



REVIEW ARTICLE

ANTI-INFLAMMATORY POTENTIAL OF *OCIMUM SANCTUM* (TULSI): A COMPREHENSIVE REVIEW OF PHYTOCHEMISTRY AND ENZYME INHIBITION MECHANISMS

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ABSTRACT: Inflammation, while essential for host defense, becomes a driving force behind a wide spectrum of chronic disorders when dysregulated, including arthritis, cardiovascular diseases, metabolic syndrome, and neurodegeneration. Conventional anti-inflammatory therapies, though effective, are often constrained by adverse effects, drug resistance, and limited long-term safety, prompting a paradigm shift toward safer, multi-targeted natural interventions. In this context, *Ocimum sanctum* (Tulsi), an eminent medicinal herb in Ayurvedic medicine, has emerged as a promising candidate owing to its diverse bioactive profile and broad-spectrum pharmacological activities. This review presents a comprehensive synthesis of the phytochemistry of *Ocimum sanctum* with a particular emphasis on its enzyme-mediated anti-inflammatory mechanisms. Tulsi contains a rich array of phytoconstituents, including eugenol, ursolic acid, rosmarinic acid, apigenin, and other flavonoids and terpenoids, which collectively orchestrate its therapeutic effects. These compounds exert potent anti-inflammatory actions by targeting key enzymatic pathways such as cyclooxygenase (COX) and lipoxygenase (LOX), thereby attenuating the biosynthesis of pro-inflammatory mediators like prostaglandins and leukotrienes. Furthermore, Tulsi modulates intracellular signaling cascades, notably inhibiting nuclear factor-kappa B (NF- κ B) activation, resulting in suppressed expression of inflammatory cytokines including TNF- α , IL-1 β , and IL-6. Its strong antioxidant capacity further complements these effects by neutralizing reactive oxygen species and mitigating oxidative stress-induced tissue damage. Collectively, *Ocimum sanctum* represents a multi-mechanistic, plant-based anti-inflammatory agent with significant therapeutic promise. Future research should prioritize standardization, molecular-level validation, and well-designed clinical trials to facilitate its integration into evidence-based modern therapeutics.

Keywords: *Ocimum sanctum*, Tulsi, Anti-inflammatory, Phytochemistry, Enzyme inhibition

I. INTRODUCTION

Inflammation is a necessary physiological reaction which safeguards the body against the harmful stimuli or pathogen, toxins and tissue damage. It entails a cascade of cellular and molecular processes that are coordinated to remove the original cause of damage and start the process of repairing the tissue. Nevertheless, in case of chronic and dysregulated inflammation, it also leads to the onset and progression of a large number of diseases, such as rheumatoid arthritis, cardiovascular diseases, diabetes mellitus, cancer, and neurodegenerative disorders, including Alzheimer disease [1]. There is an increased need to study the phenomenon of inflammation because the global burden of these inflammatory disorders has increased significantly during the past decades due to aging, lifestyle alterations, and environmental factors, becoming one of the main areas of focus in current research on therapeutic approaches [2].

Traditional pharmacological treatment, especially nonsteroidal anti-inflammatory drugs (NSAIDs) and corticosteroids, are common among the management of inflammatory disorders. NSAIDs work mainly by blocking cyclooxygenase (COX)

enzymes and decreasing the production of prostaglandins, whereas corticosteroids inhibit several different inflammatory pathways by immunomodulating [3]. Although they are effective, the long-term use of these medications can be linked to serious side effects such as gastrointestinal ulceration, renal dysfunction, cardiovascular difficulties, metabolic disruptions, and immunosuppression. Moreover, the therapies usually do not treat the causes of chronic inflammation but alleviate its symptoms; thus, they have little long-term value [4].

The difficulties have prompted the hunt of safer and more holistic options, and a resurgence of interest in plant-based therapeutics. Medicinal plants are ancient and traditional forms of medicine and are gaining popularity in their capacity to treat many pathways with relatively fewer side effects. Their high phytochemical diversity allows regulating major inflammatory mediators, enzymes and signaling pathways [5].

