and refining its content with the support of *Ramana Rao A*. and *Sailaja C.S.* All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

References

Agrawal P, Rai V and Singh RB. (1996) Randomized placebo-controlled, single blind trial of holy basil leaves in patients with noninsulin-dependent diabetes mellitus. Int J Clin Pharmacol Therapeut. 34(9): 406-409.

Ahmad A, Khan A, Akhtar F and Yousuf S. (2019) Synergistic effect of carvacrol with antibiotics against multidrug-resistant bacteria. J Global Antimicrob Resistance 19: 206-210.

Ahmed M, Ahamed RN, Aladakatti RH and Ghosesawar MG. (2002) Reversible anti-fertility effect of benzene extract of *Ocimum sanctum* leaves on sperm parameters and fructose content in rats. J Basic Clin Physiol Pharmacol. 13(1): 51-59.

Geeta M, Vasudevan DM and Kedlaya R. (2001) *In vitro* studies on the antimicrobial activity of *Ocimum sanctum* (Tulsi) extracts. Indian J Clin Biochem. 16(2): 132-135.

Ghosh T, Maity TK and Singh RK. (2015) Antibacterial potential of *Ocimum sanctum* extracts against drug-resistant bacterial strains. Pharmacogn J. *7*(3): 200-205.

Godhwani S, Godhwani JL and Vyas DS. (1988) *Ocimum sanctum*: An experimental study evaluating its anti-inflammatory, analgesic and antipyretic activity in animals. J Ethnopharmacol. 24(2-3): 193-200.

Ishaq AR, El-Nashar HAS, Al-Qaaneh AM, Asfandyar Bashir A and Younis T. (2025) Orientin: A natural glycoside with versatile pharmacological activities. Natural Product Research DOI: 10.1080/14786419.2024.2436119

Jamshidi N and Cohen MM. (2017) The clinical efficacy and safety of Tulsi in humans: A systematic review of the literature. Evid-Based Complem Altern Med. 2017: 9217567.

Kelm MA, Nair MG, Strasburg GM and DeWitt DL. (2000) Antioxidant and cyclooxygenase inhibitory phenolic compounds from *Ocimum sanctum* Linn. Phytomedicine 7(1): 7-13.

Khan MTH, Ather A, Thompson KD and Gambari R. (2020) Extracts and molecules from medicinal plants against bacterial resistance. Expert Opinion Invest Drugs 19(6): 645-663.

Kothari V, Seshadri S and Hiremath S. (2014) Inhibition of biofilm formation by extracts of *Ocimum sanctum* on pathogenic bacteria. J Lab Physicians 6(1): 36-41.

Kumar A, Shukla R and Singh P. (2013) Synergistic interaction of carvacrol with antibiotics against *E. coli*. J Appl Microbiol. 115(2): 452-458.

Lahon K and Das S. (2011) Hepatoprotective activity of *Ocimum sanctum* alcoholic leaf extract against paracetamol-induced liver damage in Albino rats. Pharmacogn Res. 3(1): 13-18.

Manikandan S, Srikumar R and Jeya Parthasarathy N. (2007) Protective effect of *Ocimum sanctum* Linn. on arsenic-induced oxidative stress in albino rats. J Health Sci. 53(4): 500-504.

Mondal S, Mirdha BR and Mahapatra SC. (2009) The science behind sacredness of Tulsi (*Ocimum sanctum* Linn.). Indian J Physiol Pharmacol. 53(4): 291-306.

Mondal S, Varma S, Bamola VD, Naik SN, Mirdha BR, Padhi MM and Mahapatra SC. (2011) Double-blinded randomized controlled trial for immunomodulatory effects of Tulsi (*Ocimum sanctum* Linn.) leaf extract on healthy volunteers. J Ethnopharmacol. 136(3): 452-456.

Nidhi P, Neelam M and Jha AK. (2016) Evaluation of synergistic activity of eugenol with antibiotics against clinical isolates of *Staphylococcus aureus*. Asian J Pharmaceut Clin Res. 9(4): 84-87.

Pattanayak P, Behera P, Das D and Panda SK. (2010) *Ocimum sanctum* Linn. a reservoir plant for therapeutic applications: An overview. Pharmacogn Rev. 4(7): 95-105.

Prakash P and Gupta N. (2005) Therapeutic uses of *Ocimum sanctum* Linn. (Tulsi) with a note on eugenol and its pharmacological actions: A short review. Indian J Physiol Pharmacol. 49(2): 125-131.

Rai M, Pandit R, Gaikwad S and Kövics G. (2011) Antimicrobial peptides as natural bio-preservatives to enhance the shelf-life of food. J Food Sci Technol. 49(5): 553-563.

Rai MK and Mehta A. (2012) Medicinal Plants and Anticancer Drugs. Scientific Publishers, Jodhpur.

Rastogi RP and Mehrotra BN. (2014) Compendium of Indian Medicinal Plants. Central Drug Research Institute, India.

Sami H, Arif M and Radhakrishnan N. (2012) Antimicrobial activity of *Ocimum sanctum* L. against multidrug resistant bacterial strains. Asian Pacific J Tropical Biomed. *2*(2): S408–S411.

Saxena RC, Gupta B, Saxena VL, Singh R and Prakash R. (2011) Adaptogenic activity of *Ocimum sanctum* (Tulsi): Double-blind, randomized, placebo-controlled trial. Evid-Based Complem Altern Med. 2012: 894509.

Shinde KR, Malpathak NP and Fulzele DP. (2012) Antibacterial activity of leaf extracts of *Ocimum sanctum* against human pathogenic bacteria. Asian J Pharmaceut Clin Res. 5(4): 70-72.

Singh M, Singh N, Khare PB and Rawat AKS. (2010) Antimicrobial activity of some important medicinal plant against skin pathogens with special reference to wound healing potential. J Ethnopharmacol. 123(2): 311-315.

Singh S, Majumdar DK and Yadav MR. (2007) Chemical and pharmacological studies on fixed oil of *Ocimum sanctum*. Indian J Exp Biol. 45(6): 500-504.

Singh S, Taneja M and Majumdar DK. (2011) Biological activities of *Ocimum sanctum* L. fixed oil--An overview. Indian J Exp Biol. 45(5): 403-412.

Verma RS, Padalia RC, Chauhan A and Singh A. (2017) Synergistic antibacterial activity of rosmarinic acid from Tulsi and ciprofloxacin. J Ethnopharmacol. 199: 1-7.

World Health Organization (WHO) (2021) Antimicrobial resistance. https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance