

Alpinia galanga (L.) Willd: A comprehensive review on phytochemistry, pharmacology, analytical characterization, nanotechnology applications, clinical evidences and safety profile

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Abstract

Alpinia galanga (L.) Willd., popularly known as greater galangal, is a rhizomatous plant widely utilized in Ayurveda, Unani, and traditional Southeast Asian medicine for its diverse therapeutic benefits. The plant is enriched with phytoconstituents such as flavonoids, phenolics, terpenoids, and essential oils that contribute to its broad pharmacological spectrum. Extensive research highlights its antioxidant, anti-inflammatory, antimicrobial, hepatoprotective, neuroprotective, anticancer, and cardioprotective activities, thereby supporting its traditional claims with modern scientific evidence. In addition to conventional ethnomedicinal usage, emerging computational approaches and cheminformatics-based analyses have provided valuable insights into the drug-likeness and pharmacokinetic profiles of its bioactive molecules. Advancements in analytical tools, particularly LC-MS, HPLC, and spectroscopic techniques, have enabled precise characterization and quantification of key markers such as galangin, enhancing its quality control and standardization potential. Moreover, modern formulation strategies, including phytosomes, nanoemulsions, and flavonosomes, are being explored to overcome limitations of poor bioavailability and improve therapeutic efficacy. Despite promising preclinical evidence, challenges remain in terms of clinical validation, large-scale standardization, and regulatory acceptance. Future research integrating Quality by Design (QbD), green extraction methods, and systematic clinical trials could pave the way for its development as a novel phytopharmaceutical or nutraceutical. This review comprehensively presents the ethnomedicinal relevance, phytochemistry, pharmacology, and modern innovations on *A. galanga*, emphasizing its scope in contemporary healthcare.

Keywords: *Alpinia Galanga*; Phytochemistry; Pharmacological Activities; Nanotechnology; Phytopharmaceuticals; Drug Discovery; Traditional Medicine.

1. Introduction

Plants have always been central to healthcare, providing both preventive and therapeutic benefits across cultures. Traditional systems such as Ayurveda, Unani, and Traditional Chinese Medicine rely heavily on botanicals, while in modern drug discovery, many approved medicines are either derived directly from plants or developed using phytochemical leads [1]. This dual role underlines the continuing global relevance of medicinal plants in bridging traditional knowledge with contemporary biomedical science [2]. One such important species is *Alpinia galanga* (Linn.) Willd., (Figure 1) commonly called greater galangal, a member of the family Zingiberaceae. It is widely cultivated in tropical Asia, particularly in India, Thailand, and Indonesia. Locally, it is known as “Kulanjan” in Ayurveda and “Thai ginger” in Southeast Asian cuisines [3]. The rhizome, which is aromatic and rich in bioactive compounds, has been used both as a spice and as a household remedy. Documented ethnomedicinal applications include its use as a digestive aid,

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carminative, expectorant, stimulant, and anti-inflammatory agent [4]. Recent pharmacological research has validated several of these traditional claims by demonstrating antioxidant, antimicrobial, anticancer, neuroprotective, and cardioprotective properties of *A. galanga* extracts and isolated constituents [5]. Despite these promising findings, systematic investigations into its phytochemistry, mechanisms of action, clinical efficacy, and safety remain relatively limited compared with other members of the Zingiberaceae family. The importance of this review lies in consolidating the fragmented data on *A. galanga* and highlighting its therapeutic potential. By presenting a comprehensive overview of its botanical features, traditional uses, phytoconstituents, pharmacological activities, toxicological findings, and formulation advances, this review aims to identify existing research gaps and outline directions for future studies. Such an effort is essential to support its rational use in evidence-based medicine and to explore its potential in modern drug development.

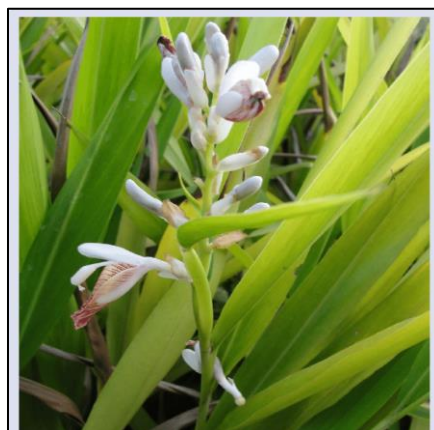


Figure 1 *Alpinia galanga* (Linn.) Willd.