One of them, *Ocimum sanctum* (Tulsi), also known as Holy Basil, has a special place in Ayurveda and other traditional medicine systems. Being the Queen of Herbs, Tulsi has been widely exploited due to its medical usefulness in the treatment of inflammation, respiratory diseases, infection and metabolic

conditions. Its pharmacological action can be explained by its richness in bioactive compounds such as eugenol, ursolic acid, rosmarinic acid, flavonoids, and essential oils that combine their anti-inflammatory, antioxidant, and immunomodulatory properties [6].

The current review intends to critically assess and elaborate on the phytochemical make-up of *Ocimum sanctum* as well as shedding some light on its anti-inflammatory properties with special emphasis on enzyme inhibition pathways. The particular focus is on its actions on the major inflammatory targets including cyclooxygenase (COX), lipoxygenase (LOX), and nuclear factor-kappa B (NF-kB) signaling, thus providing a mechanistic insight into its therapeutic potential in chronic inflammatory diseases [7].

2. Literature Search Methodology

A systemic and extensive literature review was performed to obtain the scientific data on the antiinflammatory properties of *Ocimum sanctum*, especially its phytochemistry, and enzyme inhibition processes. Several electronic databases such as PubMed, Scopus, Web of science and Google Scholar were thoroughly searched so as to cover a wide scope of peer-reviewed research articles, reviews, and experimental studies [8].

The search strategy was refined with the help of appropriate keywords and combinations. These were terms like: *Ocimum sanctum*, Tulsi, anti-inflammatory activity, phytochemistry, cyclooxygenase inhibition (COX), lipoxygenase inhibition (LOX), enzyme inhibition, NF- and -pathway, and oxidative stress. The relevance and specificity of the retrieved studies were increased with the use of the Boolean operators (AND, OR). Also, the reference lists of the chosen articles were screened manually in order to determine more relevant publications [9].

Inclusion criteria were also well formulated so as to guarantee the scientific relevance and validity of the studies picked. Peer-reviewed articles in English only were taken into account. Research was contained within both *in vitro* (e.g., enzyme inhibition and cell-based cytokine) and *in vivo* experimental models (e.g., animal models of inflammation) as well as research on phytochemical characterization and mechanistic pathways of *Ocimum sanctum*. Both quality review papers and original research articles were taken in order to offer a holistic view of the subject [10].

The following criteria were used as exclusion criteria: non-peer-reviewed sources, abstracts of conferences containing no full data, repeated studies, and articles with no clear description of the experimental methodology or reproducible results. Incomplete studies, ambiguous results and lack of methodological information were also left out in order to uphold the integrity and reliability of the review [11].

The literature gathered was critically reviewed, systematized, and summarized in order to give a coherent and evidence-

based expression of the anti-inflammatory activities of *Ocimum sanctum*, especially the enzyme inhibitory activities and molecular pathways.

3. Botanical Description and Ethnomedicinal Uses

Ocimum sanctum L. (syn. Tulsi or Holy Basil is an aromatic herb that is perennial and a member of the Lamiaceae family (*Ocimum tenuiflorum*). The plant has an average height of 30-60 cm and the stems are highly branched, erect and usually purplish in color. Leaves are simple, opposite, oval, a bit toothed and have a characteristic clove like smell because of the presence of essential oils. Depending on the type, they can be green (Rama Tulsi) or purple (Krishna Tulsi). Its flowers are minute, purplish or white, in racemes at the end of the stalks, and its seeds are minute and smooth, and gelatinous when in contact with water. Despite morphological differences among various cultivars, the plant is readily recognizable because it has a strong fragrance and typical leaf structure [12].

Ocimum sanctum is found in a vast number of countries in tropical and subtropical climates, but it is also highly common in India where it is grown at home and in large scale. It is also present in the Southeast Asian countries, including Thailand, Indonesia, and Malaysia and has adapted to the diverse climatic conditions including warm temperate areas. The plant does well in well-drained soils and needs moderate amounts of sunlight making it suitable in both rural and urban farms. Tulsi is a culturally and religiously important plant in India, commonly cultivated in homes and temples, as well as possessing medicinal value [13].

