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REVIEW ARTICLE

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UNLOCKING THE THERAPEUTIC POTENTIAL OF *BOSWELLIA SERRATA* IN CHRONIC INFLAMMATORY DISORDERS

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ABSTRACT: Chronic inflammatory disorders such as rheumatoid arthritis, osteoarthritis, inflammatory bowel disease (IBD), and asthma are major contributors to global morbidity, characterized by persistent immune activation, oxidative stress, and progressive tissue damage. Despite advances in pharmacotherapy, conventional anti-inflammatory agents including nonsteroidal anti-inflammatory drugs (NSAIDs) and corticosteroids are associated with significant limitations such as gastrointestinal toxicity, immunosuppression, and lack of long-term disease-modifying effects. These challenges have prompted increasing interest in plant-derived therapeutics with improved safety and multi-target mechanisms of action. *Boswellia serrata*, commonly known as Indian frankincense, is a well-recognized medicinal plant in Ayurvedic medicine traditionally used to treat inflammatory conditions. Its therapeutic potential is largely attributed to boswellic acids, particularly 3-O-acetyl-11-keto-β-boswellic acid (AKBA), which exhibits potent biological activity. Extensive studies have demonstrated that these bioactive compounds possess significant anti-inflammatory, immunomodulatory, and anti-arthritic effects. Mechanistically, boswellic acids inhibit 5-lipoxygenase (5-LOX), leading to reduced leukotriene synthesis, and suppress pro-inflammatory cytokines such as tumor necrosis factor-α, interleukin-1β, and interleukin-6 via modulation of nuclear factor kappa B (NF-κB) signaling pathways. Furthermore, *Boswellia serrata* exhibits antioxidant properties that help mitigate oxidative stress and protect cellular components. Recent advances in formulation strategies, including nanoparticles and phytosome-based delivery systems, have improved the bioavailability and therapeutic efficacy of boswellic acids. Overall, *Boswellia serrata* represents a promising natural therapeutic agent for chronic inflammatory disorders. However, further well-designed clinical trials and standardized formulations are essential to validate its safety, efficacy, and clinical applicability.

Keywords: *Boswellia serrata*, Boswellic acids, Chronic inflammation, 5-LOX inhibition, Herbal therapeutics

I. INTRODUCTION

Chronic inflammatory diseases, such as rheumatoid arthritis, osteoarthritis, inflammatory bowel disease (IBD), asthma, and other neuroinflammatory diseases, present a significant and increasing global health burden. These diseases contribute to morbidity over the long term, decreased life quality, and high global healthcare expenses [1]. The similar background of these diseases is a constant and unregulated inflammation, which not only leads to the occurrence of diseases but also further complicates their progression and the further development of complications. Though inflammation is a defense mechanism to injury or infection, when it is chronically precipitated, it results in the overproduction of pro-inflammatory mediators, oxidative stress, and ongoing tissue damage. Such persistent inflammatory condition impairs normal cellular homeostasis and is central to the pathophysiology of many chronic diseases [2].

The most common therapeutic measures used in the present day are synthetic anti-inflammatory drugs like nonsteroidal anti-inflammatory drugs (NSAIDs), corticosteroids, and disease-modifying immunosuppressants. Although these treatments may be effective in symptomatic relief and in the short term, their long-term use is commonly linked to serious side effects, such as gastrointestinal irritation, cardiovascular risks, hormonal imbalance, immunosuppression, and possible drug resistance. Furthermore, these treatments usually focus on one or two pathways and might not be sufficient to deal with the complexity of chronic inflammation as it is a multifactorial condition [3].

As a result, phytopharmaceuticals and plant-based therapeutics have garnered increasing interest based on their multi-target properties that have superior safety profiles. In that regard, a lot of attention has been devoted to *Boswellia serrata*, which is often referred to as Indian frankincense. Its oleo-gum resin is traditionally used in Ayurvedic medicine and has a long-standing history of use to treat pain, inflammatory disorders, and wound healing. Contemporary studies have started to confirm these historical arguments pointing to its high phytochemical content and its wide range of pharmacological effects [4].

The objective of the current review is to critically and systematically examine the phytochemistry, pharmacological actions and therapeutic opportunities of *Boswellia serrata* in chronic inflammatory diseases, its molecular targets, formulation developments, and its future clinical uses [5].

