



RESEARCH ARTICLE

Gloriosa superba L.: A comprehensive review of ethnomedicinal uses, pharmacological potential, ecological significance, cultural importance and conservation efforts

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Abstract

Gloriosa superba L. (flame lily or glory lily) is a perennial herbaceous climber renowned for its striking appearance and multifaceted significance. It is often regarded as a medicinal herb for treating numerous ailments such as gout, rheumatism, wounds, snakebite, skin disease, leprosy, inflammation, etc. Besides its medicinal properties, the plant plays an important role in ecological interactions with the surrounding environment by being pollinated by various insects and associated with various microorganisms. It is also a part of tribal culture, influencing daily routines and festivals. Driven by escalating global demand for colchicine, excessive industrial exploitation has resulted in documented local extinctions in regions such as the Darjeeling Himalaya. This pressure is compounded by poor natural propagation, characterised by an inherently low seed set, reduced seed germination and a strict dependency on specialist pollinators like sunbirds and butterflies. This synergy of intense commercial reaping and biological reproductive bottlenecks indicates that the plant is now on the verge of extinction within several of its primary wild habitats. Diverse bioactive compounds were analysed and compiled, with colchicine and gloriosine being the key substances that account for the therapeutic benefits of this plant. Additionally, 13 other biomolecules are reported to possess the anti-inflammatory, anti-cancer, antioxidant, anti-microbial, anti-gout, anti-pox, anti-coagulant and antirheumatic activities. It is economically important due to the production of many drugs and biochemicals in pharmaceutical industries. It is also an endangered medicinal plant used to cure various ailments from ancient times to the modern pharmaceutical era. Therapeutic uses, ecological interactions and cultural values make this plant unique. Conservation efforts must be implemented to preserve this plant from extinction.

Keywords: conservation; ethnomedicinal plant; *Gloriosa superba*; glory lily; secondary metabolites

Introduction

From the beginning of civilisation, humans have related to their surrounding environment, especially with plants that provide food, shelter, fibre and medicine and possess cultural value. Throughout history, numerous plants have served medicinal purposes in diverse areas around the world. *Gloriosa superba* L. is recognised as a medicinal plant that is used to address a range of ailments in various traditional systems of medicine. *G. superba* is a perennial herbaceous climber belonging to the Colchicaceae (formerly Liliaceae) family and originates from South-East Asia and Africa (Fig. 1). *Gloriosa superba* is the national flower of Zimbabwe and the state flower of Tamil Nadu in India (1–3).

The name ‘gloriosa’ is derived from the word “gloriosus,” means- handsome and “superba,” has originated from the term “superb,” means-something magnificent or splendid. It is a popular ornamental plant cultivated in gardens due to its fascinating flowers. It is commonly known as ‘flame lily’, ‘glory lily’, ‘fire lily’, ‘climbing lily’, ‘Malabar glory lily’ (English), ‘Kalihari’ (Hindi), ‘Agnisikha’ (Sanskrit) and langali (Ayurvedic pharmacopoeias) (Table 1) (4–7).

The most common name of *G. superba* in rural areas of

Table 1. Systematic classification of *Gloriosa superba*

Kingdom	Plantae
Phylum	Streptophyta
Class	Liliopsida
Subclass	Lilianae
Order	Liliales
Family	Colchicaceae
Genus	<i>Gloriosa</i>
Species	<i>superba</i>

Classification of *Gloriosa superba* is based on the current systematic understanding supported by recent studies (11, 67, 80).

Chhattisgarh and Madhya Pradesh is “Jhagrahi”. This name is due to a belief that “it creates a fight between the members of two different families if the tuber of the plant is kept in their house”. *Gloriosa superba* is extensively employed as a medicinal plant and has been utilised in both traditional and contemporary medical practices such as allopathy. Its seeds and tubers are recognised for their therapeutic effects on conditions such as gout and rheumatism and possess purgative, anthelmintic, bitter, acrid, astringent and germicidal properties (8).