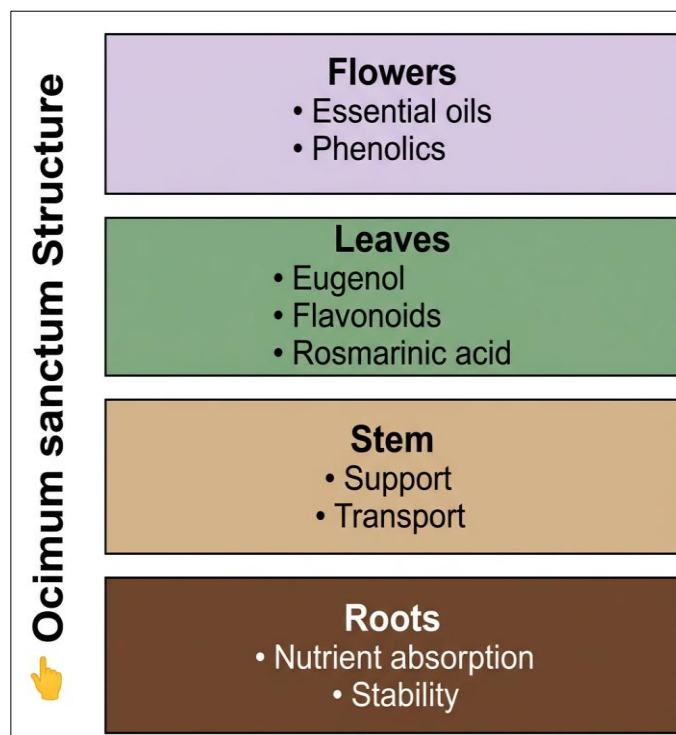


Figure 1: Phytochemical Localization Map of *Ocimum sanctum* [15]

Historically, *Ocimum sanctum* is ethnomedically widely used in traditional systems of medicine, especially Ayurveda. The plant is used in its therapeutic properties in different parts of its body particularly the leaves. Traditionally, tulsi has been used in treating fever, inflammatory diseases, arthritis, and respiratory diseases like cough, asthma, and bronchitis. It is also employed due to its antimicrobial, adaptogenic, and immunomodulatory. The fact that Tulsi is widely used traditionally in the treatment of the diseases associated with inflammation offers a solid basis to its scientific research as an anti-inflammatory agent (Table 1) [14].

Table 1: Taxonomical Classification and Traditional Uses of *Ocimum sanctum* [16]

S. No.	Parameter	Description
1	Kingdom	Plantae
2	Subkingdom	Tracheobionta (Vascular plants)
3	Division	Magnoliophyta (Angiosperms)
4	Class	Magnoliopsida (Dicotyledons)
5	Subclass	Asteridae
6	Order	Lamiales
7	Family	Lamiaceae
8	Genus	<i>Ocimum</i>
9	Species	<i>Ocimum sanctum</i> L. (<i>Ocimum tenuiflorum</i>)
10	Common Names	Tulsi, Holy Basil, Sacred Basil
11	Plant Type	Aromatic perennial herb
12	Parts Used	Leaves, seeds, roots, whole plant
13	Distribution	India, Southeast Asia, tropical regions
14	Traditional Uses	Anti-inflammatory, antipyretic, antimicrobial, adaptogenic
15	Therapeutic Applications	Fever, arthritis, respiratory disorders, stress-related conditions

4. Phytochemical Profile of *Ocimum sanctum*

4.1 Preliminary Phytochemical Screening

Phytochemical screening of *Ocimum sanctum* (preliminary) indicates that the plant contains a wide range of bioactive secondary metabolites which are responsible to its medicinal effects. Common qualitative analyses made on different extracts (aqueous, ethanolic, and methanolic) always show the existence of alkaloids, flavonoid, phenolic compounds, terpenoid, tannin, and saponin (Fig. 1) [17]. The flavonoids and phenolics are the most common of these and have a close relationship with the antioxidant and anti-inflammatory

processes. Components of terpenoids and essential oils also enrich its pharmacological profile by regulating the action of the inflammatory media, and alkaloids add to other biological actions. This extensive phytochemical base supports the multi-targeted effect of *Ocimum sanctum* in inflammatory disorders [18].