2. Methodology

The present review was carried out by carefully gathering and evaluating information on *Alpinia galanga* from reliable scientific and traditional sources. A structured search strategy was employed using online databases such as PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar. Keywords applied in the search included “*Alpinia galanga*,” “greater galangal,” “phytoconstituents,” “pharmacological activities,” and “ethnomedicinal uses” [6]. Literature published between 1980 and 2025 was considered in order to include both older ethnomedicinal records and recent pharmacological evidence. In addition to electronic searches, authoritative texts such as pharmacopoeias, ethnobotanical compendia, and books on Indian and Southeast Asian medicinal plants were consulted to capture traditional uses and regional importance [7]. Articles included in this review comprised original research papers, systematic reviews, dissertations, and relevant technical reports that addressed the plant’s taxonomy, chemical constituents, therapeutic activities, toxicological evaluations, or formulation aspects. Preference was given to peer-reviewed studies with transparent methodologies and reproducible findings to ensure reliability. Data extracted from eligible studies were compared, analyzed, and synthesized into an integrated narrative. This systematic approach ensured that the review remains comprehensive, evidence-based, and reflective of both traditional knowledge and contemporary scientific understanding of *A. galanga*.

2.1. Botanical Description

Taxonomy: *Alpinia galanga* (L.) Willd., commonly known as greater galangal, belongs to the family *Zingiberaceae*, which includes other medicinally significant plants such as ginger and turmeric. The genus *Alpinia* is one of the largest within this family and is widely distributed in tropical Asia [8].

Morphology: The plant is a robust perennial herb with aromatic rhizomes that are thick, reddish-brown externally, and pale yellow inside. The leaves are long, lanceolate, and arranged alternately on pseudostems. Flowers are showy, white to pale yellow with red streaks on the lip, arranged in dense panicles. Fruits are round, fleshy, and reddish-orange when ripe, containing seeds that are often used in traditional medicine [9]. The rhizome, being rich in essential oils and bioactive compounds, is the most utilized part in therapeutic and culinary applications [1].

Geographical Distribution and Cultivation: *Alpinia galanga* is native to Southeast Asia, particularly Indonesia, Malaysia, and Thailand, but has also been cultivated in India, China, and other tropical regions due to its medicinal and culinary

value [10]. It thrives in humid climates with fertile, well-drained soil and is usually propagated through rhizome cuttings. Cultivation practices emphasize shaded areas with sufficient irrigation to maintain rhizome yield and phytochemical content [11].

Ethnobotanical Relevance: Traditionally, *A. galanga* has been employed in Ayurveda, Unani, and traditional Chinese medicine for its carminative, stimulant, and anti-inflammatory properties [2,4]. In folk practices, the rhizome is used for gastrointestinal ailments, respiratory conditions, and as a flavoring agent in food preparations. Beyond medicine, its essential oils are valued in perfumery and as natural preservatives. The ethnobotanical importance highlights its role as both a cultural and pharmacological resource, warranting systematic scientific exploration [12].

2.2. Traditional and Ethnomedicinal Uses

Alpinia galanga holds a valued place in several traditional medical systems. In Ayurveda, it is classified under pungent rhizomes used as a digestive stimulant, carminative, and anti-inflammatory agent, often combined with licorice or honey to alleviate respiratory and gastrointestinal discomforts [13, 1]. In Unani medicine, it appears in classical formulations as a cardiac tonic, expectorant, and aphrodisiac; it is used to manage cough, sore throat, and asthma, and is a component in remedies like Habb-e-Jadwar and Jawarish Jalinus [14]. In Chinese and Thai traditions, greater galangal is prized for its carminative and antimicrobial properties. It is used in remedies for indigestion, colds, and respiratory complaints [15, 4]. In Thai folk medicine, the rhizome is chewed or included in herbal decoctions to relieve indigestion and bloating, and applied externally to soothe throat and chest discomfort [15]. Additionally, in everyday folk and culinary practices, *A. galanga* plays a dual role: as a spice enhancing flavor and as a functional ingredient, particularly in Southeast Asian cuisines. Beyond the kitchen, in rural Indian households, powdered rhizome is mixed with honey to treat coughs and colds, while chewing a small piece fresh is believed to freshen breath and improve oral hygiene [13, 15].