2. Literature Search Methodology

The systematic and far-reaching literature search was carried out to obtain the necessary scientific knowledge on *Boswellia serrata* and its treatment opportunities in chronic inflammatory disorders. Several electronic databases, such as PubMed, Scopus, ScienceDirect, and Google Scholar were searched thoroughly, in the case of covering a wide range of experimental and clinical studies [6].

Relevant publications, including those about *Boswellia serrata*, boswellic acids, AKBA, anti-inflammatory, chronic inflammation, immunomodulatory, and herbal therapeutics, were retrieved using appropriate keywords and combinations of these keywords. It was narrowed down using the operators of Boolean (AND, OR) to enhance the specificity of the results. Moreover, selected articles reference lists were manually filtered to reveal other relevant articles [7].

The inclusion criteria were well outlined so as to guarantee the quality and relevancy of the literature selected. The studies contained both original research and review articles on the *in vitro* experiments, *in vivo* animal studies, and clinical trials on the pharmacological effects, mechanism of action, and therapeutic uses of *Boswellia serrata*. Special consideration was paid to the works that conducted the research of its role in chronic inflammatory diseases [8].

The exclusion criteria included articles not peer reviewed, conference abstracts and lack of adequate data, duplication of articles, and absence of clear methodology or scientific validation. Articles that were not in English or had partial or unclear outcomes were also left out [9].

The literature search was mainly restricted to publications that were published in the past 20 years to provide current information although landmark publications of the past were taken when necessary. Data collected were screened, organized and critically analyzed in a systematic manner to give a structured and evidence-based review.

3. Botanical Description and Ethnomedicinal Uses

Boswellia serrata (Burseraceae) is a common medicinal plant that is known to contain oleo-gum resin, popularly known as Indian frankincense. It is a medium sized and deciduous tree that is usually found in dry and hilly areas. The plant has a morphological characteristic of a straight trunk with easy-peeling thin papery bark. When cut, the bark gives out a resin that is very fragrant and solidifies when exposed to air and provides the major source of its medicinal constituents. The leaves are pinnate, serrated on the margin and the flowers are small, whitish to pale pink and form axillary racemes [10].

Geographically, *Boswellia serrata* is mainly found in India especially in states like Rajasthan, Madhya Pradesh and Gujarat and also in some parts of Middle East and Africa. It is also adapted to arid and semi-arid conditions and it can grow on rocky soils with low water content which helps in the buildup of its bioactive resin constituents [11].

Traditionally, *Boswellia serrata* has long been a part of traditional medicine systems, notably Ayurveda, and has been in extensive use ethnomedically over the centuries. The resin of it has been used in the treatment of a variety of inflammatory and chronic diseases. Conventionally, its application widely occurs in the management of arthritis because of its capacity to inhibit inflammation and pains of the joints [12]. It is also applied in respiratory diseases like asthma where it is used to relieve bronchial inflammation and enhance airflow. It has been found to be useful in the case of gastrointestinal diseases such as ulcerative colitis wherein it helps to reduce the inflammation of the intestine. Also, the resin is used in wound healing procedures because of its antimicrobial and tissue-rejuvenating effects, which promote the early recovery and restoration (Table 1) [13].

Table 1: Taxonomy and Traditional Uses of *Boswellia serrata* [14]

Parameter	***Description***
Kingdom	Plantae
Subkingdom	Tracheobionta (vascular plants)
Division	Magnoliophyta (angiosperms)
Class	Magnoliopsida (dicotyledons)
Order	Sapindales
Family	Burseraceae
Genus	Boswellia
Species	*Boswellia serrata* Roxb.
Common names	Indian frankincense, Salai guggul
Plant type	Medium-sized deciduous tree
Part used	Oleo-gum resin (primary), bark
Geographical distribution	India, Middle East, North Africa
Traditional use – Arthritis	Reduces joint inflammation and pain
Traditional use – Asthma	Relieves bronchial inflammation
Traditional use – Ulcerative colitis	Reduces intestinal inflammation
Traditional use – Wound healing	Promotes tissue repair and antimicrobial action

