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BOSWELLIC ACID: A MULTIFUNCTIONAL PHYTOCHEMICAL WITH PROMISING THERAPEUTIC POTENTIAL

Yogesh Kumar Apurva[1], Vaibhav Rathore[2], Akhil Mangal[3], Suresh Kumar Dev*[1], Chetna Baregama[1], Vijay Singh Kachawa[4], Vijay Kumar Bansal[5], Mohammad Junaid Alam Mansoori[1], Ayush Garg[1]

[1]Venkateshwar Institute of Pharmacy, Sai Tirupati University, Udaipur, Rajasthan-313015, India.
[2]Teerthanker Mahaveer College of Pharmacy, Teerthanker Mahaveer University, Delhi Road, NH 9, Moradabad, Uttar Pradesh-244102, India.
[3]Bhai Gurudas College of Pharmacy, Sangrur, Punjab-148002, India.
[4]Satyam Institute of Pharmacy, Sai Tirupati University, Udaipur, Rajasthan-313015, India.
[5]Lachoo Memorial College of Science & Technology "Pharmacy Wing" Jodhpur, Rajasthan- 342001, India.

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***Corresponding author:**

Dr. Suresh Kumar Dev

Venkateshwar Institute of Pharmacy, Sai Tirupati University, Udaipur, Rajasthan-313015, India.

ABSTRACT

Boswellic acids, a class of pentacyclic triterpenes extracted from the gum resin of Boswellia species, have been recognized as bioactive compounds of significant pharmacological importance. People often call Boswellia serrata "Salai guggal." The resin part of Salai guggal is full of Boswellic acids, while the essential oil part is made up of a combination of mono-, di-, and sesquiterpenes. The gum part is mostly made up of pentose and hexose sugars. Traditional Chinese and Indian medicine practitioners use this oleo-gum resin a lot because it has a lot of useful biological properties. For example, it can reduce inflammation, arthritis, rheumatism, diarrhea, high cholesterol, asthma, cancer, and microbes, and it can also relieve pain. Boswellic acids have also been shown to be strong against viruses, cancer, and inflammation. It has been utilized as a natural remedy since prehistoric times to treat both acute and chronic conditions, including inflammatory illnesses. The goal of this study is to give an overview of boswellic acids' chemical structure, pharmacological profile, therapeutic potential, and formulation strategies. It will focus on current improvements in drug delivery systems that are meant to make them more effective and available.

KEYWORDS: Boswellic acids, Pharmacological and Therapeutic Properties, Anticancer, Anti-inflammatory, anti-microbial anti-fungal, antiviral.

INTRODUCTION

The heightened risk of side effects associated with manufactured medications has expanded the application and use of molecules derived from natural bioactives. (Srivastava R. et al 2022) A lot of people are starting to use herbal plant items. (Dev SK et al. 2017). Natural products are derived from nature and provide excellent biological and physiological features that can be employed in drug research and design. (Ashish Garg et al. 2016). Bioactives from plants have a wide range of biological effects, such as antibacterial, anticancer, vasorelaxant, immunosuppressive, antimalarial, and many others. Plants produce also significant number of antioxidants to prevent the oxidative stress caused by photons and oxygen thus can be a potential source for newer compounds with antioxidant activity. (Maya

Sharma et al. 2018), (Dev SK et al. 2018). These bioactives comprise phytoconstituents such as alkaloids, flavonoids, and phenolics, which are also responsible for anti-inflammatory and antioxidant actions that work together to help treat skin infections. (Kajal Jain et al. 2017).