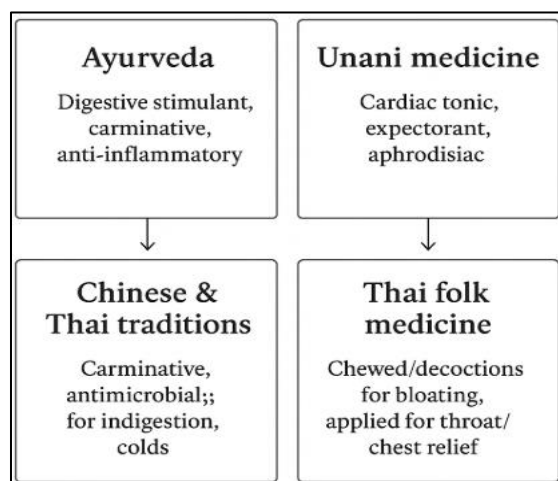


Figure 2 Traditional Uses of *Alpinia galanga*

2.3. Phytochemistry

The phytochemical profile of *Alpinia galanga* is diverse, encompassing both primary and secondary metabolites that contribute to its pharmacological significance. The plant is particularly rich in flavonoids, terpenoids, phenolic compounds, and essential oils, many of which serve as chemical markers for quality control and therapeutic evaluation. Among its major bioactive constituents, galangin, kaempferol, alpinin, and 1'-acetoxychavicol acetate have been widely reported for their antioxidant, antimicrobial, and anti-inflammatory properties, while zerumbone represents another notable metabolite with chemopreventive potential (16,17). Extraction and characterization of these compounds have been achieved through various methods ranging from conventional techniques such as Soxhlet and maceration to modern, green approaches including ultrasound-assisted and supercritical fluid extraction, which enhance yield and minimize solvent usage (18,19). Chemotaxonomic studies suggest that the abundance of flavonoids and phenolic acids in *A. galanga* not only differentiates it from other members of Zingiberaceae but also reinforces its use in traditional formulations and modern phytopharmaceuticals (20,21). Thus, the phytochemistry of *A. galanga* provides a strong foundation for its therapeutic validation and supports its role as a promising candidate in herbal medicine. Table 1 represents the list of phytochemicals present in *A. Galanga*.

Table 1 List of phytochemicals

Compound Name	Compound Name	Compound Name
Acetyeugenol	Galanal A	Palmitic acid
Allo-Aromadendrene	Galangal acetate	p-Coumaraldehyde
alpha-Bergamotene	Galangin	p-Cymene
alpha-Copaene	Galangin 3-methyl ether	Pentadecane
alpha-Curcumene	Galanolactone	Pentyl acetate
alpha-Eudesmol	gamma-Elemene	p-Mentha-1,5-dien-8-ol
alpha-Farnesene	gamma-Terpinene	Quercetin
alpha-Fenchol	Geraniol	Sabinene
alpha-Fenchyl acetate	Geranyl acetate	Sesquisabinene
alpha-Fenchyl alcohol	Germacra-1(10),5-dien-4-ol	Spathulenol
alpha-Gurjunene	Guaiaicol	Terpinolene
alpha-Muurolene	Guaiol	Tetradecane
alpha-Terpinene	Heptadec-8-ene	T-Muurolol
beta-Caryophyllene	Humulene	trans-alpha-Bergamotene
beta-Elemene	Humulene epoxide II	trans-Sabinene hydrate
beta-Eudesmol	Isobornyl acetate	Tricyclene
beta-Farnesene	Isobornyl benzoate	Tridecane
beta-Gurjunene	Isorhamnetin	Valencene
beta-Patchoulene	Kaempferide	Viridiflorol
beta-Pinene	Levomenol	Zerumbone
beta-Selinene	Limonene	Zingiberene
beta-Terpineol	Linalool	Zingiberenol
Bornyl acetate	Methyl cinnamate	Methyleugenol
Bulnesol	Methyl isobutyl ketone	Myrcene
Camphene	Myrtenal	Neral
Camphor	Nerolidol	Neryl acetate
Carotol	Nonanal	Octadecane
Carvacrol	d-Borneol	delta-Cadinene
Carvacryl acetate	delta-Elemene	Dihydrogalangal acetate
Carvone	DL-Borneol	Docosane
Caryophyllene oxide	Elemol	Estragole
Caryophyllenol I	Eugenol	Eucalyptol
Cedr-8-ene	Farnesal	Farnesyl acetate
Cedrelanol	Fenchol	Fenchone
Cedrol	cis,cis-Farnesol	cis-beta-Farnesene