4.2 Major Bioactive Constituents

Some important bioactive *Ocimum sanctum* compounds have been recognized to play major role in its anti-inflammatory activity. Eugenol is a major phenolic component of Tulsi essential oil that has strong anti-inflammatory properties because it inhibits the production of prostaglandins and inhibits inflammatory mediators [19]. Ursolic acid is a pentacyclic triterpenoid, which is important in the inhibition of cyclooxygenase (COX) enzymes and the suppression of inflammatory signalling pathways like NF-KB. As a famous phenolic acid, rosmarinic acid offers a powerful antioxidant activity by trapping reactive oxygen species (ROS) and, thus, decreasing oxidative stress-related inflammation. The monoterpene Linalool helps in regulating cytokine synthesis and reducing inflammation. Such phytoconstituents tend to work together hence having a greater overall anti-inflammatory effect [20].

4.3 Analytical Techniques

The name and description of phytochemicals found in *Ocimum sanctum* depend on the high-level analytical methods, which are accurate and reproducible. High-Performance Liquid Chromatography (HPLC) has been extensively employed in the separation and quantification of phenolic compounds and flavonoids such as rosmarinic acid. Gas Chromatography-Mass Spectrometry (GC-MS) has been especially useful in the analysis of volatile constituents which include eugenol and linalool found in essential oils [21]. Liquid Chromatography-Mass Spectrometry (LC-MS) presents good sensitivity and accuracy in the measurement of complex phytochemical profiles and trace elements. These analytical techniques are crucial in standardization of plant extracts and aid pharmacological and mechanistic investigations (Table 2) [22].

Table 2: Major Phytochemicals and Their Anti-inflammatory Roles in *Ocimum sanctum* [23]

S. No.	Phytochemical	Class	Source (Plant Part)	Anti-inflammatory Mechanism
1	Eugenol	Phenolic compound	Leaves (essential oil)	Inhibits COX, reduces prostaglandin synthesis
2	Ursolic acid	Triterpenoid	Leaves	COX inhibition, NF-κB suppression
3	Rosmarinic acid	Phenolic acid	Leaves	ROS scavenging, antioxidant action
4	Linalool	Monoterpene	Essential oil	Reduces cytokine production
5	Apigenin	Flavonoid	Leaves	LOX inhibition, anti-inflammatory signaling
6	Carvacrol	Phenolic monoterpene	Leaves	Suppresses inflammatory mediators
7	β-caryophyllene	Sesquiterpene	Essential oil	Modulates CB2 receptor, anti-inflammatory
8	Ocimene	Terpenoid	Leaves	Reduces oxidative stress
9	Camphene	Monoterpene	Essential oil	Anti-inflammatory and antioxidant
10	Methyl eugenol	Phenylpropanoid	Leaves	Inhibits inflammatory enzymes
11	Orientin	Flavonoid	Leaves	Reduces oxidative stress and cytokines
12	Vicenin	Flavonoid	Leaves	Anti-inflammatory and antioxidant
13	Tannins	Polyphenols	Whole plant	Astringent, reduces inflammation
14	Saponins	Glycosides	Leaves	Modulates immune response
15	Alkaloids	Nitrogen compounds	Whole plant	Regulates inflammatory pathways

5. Anti-inflammatory Activity

5.1 In Vitro Studies

Ocimum sanctum anti-inflammatory effect has been widely explored in a wide range of *in vitro* models which explain its action on major inflammatory enzymes and mediators. One of the key mechanisms is the inhibition of cyclooxygenase (COX) enzymes especially COX-2 which synthesise the biosynthesis of the pro-inflammatory prostaglandins through the arachidonic acid. Tulsi extracts, particularly ethanolic and methanolic extracts, have been shown to cause a dose-dependent COX inhibition, hence suppressing prostaglandin-mediated inflammation (Table 3) [24].