For hundreds of years, herbal extracts made from different kinds of Boswellia trees (family Burseraaceae) have been used in traditional medicine all over the world to cure a number of illnesses. There are about 25 different species in the Boswellia genus. Some of the most notable ones are Boswellia serrata, Boswellia sacra, Boswellia carterii, Boswellia papyrifera, Boswellia neglecta, Boswellia rivae, Boswellia frereana, and Boswellia ovalifoliolata. Contemporary phytochemistry has recognized boswellic acids as essential bioactive components accountable for its therapeutic advantages (Safayhi et al., 1996). These naturally occurring pentacyclic triterpenes regulate various biological processes, providing extensive therapeutic applications, including anti-inflammatory, anticancer, antibacterial, and neuroprotective effects (Majeed et al., 2024). Salai guggal, also known as oleo gum resin, is a combination of essential oil, gum, and resin. The main components of the essential oil are monoterpenes, diterpenes, and sesquiterpenes. It also has phenolic chemicals and a diterpene alcohol called serratol in its essential oil. The gum part has pentose and hexose carbohydrates as well as certain enzymes that break down food and oxidize it. Boswellic acid, a biologically active phytoconstituent, is present in the resin of nearly all Boswellia species and is chemically classified as a pentacyclic triterpene acid. (Farah Iram et al. 2017)

3. Sources and Biosynthesis: The oleo-gum resin of Boswellia serrata, B. carterii, B. sacra, and B. frereana is the main source of boswellic acids. Squalene cyclization is the first step in the mevalonate pathway, which is followed by enzymatic oxidation and acetylation to produce a variety of derivatives. **(Ragab et al., 2023)**. Environmental factors, collection season, and geographic origin affect the concentration and ratio of individual BAs, necessitating standardization in pharmaceutical formulations **(Majeed et al., 2024).**

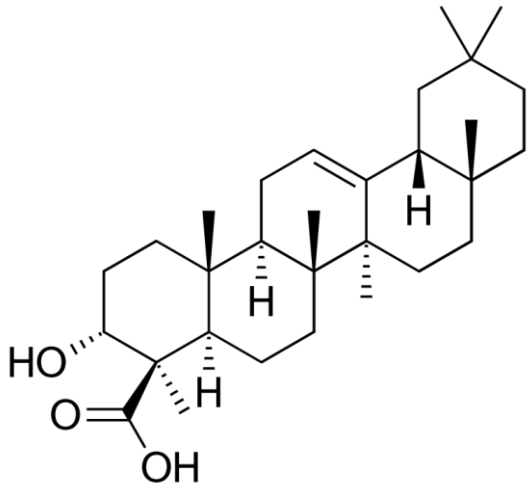

Figure 1: Structure of Boswellic Acid.

4. Pharmacological and Therapeutic Properties: Following table: 1 shows the Pharmacological and Therapeutic Properties

Table 1: Pharmacological and Therapeutic Properties of Boswellic Acids (BAs)

Pharmacological Activity	Mechanism of Action / Experimental Findings	Key Boswellic Acid(s)	Model / Study Type	References (in-text citations)
Anti-inflammatory	Inhibits 5-lipoxygenase (5-LOX) enzyme, reduces leukotriene synthesis, downregulates NF-κB, TNF-α, IL-1β, and IL-6; decreases COX-2 expression.	AKBA, KBA	In vitro and clinical (osteoarthritis)	(Safayhi et al., 1996; Kimmatkar et al., 2003; Sengupta et al., 2010; Elgazar et al., 2023; Ragab et al., 2023)
Anticancer	Induces apoptosis via caspase-3/9 activation, inhibits STAT3, NF-κB, and VEGF; arrests cell cycle and suppresses angiogenesis.	AKBA, 3-O-acetyl-β-BA	In vitro (breast, colon, glioma); in vivo models	(Trivedi et al., 2023; Gong et al., 2022; Elgazar et al., 2023; Hussain et al., 2024)
Antimicrobial	Disrupts bacterial cell membrane integrity, inhibits bacterial enzymes; shows activity against *S. aureus*, *E. coli*, *Candida albicans*.	KBA, β-BA	In vitro microbiological assays	(Hussain et al., 2024; Gong et al., 2022; Ragab et al., 2023)
Antiviral	Reduces viral replication by interfering with viral protease and host NF-κB pathways.	AKBA	In vitro (Influenza, Herpes)	(Hussain et al., 2024)
Neuroprotective	Attenuates oxidative stress and neuroinflammation, inhibits	AKBA	Spinal cord injury and	(Kirste et al., 2011; Wang et al., 2024;