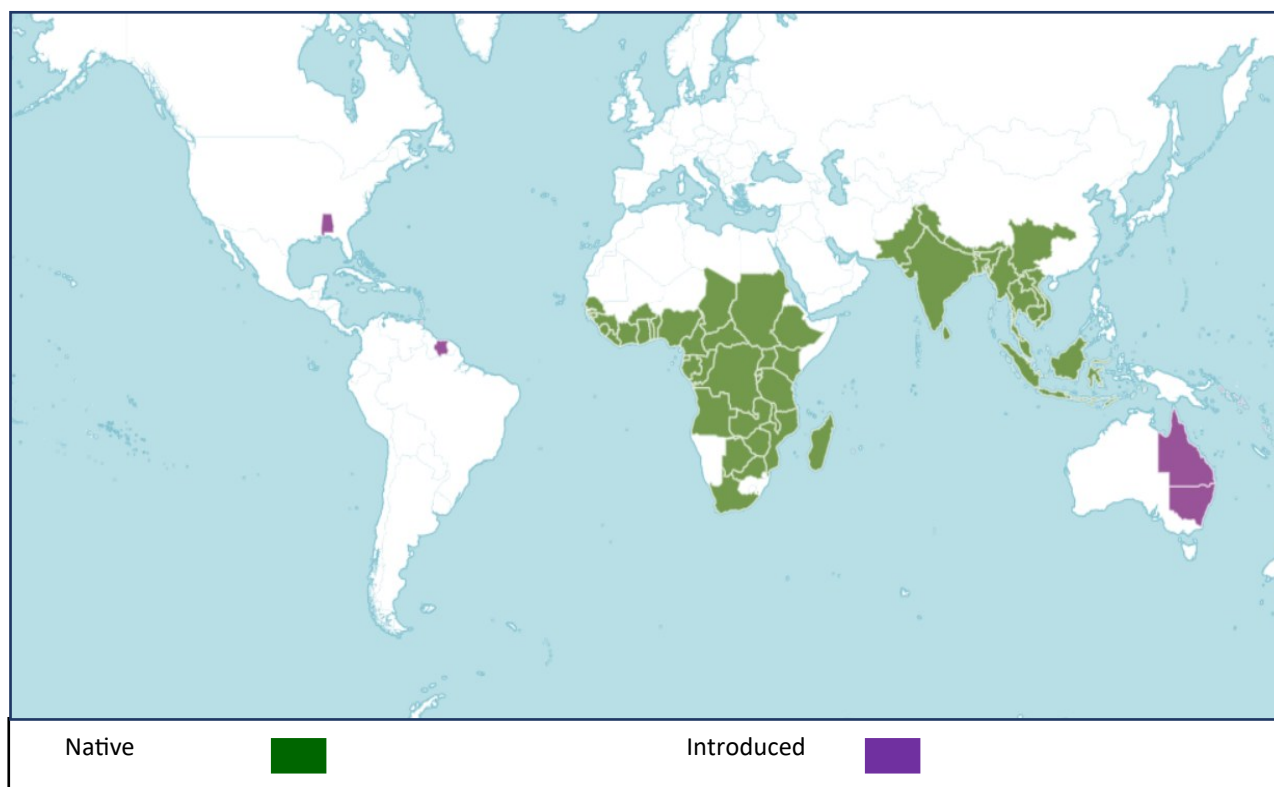


Fig. 1. Worldwide distribution of *Gloriosa superba*. This map displays the green and purple area for *Gloriosa superba* worldwide distribution. Green area shows the native place of *Gloriosa superba* and in purple are it is introduced. Source: Image is accessed from Plants of the World Online (POWO), Royal Botanic Gardens Kew (89).

The plant is of great demand due to its extremely toxic but medically important alkaloids, such as colchicine ($C_{27}H_{25}O_6N$) and its derivatives, gloriosine and colchicocide ($C_{27}H_{33}O_{11}N$), as well as the presence of sterols, benzoic acid, salicylic acid and resinous compounds. While toxic in raw form, purified colchicine is the “gold standard” treatment for acute gout and familial Mediterranean fever (1).

Due to its valuable medicinal properties, particularly its colchicine content *G. superba* is sought after by major pharmaceutical companies. This overexploitation has resulted in habitat loss, placing the plant on the International Union for Conservation of Nature (IUCN) list of endangered species (6, 9). This comprehensive review examines the multifaceted aspects of *G. superba*, encompassing its botanical characteristics, medicinal properties, ecological interactions, cultural significance and conservation efforts.

Material and Methods

The present analysis was carried out using a detailed and integrative approach to assess the ethnomedicinal relevance, bioactive substances and their therapeutic applications, ecological dynamics, cultural significance and conservation strategies of *G. superba* synthesising information from both scientific and traditional knowledge sources. The methodology adhered to PRISMA guidelines for transparency and reproducibility.