2.4. Analytical Studies

To ensure rigorous quality control and authenticate *Alpinia galanga*, modern analytical techniques have been progressively adopted. High-performance liquid chromatography (HPLC) and liquid chromatography–tandem mass spectrometry (LC-MS/MS) have become standard for precise detection and quantification of key marker compounds—especially galangin and 1'-acetoxychavicol acetate—providing high sensitivity and specificity in complex matrices [22]. Gas chromatography–mass spectrometry (GC-MS) profiling further complements these methods by characterizing essential oils and volatile constituents, enabling comprehensive chemical fingerprints useful in both research and commercial standardization [23]. Alongside chromatographic approaches, spectroscopic techniques such as ultraviolet-visible (UV), Fourier-transform infrared (FTIR), and nuclear magnetic resonance (NMR) spectroscopy play vital roles in compound identification and structural elucidation. UV spectroscopy is useful for rapid screening and quantification, FTIR aids in assessing functional groups, while NMR offers in-depth structural confirmation especially for novel or complex phytochemicals [24]. Marker-based standardization is gaining traction, with several studies utilizing galangin as a benchmark compound for determining extract quality and batch-to-batch consistency [22]. Reports from Indian labs have successfully established validation protocols, including calibration curves, precision, recovery, and linearity parameters, ensuring reproducibility in herbal formulations [22, 25].

2.5. Pharmacological Activities

Table 2 Pharmacological Activities of *Alpinia galanga*

Activity	Method	Extract / Dose	Outcomes
Anti-inflammatory	Carrageenan-induced paw edema in rats	Methanolic rhizome extract	Significant reduction in paw edema, confirming anti-inflammatory effect
Analgesic	Acetic acid-induced writhing, formalin test in mice	Methanolic / ethanolic rhizome extract	Dose-dependent reduction in nociception, comparable to indomethacin at higher doses
Antimicrobial	In vitro bacterial cultures (<i>S. aureus</i> , <i>P. aeruginosa</i> , <i>E. coli</i>)	Crude and concentrated rhizome extracts	Inhibition of bacterial growth; broad-spectrum antimicrobial activity
Antioxidant / Cytoprotective	DPPH and nitric oxide radical scavenging assays	Aqueous rhizome extract	Strong free radical scavenging; better activity than <i>Alpinia calcarata</i>
Anticancer	MCF-7 breast cancer cell line	Ethanolic rhizome extract (IC ₅₀ : 170–400 µg/mL)	Reduced cell viability via apoptosis and morphological changes
Antidiabetic	Streptozotocin-induced diabetic rats	Methanolic aerial parts extract (200–400 mg/kg)	Lowered fasting blood glucose, improved lipid profile, no acute toxicity
Hepatoprotective	Paracetamol-induced hepatic injury in rats	Rhizome extract	Reduced AST & ALT, decreased hepatic MDA, indicating liver protection
Immunomodulatory	TNF-α stimulated human PBMCs	Ethanolic rhizome extract	Increased anti-inflammatory cytokines (IL-10, TGF-β) without cytotoxicity