	microglial activation, promotes neuronal survival and motor recovery.		neurodegenerative models	Ragab et al., 2023)
Hepatoprotective	Reduces lipid peroxidation, restores antioxidant enzymes (SOD, CAT, GSH), protects against CCl_4-induced toxicity.	β-BA, AKBA	Animal models (rats)	(Majeed et al., 2024; Ragab et al., 2023)
Cardioprotective	Inhibits oxidative damage, lowers lipid peroxidation, modulates NO and inflammatory mediators in myocardial tissue.	AKBA	In vivo rat models	(Majeed et al., 2024; Vaidya et al., 2025)
Anti-ulcer	Decreases gastric acidity, protects mucosal lining, suppresses inflammatory cytokines.	AKBA	Rat gastric ulcer models	(Ragab et al., 2023; Majeed et al., 2024)
Immunomodulatory	Enhances lymphocyte proliferation and antibody titer; modulates Th1/Th2 cytokine balance.	AKBA	In vivo murine studies	(Hussain et al., 2024; Ragab et al., 2023)
Antioxidant	Scavenges reactive oxygen species (ROS), increases antioxidant enzymes; protects against lipid peroxidation.	AKBA, β-BA	In vitro assays (DPPH, FRAP)	(Gong et al., 2022; Schmiech et al., 2024)
Antidiabetic / Metabolic	Improves insulin sensitivity, reduces fasting glucose and lipid levels; modulates PPAR-γ pathway.	AKBA	Diabetic rat model	(Vaidya et al., 2025; Majeed et al., 2024)
Wound Healing	Promotes fibroblast proliferation, collagen deposition, and epithelialization; enhances angiogenesis.	AKBA, β-BA	Topical gel and in vivo wound models	(Schmiech et al., 2024; Vijayarani et al., 2020)

AKBA: *3-O-acetyl-11-keto-β-boswellic acid*, **KBA:** *11-keto-β-boswellic acid*, **3-O-acetyl-β-BA:** *3-O-acetyl-β-boswellic acid*, **β-BA:** *β-boswellic acid*.

5. Other Pharmacological Effects: Additional reported activities include hepatoprotective, cardioprotective, anti-ulcer, and immunomodulatory effects (Majeed et al., 2024; Ragab et al., 2023). Experimental studies suggest improvement in insulin sensitivity and lipid profiles, highlighting their metabolic regulatory potential **(Vaidya et al., 2025).**

Boswellic acid in peripheral nerve injury: AKBA was found to be effective for the treatment of sciaticnerve injury in animal models of rats at 5 mg/kg when administered intraperitoneally for 10 days on alternate days. Clinical efficacy was assessed by histological repairof damaged sciatic nerve and sciatic nerve-dominated effecton recovery of organ function. The results showed that AKBA has significant therapeutic potential in rats in thesciatic nerve injury model with efficacy of 100%. To confirmthe clinical efficacy of AKBA on reproducibility tests and sciatic nerve injury, the experimental results showed that AKBA has therapeutic potential on sciatic nerve injury inrats after intraperitoneal administration**. (Hussain, H et al 2024)**

6. Pharmacokinetic and Bioavailability Aspects: Boswellic acids have strong pharmacodynamics, but they don't work well when taken by mouth because they don't dissolve well in water, they go through a lot of first-pass metabolism, and they are pushed out of the body by P-glycoprotein transporters (Sharma et al., 2004; Skarke et al., 2012). AKBA and KBA exhibit minimal plasma concentrations subsequent to the oral administration of Boswellia extract (Sharma et al., 2004). Eating food helps with absorption, and optimizing the formulation greatly increases systemic exposure (Skarke et al., 2012). When used with bioenhancers such piperine or Piper longum extract, plasma levels have been observed to rise considerably (Vijayarani et al., 2020).