A systematic search was conducted across a range of databases, including PubMed, Scopus, Web of Science, SpringerLink and Google Scholar for articles published from 1950 to 2025. Using Boolean operators (AND/OR), the search combined terms such as “*Gloriosa superba*”, “glory lily”, “*Kalihari*”, “pharmacology” and “conservation”. From an initial pool of approximately 600 records,

250 full-text articles were assessed after removing duplicates. The final selection comprised 89 sources: 66 original research papers, 19 review articles and 4 reputable educational websites.

Inclusion was restricted to peer-reviewed, English-language studies focusing on validated phytochemical, pharmacological or ecological data. Information on bioactive molecules and their pharmacological effects, therapeutic uses, ecological interactions, cultural significance of *G. superba* and its conservation efforts was systematically compiled. However, this approach may overlook valuable unpublished traditional knowledge, grey literature, or non-English publications, potentially introduce selection bias and limiting the full spectrum of ethnomedicinal insights.

Results

Morphology

Gloriosa superba is an herbaceous vine that may reach a maximum length of 3.5–6 m and climbs perennially. It has a fibrous root that abruptly bends into V- or L-shape (6, 10).

The leaves are simple, opposite or alternate, ovate to lanceolate, sessile, spear shaped. Their colour is a dark, shiny green and they develop in three- to four-whorl clusters aligned with tendrils to facilitate plant attachment. The leaves are 13–20 cm long and have tendrils at the tips. The flower, which is the plant's most noticeable characteristic, is orange-red to yellow. The flowers, which are actinomorphic, solitary and axial and have 6 tepals, each approximately 6 cm long. Petaloid tepals, which mimic petals and have a linear shape and four-colour combinations ranging from orange, yellow, green, or crimson, make up the plant's perianth (6, 7) (Fig. 2).



Fig. 2. Plant *Gloriosa superba* in its natural habitat.

The leaves are simple, opposite or alternate, dark, shiny green, arranged in 3–4-whorled clusters topped by tendrils for climbing (1). The flowers, the plant's most striking feature, are orange-red to yellow, featuring six approximately 6 cm long tepals with a combination of orange, yellow, green and crimson (6, 7). The fruits are oblong, loculicidal capsules (4–6 × 1–2 cm) containing up to 20 seeds (4). The seeds are ovoid (4–5 mm in diameter) with a fleshy, red sarcotesta (2, 4, 11).

Distribution

Gloriosa superba flourishes naturally in Africa and South-East Asia and is widely distributed in the tropics and some arid regions. In Africa it is extensively disseminated from Senegal east to Ethiopia and Somalia and to South Africa. It grows naturally in several tropical Asian nations, such as Bangladesh, India, Sri Lanka, Malaysia, Pakistan and Myanmar (2, 4, 11, 12). Glory lily has been introduced into Australia and is widely distributed in coastal dry sclerophyll forest and sand dune vegetation throughout South-east Queensland and New South Wales. This species is classified as a rampant and menacing invasive weed in Australia, encroaching upon coastal dune ecosystems at the expense of native species and resulting in the loss of local wildlife and birds that rely on these for food (10). In India, glory lily is found throughout the warmer southern regions, extending to the Central India-Deccan Plateau, as well as the more temperate mid-hill areas and the Northwest Himalayas and their foothills. Consequently, it has a broad distribution in states such as Andhra Pradesh, Kerala, Karnataka, Tamil Nadu, Goa, Maharashtra, Chhattisgarh, Odisha, Jammu and Kashmir, Himachal Pradesh, Haryana, Uttar Pradesh, West Bengal and Assam (1, 2, 7, 13).

Growth requirements

This herb thrives in sandy-loam soil found within mixed deciduous forests, particularly in well-lit areas. It demonstrates a high tolerance for nutrient-deficient soils naturally but in cropland the optimal potting mix for acclimatisation and growth consists of a combination of garden soil, sand and either vermiculite or farmyard manure in a ratio of 2 : 1 : 1 (1). This blend promotes excellent survival rates and vigorous growth in both shaded and sunny environments (1, 12, 14). The nutrient absorption sequence for *G. superba* is as follows: nitrogen (N), potassium (K), magnesium (Mg), calcium (Ca), phosphorus (P), iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) (15). The nutrient absorption sequence for *G. superba*, critical for optimising cultivation in nutrient-poor sandy-loam soils (1), prioritises N, followed by K, Mg, Ca, P, Fe, Mn, Zn and Cu (15).