4. Phytochemical Profile

4.1 Major Bioactive Compounds

Boswellia serrata has an unparalleled and complicated phytochemical profile, with oleo-gum resin (the primary one) being the major source of its diverse pharmacological effects. The greatest bioactive constituents are boswellic acids, a family of pentacyclic triterpenoids that take the centre stage in its anti-inflammatory and therapeutic properties. One of the key substances of this group that leads to anti-inflammatory and analgesic effects is β-boswellic acid, which acts on the regulation of inflammatory mediators [15]. A structurally modified derivative, acetyl-2 -boswellic acid, has a stronger biological activity and better effects in inhibiting inflammatory pathways. The most powerful and the most extensively researched is 3-O-acetyl-11-keto-β-boswellic acid (AKBA) that is reported to have the strongest and the most selective inhibitory effect on 5-lipoxygenase (5-LOX) enzyme, thereby

preventing leukotriene production and regulating inflammation on the molecular level (Table 2) [16].

Along with boswellic acids, *Boswellia serrata* also has other significant constituents like terpenoids, which are useful in anti-inflammatory and antimicrobial action, and essential oils that consist of monoterpenes and sesquiterpenes that help in giving aroma and additional therapeutic effects. These compounds form a synergistic effect on the presence of the compounds thereby improving the overall pharmacological potential of the plant. There may be differences in phytochemical profile based on geographical origin, environmental factors, and methods of extraction, which further justifies the need to standardize [17].

4.2 Analytical Techniques

Advanced analytical methods are used to accurately identify, characterize and quantify phytochemicals in *Boswellia serrata*. High-Performance Liquid Chromatography (HPLC) is also extensively used to quantify boswellic acids, in particular AKBA, in a precise way, and is a vital tool in the quality control and standardization of herbal extracts [18]. The analysis of volatile constituents and essential oils is usually carried out using Gas Chromatography Mass Spectrometry (GC-MS), which has detailed information about the composition of terpenes and aromatic constituents. Moreover, Liquid Chromatography-Mass Spectrometry (LC-MS) provides both sensitive and in-depth profiling of complicated phytochemical mixtures, allowing the identification and recognition of both predominant and minor bioactive substances [19].

Combined, these analysis methods are critical to maintaining consistency, efficacy, and safety of *Boswellia serrata*-based preparations, and facilitate continued research and development in phytopharmaceutical use [20].

Table 2: Major Phytochemicals of *Boswellia serrata* [21]

S. No.	*Phytochemical*	*Class*	*Source/Part*	*Biological Activity*
1	β-boswellic acid	Pentacyclic triterpenoid	Resin	Anti-inflammatory
2	Acetyl-β-boswellic acid	Triterpenoid	Resin	Anti-inflammatory, analgesic
3	11-keto-β-boswellic acid (KBA)	Triterpenoid	Resin	Enzyme inhibition
4	3-O-acetyl-11-keto-β-boswellic acid (AKBA)	Triterpenoid	Resin	Potent 5-LOX inhibitor
5	α-boswellic acid	Triterpenoid	Resin	Anti-inflammatory
6	Acetyl-α-boswellic acid	Triterpenoid	Resin	Immunomodulatory
7	Tirucallic acids	Triterpenoid derivatives	Resin	Anti-inflammatory
8	Incensole	Diterpene	Resin	Neuroprotective, anti-inflammatory
9	Incensole acetate	Diterpene	Resin	Anti-inflammatory, CNS effects
10	Limonene	Monoterpene	Essential oil	Antioxidant, antimicrobial
11	α-pinene	Monoterpene	Essential oil	Anti-inflammatory, bronchodilator
12	β-pinene	Monoterpene	Essential oil	Antimicrobial
13	Myrcene	Monoterpene	Essential oil	Analgesic, anti-inflammatory
14	p-cymene	Monoterpene	Essential oil	Antioxidant
15	Terpinen-4-ol	Monoterpene alcohol	Essential oil	Antimicrobial, anti-inflammatory

5. Pharmacological Activities

5.1 Anti-inflammatory Activity

Boswellia serrata is a potent anti-inflammatory herb, which is mainly due to its bioactive boswellic acids. These compounds work by selectively inhibiting the enzyme 5-lipoxygenase (5-LOX), which is an important enzyme in the production of leukotrienes- important mediators of inflammation [22]. This pathway is blocked by boswellic acids thus inhibiting the synthesis of leukotrienes which reduces inflammation in different tissues. Also, *Boswellia serrata* has been demonstrated to inhibit the release of pro-inflammatory cytokines like tumor necrosis factor-alpha (TNF- alpha) and interleukin-1 beta (IL-1 b) that also help to reduce inflammation and tissue injury. This is a multi-targeted mechanism that is useful in chronic inflammatory diseases especially (Table 3 [23].