Besides COX, *Ocimum sanctum* has a high lipoxygenase (LOX) inhibitory activity. LOX enzymes are involved in the synthesis of leukotrienes, inflammatory mediators that contribute to diseases like asthma and arthritis. Tulsi also helps in reducing the production of leukotrienes and related inflammatory reactions by inhibiting the activity of LOX [25].

Furthermore, cell-based experiments with macrophages and other immune cells have shown that Tulsi extracts have a significant negative effect on the production of pro-inflammatory cytokines, such as tumor necrosis factor-alpha (TNF- α), interleukin-1 beta (IL-1 β) and interleukin-6 (IL-6). These effects are usually associated with inhibition of intracellular signal transduction pathways like nuclear factor-kappa B (NF- κ B), which is at the centre of controlling inflammatory gene expression. All these results demonstrate the potential of *Ocimum sanctum* to work on various molecular targets, which makes it a powerful anti-inflammatory agent *in vitro* [26].

5.2 In Vivo Studies

The anti-inflammatory activity of *Ocimum sanctum* has also been confirmed using the well-known *in vivo* experimental models which recapitulate both acute and chronic inflammation. One of the most commonly used models to evaluate acute inflammation is the carrageenan-induced paw edema model. Tulsi extracts have demonstrated a great inhibitory action on swelling of the paw, especially in the

initial stage (histamine-mediated and serotonin-mediated) and in the late (prostaglandin-mediated) inflammatory stages in this model. This two-phase inhibitory effect indicates that Tulsi may have an action on several inflammatory mediators at the same time [27].

Ocimum sanctum has been shown to reduce inflammation, cellular infiltration and tissue destruction in the joints, inflammation cellular infiltration and tissue destruction in the models of chronic inflammation, including adjuvant-induced or collagen-induced arthritis in experimental animals. Also reported are improvement in mobility and reduction in pain-related behaviors. The mechanisms underpinning these effects are its capacity to regulate the inflammatory enzymes, cytokines, and oxidative stress pathways in the long term. The uniformity of these results in various models confirms the therapeutic usefulness of Tulsi in the treatment of acute and chronic inflammatory diseases [28].

5.3 Role of Antioxidants

Oxidative stress is an important factor in the triggering and development of inflammation, mainly because of the excessive production of reactive oxygen species (ROS) in the inflammatory responses. These ROS may cause injury to cellular macromolecules, such as lipids, proteins, and nucleic acids, which enhances inflammatory signaling and retards tissue repair. *Ocimum sanctum* is a potent antioxidant, which is mainly attributed to presence of phenolic compounds like rosmarinic acid, flavonoids, and other polyphenols [29].

These bioactive compounds are useful in scavenging free radicals, lipid peroxidation, and increasing the endogenous antioxidant defense mechanism, which includes superoxide dismutase (SOD) and catalase. Tulsi can prevent cell damage by reducing oxidative stress, breaking the vicious cycle between oxidative stress and inflammation. Moreover, its antioxidant property has been shown to aid cellular homeostasis, tissue regeneration, and the overall anti-inflammatory response. The synergistic effect of antioxidant and enzyme inhibitory effects highlights the promise of *Ocimum sanctum* as an effective natural therapeutic agent of inflammatory diseases (Fig. 2) [30].

Table 3: Summary of Anti-inflammatory Studies on *Ocimum sanctum* [32]