Specific water and humidity requirements are not quantified for the growth of *G. superba*; however, successful acclimatisation protocols in cropland involve well-drained substrates that retain moisture but do not become waterlogged. Established plants flourish in their natural environments characterised by fluctuating humidity and water levels, indicating their ability to adapt to diverse conditions (13). Various phytochemicals required for the growth and development of plants are associated with specific temperature, precipitation and aridity gradients; however, optimal growth relies on a balance of moderate temperature and adequate rainfall with both direct sunlight and shaded conditions (14, 16).

Endophytic *Bacillus* strains and arbuscular mycorrhizal fungi (AMF) significantly contribute to the growth and development of plants, enhance stress resilience and increase the levels of secondary metabolites such as colchicine and gloriosine (Table 2). Notably, AMF species like *Acaulospora laevis* and *Glomus mosseae* contribute to improved survival rates, greater plant height, longer tuber length and enhanced biochemical properties during the acclimatisation process (17–19).

Ethnopharmacological importance

In traditional medicine, different parts of the glory lily are used for treating a range of ailments, with a primary focus on the roots and tubers (20). Due to its phytochemicals, glory lily is extremely poisonous, but after the Sodhana (purification) process, it is used for therapeutic purposes. This traditional purification involves soaking the tubers in media like cow's milk or buttermilk to reduce the concentration of irritant alkaloids while preserving therapeutic efficacy (21). Despite these protocols, the misuse of *G. superba* remains a significant clinical risk due to its narrow therapeutic index.

The roots, tubers and seeds of *G. superba* are characterised by a profound medicinal versatility driven by their unique phytochemical acidity, though they remain concurrently recognised as highly poisonous (1, 22). In traditional ethnomedicinal systems, these parts function as potent multi-systemic agents, acting as antipyretics, stomachics and purgatives to treat gastrointestinal distress such as colic, hemorrhoids and intestinal worms (1, 8). Their role as a "bitter tonic" supports digestive and cholagogue functions, while their expectorant properties are utilised to alleviate coughs and hiccups (1, 21).

Beyond systemic use, the plant is a critical resource for musculoskeletal and inflammatory disorders. It is frequently employed to manage chronic conditions like gout, rheumatism,

Table 2. List of secondary metabolites isolated from *Gloriosa superba* with their medicinal value

Sl. No.	Secondary metabolites	Plant parts from isolated	Therapeutic uses	Reference
1.	Colchicine	Whole plant especially from seed and tuber	Anti-inflammatory, anti-analgesic, alterative, anti-mitotic, anti-gout	(4, 11, 12)
2.	Colchicoside	Seed	Anti-cancer activity	(26)
3.	3-desmethycolchicine	Tuber and seed	Anti-cancer activity	(77)
4.	Estragole	Leaves	Anti-inflammatory, antiedematogenic	(81)
5.	Flavonoid	Tuber	Anti-diabetic, anthelmintic	(8, 82)
6.	Glorioside	Seed	Anti-cancer activity	(26)
7.	Gloriosine	Seed and tuber	Anti-cancer activity	(83)
8.	Lumicolchicine	Seed and tuber	Anti-cancer activity	(84)
9.	Luteolin 7-O β -D glucopyranoside	Pod	Antioxidant, antimicrobial	(26, 85)
10.	Mannose-binding lectin	Root	Anti-Poxviral	(86)
11.	Monoethyl ester of 2,6-dihydroxybenzoic acid	Tuber	Antidote for snake bite	(87)
12.	Quercetin	Tuber and seed	Antioxidant, anti-inflammatory, anti-gout activity	(16, 41)
13.	Tannin	Leaves	Anticoagulant	(88)
14.	Thiocolchicoside	Seed	Orthopedic, traumatic, rheumatological disorders	(2, 11)
15.	Vanillylmandelic acid (VMA)	Tuber	Anti-cancer	(27)

arthritis and paralysis, as well as acute injuries such as sprains and bruises (1, 21, 23). Topically, root pastes serve a dual purpose: acting as a potent antidote for snakebites and insect stings while also treating diverse dermatological and infectious pathologies, including leprosy, leukoderma, erysipelas, chronic ulcers and boils (1, 5, 22, 24).