5.2 Immunomodulatory Effects

In addition to its anti-inflammatory effect, *Boswellia serrata* exhibits considerable immunomodulatory properties. It is known to control the immune responses by mediating the immune cell signaling pathways such as the macrophages and lymphocytes. The downregulation of the nuclear factor kappa B (NF-KB) pathway, which is a major regulator of immune responses and inflammation, is one of the most important mechanisms. *Boswellia serrata* suppresses the NF-KB activation, thus lowering the levels of inflammatory genes and cytokines, which will restore immune balance and avoid excessive immune activation [24].

5.3 Anti-arthritic Activity

Boswellia serrata has anti-arthritic effects that are supplemented by the anti-inflammatory and immunomodulatory properties of this substance. It has also been extensively investigated in terms of its capability in alleviating swelling, pains, and stiffness of joints in particular in the cases of rheumatoid arthritis and osteoarthritis. Moreover, it also has cartilage-protective effects that suppress enzymes that degrade the connective tissue, thus maintaining joint integrity and enhancing mobility. All these measures help in its position as a natural alternative in the treatment of joint disorders [25].

5.4 Other Activities

Besides the above, *Boswellia serrata* also has other significant pharmacological activities. Its antioxidant action aids in counteracting the reactive oxygen species (ROS), which decreases the oxidative stress linked to chronic inflammation. It also exhibits anti-cancer effects in that it causes apoptosis and suppression of tumor cell growth in different experimental systems. Besides, its gastroprotective properties also aid in the treatment of gastrointestinal diseases by suppressing inflammation and the mucosal lining. These various activities underscore the wide therapeutic possibilities of *Boswellia serrata* in various disease conditions (Fig. 1) [26].

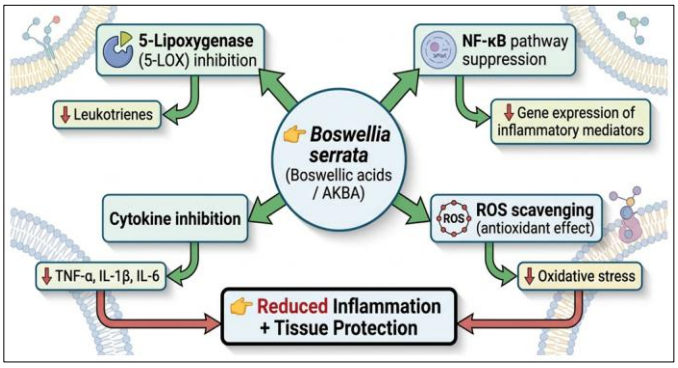

Figure 1: Molecular Mechanism of Action of *Boswellia serrata* [27]

Table 3: Pharmacological Activities and Mechanisms of *Boswellia serrata* [28]

S. No.	*Pharmacological Activity*	*Key Bioactive Compound*	*Mechanism of Action*	*Therapeutic Outcome*
1	Anti-inflammatory	AKBA	Inhibition of 5-LOX enzyme	Reduced leukotriene synthesis
2	Anti-inflammatory	β-boswellic acid	Suppression of inflammatory mediators	Decreased inflammation
3	Immunomodulatory	Acetyl-β-boswellic acid	Modulation of immune cell signaling	Balanced immune response
4	Immunomodulatory	AKBA	Downregulation of NF-κB pathway	Reduced cytokine expression
5	Anti-arthritic	Boswellic acids	Inhibition of cartilage-degrading enzymes	Joint protection
6	Anti-arthritic	AKBA	Reduction of synovial inflammation	Decreased joint swelling
7	Analgesic	Terpenoids	Modulation of pain pathways	Pain relief
8	Antioxidant	Phenolic compounds	Scavenging of reactive oxygen species (ROS)	Reduced oxidative stress
9	Anti-cancer	AKBA	Induction of apoptosis	Inhibition of tumor growth
10	Anti-cancer	Boswellic acids	Inhibition of cell proliferation	Reduced cancer progression
11	Gastroprotective	Boswellic acids	Reduction of gastric inflammation	Mucosal protection
12	Anti-asthmatic	AKBA	Inhibition of leukotriene-mediated bronchoconstriction	Improved airway function
13	Antimicrobial	Essential oils	Disruption of microbial cell membrane	Reduced infection
14	Neuroprotective	Incensole acetate	Modulation of neuronal signaling	Protection against neuroinflammation
15	Anti-ulcerative colitis	Boswellic acids	Suppression of intestinal inflammation	Improved gut health