Alpinia galanga exhibits a broad spectrum of pharmacological effects, supported by in vitro, in vivo, and some limited clinical findings. In animal models, methanolic and ethanolic extracts of the rhizome have demonstrated noticeable anti-inflammatory and analgesic properties. For instance, Sharma et al. reported that methanolic extract significantly inhibited acetic acid-induced writhing and carrageenan-induced paw edema in mice and rats, confirming both antinociceptive and anti-inflammatory action [26]. Complementary work using formalin and acetic-acid models further validated analgesic effects in mice, with higher doses nearly matching the efficacy of indomethacin [27]. The antimicrobial, antifungal, and antiviral potential of *A. galanga* has been noted across several studies. Crude and concentrated extracts have shown inhibitory activity against pathogens such as *Staphylococcus aureus*, *Pseudomonas*

aeruginosa, *E. coli*, and others commonly involved in human infections. In the realm of antioxidant and cytoprotective activity, aqueous rhizome extracts demonstrated strong free radical scavenging abilities in DPPH and nitric oxide assays, outperforming related species such as *Alpinia calcarata* [29]. These in vitro results point toward the plant's potential in mitigating oxidative stress. Anticancer effects have also been observed. Ethanolic extracts have been found to significantly reduce viability in MCF-7 breast cancer cells by inducing morphological changes and promoting apoptosis, with IC₅₀ values around 170–400 µg/mL after 48 hours compared to non-malignant controls. The antidiabetic potential has been validated in vivo using streptozotocin-induced diabetic rats. Methanolic extract of aerial parts administered at 200 and 400 mg/kg reduced fasting blood glucose, improved lipid profiles, and showed no acute toxicity at higher dose range. Moreover, broader pharmacological activities such as hepatoprotection have been reported—hemabarathy and colleagues demonstrated that rhizome extract reduced paracetamol-induced AST and ALT elevations and lowered hepatic MDA levels, indicating a protective effect against oxidative hepatic injury. Immunomodulatory effects have likewise been explored. In human peripheral blood mononuclear cell (PBMC) models stimulated with TNF-α, ethanolic galangal extract boosted anti-inflammatory cytokines IL-10 and TGF-β without cytotoxicity, suggesting a modulatory balance between pro- and anti-inflammatory responses [7-26]. Table 2 summarizes the pharmacological activities of *Alpinia galanga* rhizome and aerial extracts. In vitro, in vivo, and limited clinical studies demonstrate anti-inflammatory, analgesic, antimicrobial, antioxidant, anticancer, antidiabetic, hepatoprotective, and immunomodulatory effects. Extracts showed dose-dependent efficacy, reduced oxidative stress, and modulated cytokine responses, highlighting *A. galanga*'s therapeutic potential across multiple biological systems. Detailed references are provided for each activity.

2.6. Toxicological and Safety Aspects

Toxicological evaluation of *Triphala* has been conducted through various acute and chronic studies to establish its safety profile. Acute toxicity tests in rodents demonstrated that even at higher doses, the formulation did not induce significant behavioral or biochemical abnormalities, suggesting a wide margin of safety [28]. Sub-chronic and chronic administration studies revealed no major organ toxicity, indicating that long-term consumption at therapeutic doses is relatively safe [29]. Furthermore, biochemical and hematological parameters in animal models were found to remain within normal ranges during repeated administration, supporting its non-toxic nature [30]. Safe dosage ranges for *Triphala* have been established through clinical practice and experimental trials. Traditional Ayurvedic texts recommend moderate consumption, which has also been validated by controlled studies in humans, where doses up to 5–10 g/day in powdered form were well tolerated [5,28]. However, very high doses beyond therapeutic limits may cause gastrointestinal disturbances, including diarrhea and abdominal discomfort [31]. Despite its safety, certain contraindications have been reported. Caution is advised in individuals with chronic diarrhea, dehydration, or electrolyte imbalance, since the formulation possesses mild laxative activity [32]. Moreover, interactions with modern drugs cannot be overlooked. Some studies have indicated that *Triphala* may alter the pharmacokinetics of drugs metabolized by cytochrome P450 enzymes, potentially influencing drug absorption and metabolism [33]. Concomitant use with hypoglycemic drugs requires monitoring due to additive blood sugar-lowering effects [27]. Similarly, its antioxidant property might interfere with chemotherapy or radiotherapy by modulating oxidative stress pathways [34].