S. No.	Extract Type	Plant Part	Model/Assay Used	Key Findings
1	Ethanolic extract	Leaves	Carrageenan-induced paw edema	Significant reduction in paw swelling
2	Methanolic extract	Leaves	COX inhibition assay	Strong inhibition of COX enzyme
3	Aqueous extract	Leaves	Cytokine assay (TNF- α , IL-6)	Decreased pro-inflammatory cytokines
4	Essential oil	Leaves	In vivo inflammation model	Marked anti-inflammatory effect
5	Hydroalcoholic extract	Leaves	LOX inhibition assay	Reduced leukotriene synthesis
6	Methanolic extract	Whole plant	NF- κ B assay	Suppression of inflammatory signaling
7	Ethanolic extract	Leaves	Arthritis model (rats)	Reduced joint inflammation and swelling
8	Aqueous extract	Leaves	Antioxidant assay (DPPH)	High free radical scavenging activity
9	Essential oil	Aerial parts	Cytokine inhibition assay	Reduced IL-1 β and TNF- α levels
10	Methanolic extract	Leaves	Macrophage cell line study	Inhibited inflammatory mediator release
11	Ethanolic extract	Seeds	In vivo edema model	Moderate anti-inflammatory activity
12	Aqueous extract	Roots	Oxidative stress assay	Reduced ROS generation
13	Hydroalcoholic extract	Leaves	Prostaglandin inhibition assay	Decreased prostaglandin production
14	Essential oil	Leaves	Enzyme inhibition study	Inhibited COX and LOX pathways
15	Methanolic extract	Leaves	Chronic inflammation model	Reduced tissue damage and inflammation

Inhibitory Activity of Selected Phytochemicals					
Targets Phytochemicals	COX	LOX	NF-κB	Cytokines	ROS
Eugenol	+++				
Ursolic acid			++		
Rosmarinic acid					+++
Linalool				+	
Flavonoids		+++			

Legend: +++ = Strong inhibition ++ = Moderate + = Weak/Mild Blank = No effect

Figure 2: Phytochemical–Enzyme Interaction Matrix of *Ocimum sanctum* [31]

6. Enzyme Inhibition Mechanisms

The anti-inflammatory effect of *Ocimum sanctum* is well-established as it interferes with the major enzymatic events and intracellular signaling cascades that control the inflammatory processes. Tulsi is a multi-dimensional multi-target synthetic drug in contrast to single-target synthetic drugs, as it inhibits pro-inflammatory enzymes, suppresses transcription factors, and regulates cytokine networks simultaneously. Such a coordinated activity not only decreases the development of an inflammation process but also suppresses its further growth and development. *Ocimum sanctum* has a wide-spreading effect at molecular, cellular and biochemical level due to the presence of a variety of phytoconstituents like eugenol, ursolic acid, rosmarinic acid and flavonoids [33].

6.1 Cyclooxygenase (COX) Inhibition

The inflammatory response is centered on cyclooxygenase enzymes, especially the inducible form, which is COX-2, which catalyzes the breakdown of arachidonic acid into prostaglandins, which are important mediators of pain, swelling, vasodilation and fever. COX-2 overexpression is a typical feature of chronic inflammatory diseases. Eugenol and ursolic acid are some of the bioactive compounds in *Ocimum sanctum* which have shown a powerful inhibitory effect on the activity of COX. Tulsi disrupts this pathway of the enzyme and thus the production of prostaglandins, thus lowering inflammation and other related symptoms [34].

Notably, the COX inhibition of Tulsi is assumed to be more balanced than the traditional NSAIDs which may reduce the gastrointestinal and cardiovascular side effects. This renders *Ocimum sanctum* a potential natural substitute of long-term control over inflammatory disorders [35].

6.2 Lipoxygenase (LOX) Inhibition

Another important alternative of the arachidonic acid metabolite pathway is the Lipoxygenase (LOX) enzymes which convert arachidonic acid to leukotrienes. These molecules are important in maintaining inflammation, facilitating leukocytes recruitment, and playing a role in

allergic and respiratory ailments like asthma. *Ocimum sanctum* extracts have demonstrated good inhibitory activities against LOX enzymes that result in inhibition of leukotriene synthesis [36].

Dual inhibition of COX and LOX pathways by Tulsi is of special importance because it enables a comprehensive regulation of the production of the inflammatory mediators. Besides decreasing inflammation, this dual effect also curbs tissue damage and hypersensitivity responses that come along with chronic inflammatory diseases [37].