6. Role in Chronic Inflammatory Disorders

Boswellia serrata has gained significant attention for its therapeutic role in managing various chronic inflammatory disorders due to its multi-target pharmacological actions, particularly its ability to modulate inflammatory mediators and immune responses [29].

Rheumatoid Arthritis (RA): *Boswellia serrata* has demonstrated encouraging effects in rheumatoid arthritis, a chronic autoimmune disease, which is marked by inflammation of the synovium, and destruction of the joints. Boswellic acids inhibit the synthesis of leukotrienes and prevent the pro-inflammatory cytokines, which reduce inflammation. It leads to a reduction of joint swelling, pain, and morning stiffness, as well as, an increase in joint mobility and overall functioning [30].

Osteoarthritis (OA): In osteoarthritis, where the cartilage and joint structures undergo degeneration, *Boswellia serrata* has protective effects by suppressing cartilage-degrading enzymes like matrix metalloproteinases. It occurs by decreasing pain and inflammation, enhancing joint health, and thereby decelerates the disease progression and improves the quality of life [31].

Inflammatory Bowel Disease (IBD): *Boswellia serrata* has demonstrated therapeutic potential in conditions such as ulcerative colitis and Crohn's disease. Its anti-inflammatory properties help reduce intestinal inflammation by suppressing cytokine production and oxidative stress. This leads to improvement in symptoms such as abdominal pain, diarrhea, and mucosal damage [32].

Asthma: In asthma, a chronic inflammatory airway disease, *Boswellia serrata* acts by inhibiting leukotriene-mediated bronchoconstriction [33]. These results in reduced airway inflammation, improved airflow, and decreased frequency of asthma attacks, making it beneficial as an adjunct therapy.

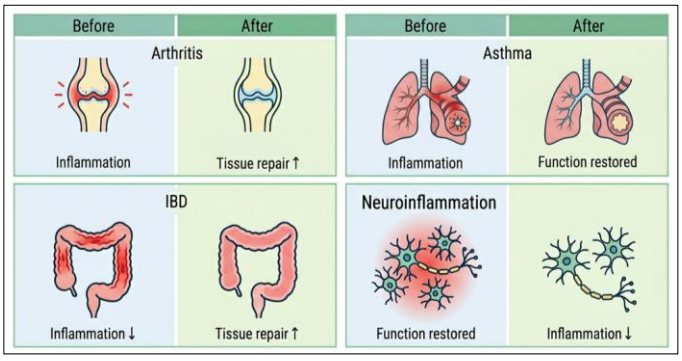

Figure 2: Therapeutic Application in Chronic Inflammatory Disorder[35]

Neuroinflammation: Emerging evidence suggests that *Boswellia serrata* may play a role in managing neuroinflammatory conditions by modulating inflammatory signaling pathways in the central nervous system. Its antioxidant and anti-inflammatory effects help protect neurons from damage, potentially benefiting conditions such as Alzheimer's disease and other neurodegenerative disorders (Fig. 2) [34].

7. Pharmacokinetics and Bioavailability of Boswellic Acids

Absorption and Metabolism of Boswellic Acids

The major bioactive compounds of *Boswellia serrata* are boswellic acids, which have low absorption rates and limited absorption after oral intake because they are highly lipophilic and insoluble in water [36]. Once consumed, they are absorbed via the gastrointestinal tract and are metabolized in the liver, with the metabolism mainly consisting of phase I and phase II processes. Research indicates that boswellic acids can be metabolized into different derivatives, which can also be involved in their biologic action. But they have low plasma concentrations and the highest levels are obtained after a long time, which means inefficient pharmacokinetic behavior [37].