In the context of reproductive and specialised health, *G. superba* is valued for its oxytocic properties to assist in labor and its use in managing impotence and nocturnal emissions; however, its potent alkaloids also necessitate its use in traditional abortions (1, 21). Modern pharmacological evaluations have further validated these traditional claims, identifying significant antibacterial, antifungal and anticancer activities (5, 8, 24). Specifically, the plant's secondary metabolites demonstrate apoptotic effects on hepatic and squamous carcinomas and provide robust antioxidant protection, bridging the gap between historical ethnomedicinal use and modern therapeutic potential (22, 25–27).

For therapeutic purposes, the dosage of glory lily is crucial. It is used for ethnogynaecomedicinal purposes for both abortion and delivery in different methods and dosages. It possesses abortifacient characteristics as its tuber induces the expulsion of the fetus from the uterus and is used to facilitate delivery; its tuber paste is applied externally to alleviate labor pain (28, 29).

Glory lily possesses two main alkaloids: colchicine and gloriosine, which are used to treat gout and rheumatism (7, 24, 25, 29).

In Ethiopia's traditional medicine system, the tuber of the glory lily is chewed and externally applied to the affected area of the breast for breast cancer treatment (22). The glory lily's leaves have been recognised for their medicinal properties in treating wound healing, hemorrhoids, ulcers, asthma and inflammation (1). Moreover, an infusion made from the leaves is used to relieve cough and throat irritation (1, 23, 26). Oral administration of crushed leaf filtrate is used to manage epilepsy (22).

There are 35 tribal communities from various regions of India that have been reported to use glory lily as a traditional medicine: they are Santal, Munda, Oraon, Irular, Baiga, Gond, Mullu Kuruma, Pawara, Mavachi, Kokani, Tadv, Kodava, Bhilala, Bhil, Garasia, Damor, Gamati, Kathodia, Menna, Kharadi, Mohradi, Randhor, Parmar, Meghwal, Chakma, Marma, Tripura, Kondareddi, Bhumij, Lambanis, Korwa, Korku, Dimasa, Malayali

and Jaunsuri (9, 21).

Applications in Ayurveda

While the broad ethnopharmacological profile of *G. superba* reflects its diverse utility among global indigenous populations and 35 distinct Indian tribal communities, its most historically codified and systematic applications are preserved within the classical Ayurvedic tradition (9, 21). Unlike general folk medicine, Ayurveda provides a formalised framework that categorises the plant canonically known as Langali or Kalihari as one of the nine Upavishas (semi-poisonous agents) (6, 21). This classification highlights a sophisticated understanding of the plant's dual nature, where its high toxicity is managed through specific Shodhana (purification) processes to unlock its therapeutic potential (21).

Ancient Indian scholars such as Charaka and Sushruta documented Langali as a vital constituent in formulations targeting specialised conditions, ranging from labour induction (Mudhagarbha) to the management of chronic skin ailments and inflammatory disorders (21, 23).

Today, this classical foundation is reflected in the 158 distinct drug formulations reported in Ayurvedic pharmacopoeias, which utilise the plant in various dosage forms, including svarasa, kvatha, lepa, varti, avaleha, taila, rasa, vati, kshara, modaka, ghruta, loha, rasakriya, churna, dhupa, nasya and udvartana to treat over 30 medical conditions such as mudhagarbha (dead foetus), agnimandya (loss of appetite), sotha (inflammation), aparapatana (removal of placenta), vrana (wound), jvara (fever), kasa (cough), grahani (irritable bowel syndrome), hikka (hiccough), kushtha (leprosy), gandmala (lymphadenitis), charmaroga (skin disease), shvitra (leucoderma), visarpa (erysipelas), khalitya (hair loss), arsha (piles) as well as vatavyadhi (joint pain/arthritis) especially vatarakta, apache, granthi, galaganda, sarpavisha, arbuda, ajagallika, rajayakshama, dantakrumi, prameha, khalitya-indralupta, nasaroga, kamaroga-krumikarna, etc. (9, 21).

The role of glory lily as a constituent in various formulations has been documented in samhita (treatise) and samgraha granthas. There is a systematic compilation of the synonyms, properties, actions and various formulations of glory lily, including their adhikara (main indications) in some ancient Indian literature such as a range of Samhita (classical texts), nighantus (lexicons), Samgraha granthas (compendia). Some contemporary Ayurveda scholars, including Bapalal Vaidya, dispute the notion that it is poisonous. He suggested that a non-toxic drug has been inaccurately deemed poisonous,

likely because of its abortifacient effects (30).