6.3 NF-κB Pathway Suppression

The nuclear factor-kappa B (NF-κB) is a key transcriptional factor controlling the expression of a broad spectrum of inflammatory, immunological, and survival genes. NF-κB is activated under the influence of inflammatory triggers and translocates into the nucleus where it enhances the transcription of pro-inflammatory genes, such as cytokines, enzymes (COX-2, iNOS), and adhesion molecules [38].

It is demonstrated that phytochemicals found in *Ocimum sanctum*, especially flavonoids, and phenolic compounds can prevent NF-B activation and nuclear translocation. This leads to the down-regulation of inflammatory genes at the basic level. By inhibiting this central signaling junction, Tulsi is able to suppress the amplification cascade of inflammation, having a deeper and more permanent anti-inflammatory effect [39].

6.4 Cytokine Modulation

Cytokines are major signaling molecules which mediate and regulate immunity and inflammation responses. The pro-inflammatory cytokines (TNF-α, IL-1β and IL-6) are crucial in the development of chronic inflammatory diseases through stimulating the activity of immune cells, tissue destruction, and systemic inflammation. It has been demonstrated that *Ocimum sanctum* also significantly decreased the concentrations of these cytokines, both directly and indirectly [40].

Direct effects are inhibition of production of cytokines, whereas indirect mechanisms are realized through the regulation of upstream pathways like NF-KB and oxidative stress. Also, Tulsi could be used to restore the balance between pro-inflammatory and anti-inflammatory cytokines, which is a part of immune homeostasis. This cytokine-regulating effect is particularly helpful in those conditions when there is overproduction of cytokines like autoimmune and inflammatory diseases [41].

7. Formulation Approaches and Safety

7.1 Formulation Approaches

Numerous formulations plan other than the crude plant extracts have been designed to improve the therapeutic effects, stability and bioavailability of *Ocimum sanctum*. Aqueous and alcoholic extracts are still popular since they are easy to

prepare and have a wide spectrum of phytochemicals. These extracts are usually used in oral (capsules, syrups) and topical preparations in the use of anti-inflammatory agents [42]. Tulsi-derived essential oils with a high content of volatile compounds like eugenol and linalool have received significant interest due to their strong anti-inflammatory and antimicrobial effects. These oils may be employed in aromatherapy, topical ointments and transdermal formulations and offer quick absorption and localized effects [43].

Nanoformulations are some of the latest drug delivery systems which are proving to be effective in enhancing the pharmacokinetic characteristics of Tulsi-derived compounds in recent years. Nanoparticles, nanoemulsions, liposomes, and polymer-based carriers increase the solubility, prevent the degradation of bioactive constituents, and allow the controlled and targeted release of drugs. These systems have demonstrated enhanced anti-inflammatory effects because of enhanced cellular uptake and protracted therapeutic effect. These new formulations are a major step towards the inclusion of *Ocimum sanctum* in pharmaceutical practice in the modern world [44].

7.2 Toxicity Studies

Ocimum sanctum toxicological assessment has been performed based on different *in vitro* and *in vivo* research studies to determine the safety profile of the plant. Experimental animal acute toxicity studies have typically shown a large margin of safety whereby no significant mortality or behavioral change is found even at a relatively high dose. Sub-acute and chronic toxicity tests have also shown that there are very low toxicity effects, and no significant changes to biochemical, hematological and histopathological parameters were observed [45].

Moreover, cytotoxicity experiments with cell lines have revealed that Tulsi extracts are comparatively non-toxic at therapeutic levels, hence, their safe pharmacological use. Nevertheless, certain toxicity differences might exist based on the nature of extract, dose, and exposure duration and administration routes, which highlights the importance of standard preparations [46].

7.3 Safety Profile

The use of *Ocimum sanctum* as a medicinal plant is generally considered safe based on many years of traditional use and scientific evidence. When taken in prescribed dosages, it is mostly well tolerated, and there are very few side effects. The plant has a good safety profile as it is of natural origin and has a balanced phytochemical profile that minimizes chances of serious adverse reactions typical of synthetic drugs [47].

Tulsi extracts and oils have been found to be topically compatible with the skin with minimal cases of irritation or allergy. There is also no known harm when taken orally but with high dosage, it could cause mild gastrointestinal disturbance in some sensitive individuals [48].