Low Bioavailability Challenges

Low oral bioavailability is one of the significant problems of the clinical use of boswellic acids. This is mainly explained by the low water solubility, low intestinal permeability, high metabolism and possible efflux through the intestinal transporters. Moreover, active compounds are also further decreased in systemic availability by first-pass metabolism in the liver. All these leads to decreased therapeutic efficacy especially with conventional formulations [38].

Factors Affecting Drug Absorption

Several factors influence the absorption of boswellic acids, including physicochemical properties (lipophilicity, molecular size), formulation type, and presence of dietary fats. Co-administration with fatty meals has been reported to enhance absorption due to improved solubilization of lipophilic compounds. Gastrointestinal conditions, pH, and enzymatic activity also play significant roles in determining the extent of absorption. Furthermore, the choice of extraction method and standardization of boswellic acid content can impact bioavailability [39].

Role of AKBA Pharmacokinetics

Among the boswellic acids, 3-O-acetyl-11-keto-β-boswellic acid (AKBA) is considered the most potent but exhibits particularly poor bioavailability. Its pharmacokinetic profile is characterized by low plasma concentration, limited tissue distribution, and rapid elimination. Despite its strong *in vitro* activity, these limitations hinder it's *in vivo* effectiveness, making it a critical focus for formulation optimization [40].

Strategies to Enhance Bioavailability

In order to overcome these shortcomings, various sophisticated formulation approaches have been devised. They comprise phytosome-based systems, which enhance lipid compatibility and absorption, and nanoparticles, liposomes, and solid lipid carrier, which enhance solubility, stability, and controlled release. Self-emulsifying drug delivery systems (SEDDS) and co-administration with bioenhancers are also under consideration to enhance systemic availability. These methods dramatically improve therapeutic potential and pharmacokinetic profile of boswellic acids and increase their applicability in clinical practice [41].

8. Formulation Approaches and Drug Delivery

Standard Extracts (*Boswellia Extract* Capsules)

Traditional preparations of *Boswellia serrata* are mostly in the form of standardized extracts in capsule and tablet forms. These preparations usually have a specified percentage of boswellic acids, which guarantee predictability and reproduciability of therapeutic effects. Standard extracts are commonly used because they are easy to administer and their safety has been proven. Nevertheless, they lack a clinical potential due to low bioavailability of boswellic acids, especially AKBA, which limits the ability to achieve the best therapeutic response [42].

Phytosomes (Enhanced Bioavailability)

Phytosome technology has emerged as a promising strategy to enhance the bioavailability of boswellic acids. In this approach, the active phytoconstituents are complexed with phospholipids, improving their lipid compatibility and facilitating better absorption across biological membranes. Phytosomal formulations of *Boswellia serrata* have demonstrated improved pharmacokinetic profiles, higher plasma concentrations, and enhanced therapeutic efficacy compared to conventional extracts. This system also offers improved stability and targeted delivery of active compounds [43].

Nanoparticles and Liposomes

Advanced drug delivery systems such as nanoparticles and liposomes have been extensively explored to overcome the limitations associated with boswellic acids. Nanoparticles, including solid lipid nanoparticles and polymeric nanoparticles, enhance solubility, protect bioactive compounds from degradation, and enable controlled release. Liposomes, which are phospholipid-based vesicles, improve drug encapsulation and facilitate targeted delivery to inflamed tissues. These systems significantly enhance bioavailability, prolong circulation time, and increase therapeutic effectiveness, making them highly suitable for chronic inflammatory conditions [44].

Topical Formulations

Topical formulations of *Boswellia serrata*, including gels, creams, and ointments, are particularly useful for localized inflammatory conditions such as arthritis and musculoskeletal pain. These formulations allow direct delivery of active compounds to the affected site, minimizing systemic exposure and reducing the risk of side effects. Additionally, topical applications provide sustained release and improved patient compliance. Recent advancements have also incorporated nanocarriers into topical systems to further enhance skin penetration and therapeutic outcomes [45].