2.7. Formulation and Nanotechnology Applications

Alpinia galanga has been incorporated into various herbal formulations, including traditional extracts, syrups, and essential oils utilized in traditional medicine and aromatherapy. Contemporary advances have expanded its applications into nanotechnology-enhanced systems. Silver nanoparticles synthesized from its methanolic rhizome extract exhibit strong anticancer activity against cervical cancer cell lines and are eco-friendly in synthesis, involving UV-Vis, FTIR, zeta-sizer, and TEM characterization techniques [35]. A non-aqueous nanoemulsion (NANE) containing *A. galanga* extract, optimized via Box–Behnken design, markedly improved skin permeation—displaying a 10-fold increase in flux compared to the extract alone—making it a promising topical delivery system [36].

2.8. Clinical Studies

Clinical exploration of *A. galanga* remains limited but promising. A triple-blind randomized clinical trial added 500 mg of *A. galanga* extract to SSRI regimens in adult men and observed significantly greater improvements in International Index of Erectile Function (IIEF) scores than placebo after four weeks, suggesting potential to mitigate SSRI-induced sexual dysfunction [37]. Additionally, human trials of the proprietary extract demonstrated enhanced mental alertness, focus, and energy, with reduced daytime sleepiness and fatigue over four weeks of supplementation in healthy adults [38, 39].

2.9. Industrial and Nutraceutical Applications

In culinary industries, *A. galanga* rhizomes are valued for imparting distinct flavor notes to Southeast Asian dishes and herbal preparations. Its essential oils find roles in perfumery and cosmetic formulations, leveraging its aromatic and therapeutic qualities. Nutraceutical applications are emerging, with products such as encapsulated extracts or functional food supplements targeting cognitive health.

2.10. Quality Control and Standardization

Quality evaluation of *A. galanga*-based products follows WHO guidelines for herbal medicines, emphasizing parameters such as ash values, extractive yields, and moisture content to ensure purity and authenticity [1, 3]. Marker-based standardization particularly quantifying galangin via validated HPLC protocols enables consistent dosing. Integrating physicochemical assessments alongside chromatographic and spectroscopic profiling ensures robust quality control frameworks suited for both traditional formulations and modern commercial extracts. [22]

2.11. Research Gaps and Future Perspectives

Despite traditional significance and promising preclinical data, *A. galanga* faces several research limitations. Human clinical validation remains sparse, with only a few pilot studies exploring cognitive and sexual health outcomes [37–39]. Standardization across extract types is critical, as phytochemical variability can affect efficacy and reproducibility. Integrating computational tools-such as molecular docking and in silico ADMET profiling of key constituents-could accelerate drug discovery pipelines. Moreover, opportunities exist for applying green chemistry principles and personalized medicine strategies, as well as expanding sustainable cultivation practices aligned with environmental stewardship.

3. Conclusion

Alpinia galanga has demonstrated remarkable therapeutic promise through its broad spectrum of pharmacological properties, supported by extensive phytochemical and preclinical evidence. The plant's bioactive compounds, particularly flavonoids and essential oils, contribute to antioxidant, anti-inflammatory, antimicrobial, anticancer, and neuroprotective effects, underscoring its multifaceted medicinal relevance. Advances in nanotechnology-based formulations, cheminformatics, and green extraction methods are paving the way for enhanced bioavailability and clinical applicability. Nonetheless, systematic clinical validation, regulatory approval, and standardization remain critical to transform these findings into evidence-based therapeutic interventions. Integrating traditional wisdom with modern pharmacology highlights *A. galanga* as a potential phytopharmaceutical candidate for future drug development and nutraceutical applications

Compliance with ethical standards

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Disclosure of conflict of interest

The Authors proclaim no conflict of interest.

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