Although safe, it is recommended with caution in certain groups of people e.g. pregnant or lactating and those with underlying medical conditions because the full clinical picture of these groups is yet to be established. Moreover, the possibility of herb-drug interactions must be taken into account, in particular, when Tulsi is combined with traditional drugs [49].

8. Limitations and Future Perspectives

Although *Ocimum sanctum* has a good potential in terms of anti-inflammatory effects, there are various constraints that prevent its complete translation into evidence-based clinical practice. The absence of properly-designed clinical trials is one of the greatest challenges. The evidence available is mainly based on *in vitro* studies and animal models which, as informative as they are, might not be a complete reflection of human physiological conditions. Lack of big, randomized, controlled clinical trials limits the possibility of conclusively determining its effectiveness, optimal dose, and safety in humans long-term [50].

The second important limitation is that plant extracts have not been standardized. Phytochemical composition of *Ocimum sanctum* can vary greatly based on the geographical locality, conditions of cultivation, harvesting date and mode of extraction. This inconsistency causes variation in the results of the therapy, hence comparison of results across different studies is challenging. Thus, standardization of extracts and the establishment of concentration of major bioactive compounds (eugenol, ursolic acid, and rosmarinic acid) are vital in achieving reproducibility, quality control, and regulatory acceptance [51].

In addition, additional deeper molecular-based studies should be conducted to gain a clearer insight in to the exact mechanisms of its anti-inflammatory actions. Although the existing body of research emphasizes the role of such pathways as COX, LOX, and NF- κ B, extensive research with the help of the newest methods, such as genomics, proteomics, and metabolomics, is needed to determine particular molecular targets and signaling pathways. These studies would offer more mechanistic validation and can be used to develop specific therapeutic uses [52].

In the future, it is recommended that future studies should be conducted on the integration of traditional knowledge and modern scientific methods. These involve carrying out rigorous clinical trials, standardization of formulations, and investigating new drug delivery systems which include nanoformulations. Also, the exploration of the synergistic impact with other phytochemicals or standard drugs can be further used to increase its therapeutic effect [53].

To summarize, although *Ocimum sanctum* has a high potential as a natural anti-inflammatory, the challenges identified above will be essential to overcome with the help of multidisciplinary and systematic research to implement it in contemporary medical practice [54].

CONCLUSION

Ocimum sanctum (Tulsi) demonstrates strong and well-supported anti-inflammatory potential, supported by a substantial body of preclinical evidence. Its rich phytochemical composition, including compounds such as eugenol, ursolic acid, rosmarinic acid, and flavonoids, contributes significantly to its therapeutic effects. These bioactive constituents work synergistically to modulate key inflammatory pathways, making Tulsi an effective natural agent in controlling both acute and chronic inflammation.

One of the most important highlights of Tulsi is its multi-target enzyme inhibition mechanism. Unlike conventional drugs that typically act on a single pathway, *Ocimum sanctum* simultaneously inhibits major inflammatory mediators such as cyclooxygenase (COX) and lipoxygenase (LOX), suppresses transcription factors like NF- κ B, and regulates pro-inflammatory cytokines including TNF- α , IL-1 β , and IL-6. This integrated and multi-level mechanism not only enhances therapeutic efficacy but also reduces the likelihood of adverse effects associated with single-target synthetic drugs. In addition, its antioxidant properties further strengthen its anti-inflammatory action by reducing oxidative stress and protecting cellular components from damage. The combination of enzyme inhibition, cytokine modulation, and antioxidant activity positions Tulsi as a comprehensive and holistic anti-inflammatory agent.

Overall, *Ocimum sanctum* emerges as a promising herbal therapeutic with significant potential for development into modern pharmaceutical formulations. However, to fully establish its clinical utility, further research focusing on standardization, molecular validation, and well-designed clinical trials is essential. With continued scientific exploration, Tulsi holds great promise for integration into evidence-based medicine as a safe and effective natural anti-inflammatory therapy.

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CONFLICT OF INTEREST: Nil

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