7. Formulation and Nanotechnology-Based Delivery: Multiple formulation strategies have been developed to address the challenges of poor solubility and low bioavailability associated with Boswellic acids. Phospholipid complexes and phytosomes have been employed to enhance membrane permeability and intestinal absorption **(Schmiech et al., 2024).** Solid lipid nanoparticles (SLNs) improve solubility, stability, and provide sustained drug release, offering a promising platform for oral and parenteral formulations **(Vijayarani et al., 2020).** Nanoemulsions and liposomes allow for controlled release and targeted delivery, which

increases the therapeutic concentration at the site of action. **(Ragab et al., 2023).** Co-formulation with piperine, a bioenhancer, has been shown to significantly increase oral bioavailability by inhibiting drug-metabolizing enzymes and first-pass metabolism **(Vijayarani et al., 2020).** Furthermore, chitosan-based niosomes have demonstrated improved topical and transdermal delivery, particularly beneficial for wound healing and anti-inflammatory applications **(Schmiech et al., 2024).** Collectively, these advanced nanotechnology-based delivery systems have resulted in improved pharmacokinetic profiles and enhanced pharmacological efficacy in preclinical and limited clinical investigations **(Majeed et al., 2024).**

8. Clinical Studies and Safety Profile: The safety and therapeutic effectiveness of standardized Boswellia serrata extracts in a range of inflammatory and degenerative disorders have been confirmed by several clinical studies. After eight weeks of treatment, Kimmatkar et al. (2003) showed that individuals with osteoarthritis saw a significant decrease in pain and an improvement in knee flexibility. After administering standardized formulations like 5-Loxin® and Aflapin®, Sengupta et al. (2008, 2010) also observed a significant reduction in inflammatory biomarkers like TNF-α and IL-1β as well as a rapid improvement in symptoms. Similar to this, Majeed et al. (2019, 2024) demonstrated a significant improvement within 5–7 days of administering a unique standardized Boswellia extract, confirming its therapeutic efficacy. A meta-analysis by (**Yu et al. 2020)** reinforced these findings, indicating consistent pain reduction and functional recovery across multiple randomized controlled trials. In terms of safety, (**Lalitha kumari et al. 2006)** and Krishnaraju et al. (2010) reported excellent tolerability, with only mild gastrointestinal discomfort or rare allergic reactions. Long-term clinical observations suggest that *Boswellia serrata* preparations are generally safe; however, (**Vishal et al. 2011)** emphasized the need for larger, multicentric trials to comprehensively evaluate their long-term safety and efficacy profiles.

9. Future Perspectives: Future research on Boswellic acids should focus on several crucial areas to enhance their therapeutic potential and clinical applicability. First, there is a pressing need for the standardization of Boswellia extracts and the identification of reliable bioactive markers to ensure consistency, efficacy, and quality control in formulations **(Ragab et al., 2023)**. Second, well-designed multicentric clinical trials are essential to establish clear dose–response relationships and to validate the efficacy and safety of Boswellic acids across diverse populations **(Majeed et al., 2024).** Third, the development of innovative nano-delivery systems, such as liposomes, nanoparticles, and solid lipid carriers, should be prioritized to overcome challenges related to poor solubility, low bioavailability, and limited tissue distribution **(Schmiech et al., 2024).** Additionally, pharmacogenomic investigations are warranted to elucidate inter-individual variations in therapeutic responses, enabling the development of more personalized and targeted treatment strategies **(Vijayarani et al., 2020).** Finally, combinatorial therapeutic approaches integrating Boswellic acids with conventional pharmacological agents could be explored to achieve synergistic effects, reduce side effects, and improve clinical outcomes in complex diseases such as cancer and inflammatory disorders **(Abdullah A. Elgazar et al., 2023).**

10. CONCLUSION

Boswellic acids represent an outstanding example of a multifunctional phytochemical with wide therapeutic potential. Their diverse pharmacological activities—anti-inflammatory, anticancer, antimicrobial, and neuroprotective—are underpinned by robust mechanistic and clinical evidence. Limitations related to poor bioavailability can be mitigated through advanced formulation and nanotechnology approaches. With continued clinical validation and standardization, BAs hold promise as effective, safe, and natural alternatives or adjuncts in managing inflammatory and degenerative diseases.

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