9. Safety and Toxicity

General Safety Profile

Boswellia serrata is generally regarded as safe when used at recommended therapeutic doses, as supported by preclinical and clinical studies. Standardized extracts of boswellic acids have demonstrated a favorable safety profile with minimal systemic toxicity. Its long history of use in traditional Ayurvedic medicine further supports its tolerability and acceptability in managing chronic inflammatory conditions [46].

Adverse Effects and Gastrointestinal Disturbances

Despite its overall safety, some mild adverse effects have been reported, particularly involving the gastrointestinal tract. These may include nausea, abdominal discomfort, diarrhea, and acid reflux. Such effects are usually transient and dose-dependent, resolving upon dose adjustment or discontinuation. Compared to conventional anti-inflammatory drugs, these side effects are relatively mild and less frequent [47].

Need for Long-Term Toxicity Studies

Although short-term studies indicate good safety, there is a need for more comprehensive long-term toxicity and safety evaluations. Limited data are available regarding chronic exposure, high-dose usage, and potential interactions with other medications. Well-designed clinical trials are essential to establish its long-term safety, pharmacovigilance, and risk-benefit profile. Standardization of extracts and controlled dosing regimens will further enhance its safe integration into modern therapeutic practice [48].

10. Future Perspectives

Standardization of Boswellic Acid Content

The absence of standardization of the active constituents of *Boswellia serrata* especially boswellic acids like AKBA is one of the critical issues in the clinical use of *Boswellia serrata*. The next line of research ought to be coming up with validated analytical procedures and quality control measures that can be used to guarantee consistency in composition, potency, and reproducibility of herbal preparations. It will be essential to set pharmacopeial standards to be accepted and used widely in therapeutics [49].

Clinical Trials in Chronic Diseases

Despite the significant body of preclinical evidence on the anti-inflammatory role of *Boswellia serrata*, there are few clinical trials of large size and high-quality. Future research ought to consider its effectiveness, optimal dose, long-term safety and its effectiveness in comparison with conventional treatment in the chronic inflammatory diseases, including arthritis, IBD and asthma. These trials will yield powerful clinical evidence that can be utilized to incorporate it in the evidence-based medicine [50].

Targeted Drug Delivery Systems

Advancements in drug delivery technologies offer significant opportunities to enhance the therapeutic potential of boswellic acids. Future research should focus on developing targeted delivery systems such as nanoparticles, liposomes, and phytosomes to improve bioavailability, site-specific action, and sustained release. These approaches can help overcome pharmacokinetic limitations and maximize therapeutic outcomes [51].

Synergistic Herbal Combinations

The exploration of synergistic combinations of *Boswellia serrata* with other medicinal plants or bioactive compounds represents a promising area of research. Combining herbs with complementary mechanisms of action may enhance therapeutic efficacy, reduce required dosages, and minimize side effects. Scientific validation of such polyherbal formulations through mechanistic and clinical studies will be essential for their successful development and application [52].

Conclusion

Boswellia serrata has emerged as a highly promising medicinal plant with significant therapeutic potential in the management of chronic inflammatory disorders. Extensive scientific evidence highlights its strong anti-inflammatory activity, primarily attributed to boswellic acids, particularly AKBA, which effectively modulate key inflammatory pathways such as 5-lipoxygenase inhibition and cytokine suppression. The plant demonstrates a multi-target mechanism of action, encompassing anti-inflammatory, immune-modulatory, antioxidant, and tissue-protective effects. This multifaceted activity enables it to address the complex pathophysiology of chronic inflammatory diseases more effectively than single-target conventional therapies. Additionally, its relatively favorable safety profile further supports its potential as a long-term therapeutic option. Given these advantages, *Boswellia serrata* represents a promising alternative or adjunct therapy for conditions such as arthritis, inflammatory bowel disease, asthma, and other inflammation-related disorders. However, despite encouraging preclinical and preliminary clinical findings, there remains a critical need for well-designed, large-scale clinical trials to establish its efficacy, optimal dosing, safety, and long-term outcomes.

Furthermore, standardization of extracts and advancements in drug delivery systems will play a vital role in translating its traditional use into modern evidence-based medicine. Overall, *Boswellia serrata* holds substantial potential as a natural, multi-target therapeutic agent, but its full clinical applicability depends on rigorous scientific validation and regulatory acceptance.

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