Secondary metabolites

Plants contain two categories of metabolites or phytochemicals: primary and secondary metabolites. Secondary metabolites are not essential for plant growth but are involved in the plant defence mechanisms (31). Medicinal plants contain a mixture of secondary metabolites, including colchicine, colchicoside, 3-desmethylcolchicine, estragole, gloriosine, glorioside, vanillylmandelic acid, luteolin 7-O β -D glucopyranoside which dictate their therapeutic potency (32). These phytochemicals contain numerous pharmacological properties, including anti-inflammatory, anti-cancer and anti-gout (11) (Fig. 3).

Anticancer activity

Plants possess a diversity of phytochemicals with multiple medicinal properties, including anticancer activity. Some anticancer metabolites are colchicine, colchicoside, 3-desmethylcolchicine, gloriosine, glorioside, lumicolchicine, Vanillylmandelic acid etc (26). The plant glory lily plays an important pharmacological role in combating cancer due to the presence of a significant alkaloid, colchicine (33). Colchicine has antimitotic properties, as it arrests the cell cycle by binding to α - and β -tubulin heterodimers (6). Numerous cancer research studies have confirmed the plant's potential effectiveness against different forms of carcinoma. At 46.54 $\mu\text{g/mL}$ (IC_{50}), a silver nanoparticle produced by green synthesis was found to have significant cytotoxic effect on human lung tumor cell (A549) in culture by reducing cell proliferation and triggering programmed cell death (34).

The synthesis of biomolecule-coated nanotitania catalysts was accomplished using the rhizome extract of *G. superba*, which exhibited considerable anti-cancer activity against breast cancer, indicated by IC_{50} values of 46.64 $\mu\text{g/mL}$ for MCF-7 (cancer cell lines) and 61.81 $\mu\text{g/mL}$ for L929 (normal cell lines) (35). The root extract exhibited the highest level of cytostatic activity against human colon cancer (HT-29) cell lines and human skin fibroblast cells, with an IC_{50} value of 0.12 $\mu\text{g/mL}$, which is 9.17 and 1.58 times more potent than cisplatin and doxorubicin respectively. Methanol-water fraction of root extract showed the most significant antiproliferative activity with an IC_{50} value of 0.14 $\mu\text{g/mL}$, which is nearly equivalent to its methanolic extract (IC_{50} = 0.12 $\mu\text{g/mL}$) and is 7.73 and 1.34 times more potent than cisplatin and doxorubicin respectively (36).

Methanolic extract is used to produce silver nanoparticles that lower their toxicity through encapsulation. The resulting encapsulated silver nanoparticles, known for their significant cytotoxicity, initiate apoptotic processes in Dalton's lymphoma ascites (DLA) cells (37). The ethanolic extract contains 3-Hydroxy-4-methoxymandelic acid ($\text{C}_9\text{H}_{10}\text{O}_5$), which exhibited the anticancer activity against Hep-G2 and A431 cell lines (27). Ethanol extracts revealed a significant effect on the initiation of mPT pore opening, promoting the liberation of cytochrome c, enhancing mitochondrial ATPase activity, inhibiting peroxidation of lipids and activating caspase 9 and caspase 3. These actions, initiated by glory lily extracts, encourage apoptosis and safeguard against proliferative disorders in both the prostate and uterus (38).

Antioxidant activity

Oxidative stress arises from an imbalance between the generation of reactive oxygen species (ROS) and the cell's ability to neutralise them. This imbalance causes damage to biological molecules,

including DNA, RNA, lipids, proteins and micronutrients such as vitamins and carotenoids. Antioxidants are substances that inhibit oxidation or oxidative damage induced by free radicals, thereby reducing ROS levels. They achieve this through mechanisms such as diminishing free radical activity, scavenging free radicals, complexing with pro-oxidant metals and quenching singlet oxygen (39).

Various extracts of *G. superba*, particularly methanolic extracts from leaves, stems and tubers, have demonstrated significant antioxidant activity across multiple assays, including DPPH, ABTS, ferric reducing antioxidant power (FRAP), phosphomolybdenum and reducing power assays, with leaves exhibiting higher capacity than stems and tubers (25, 40–43). This potency is attributed to flavonoids, polyphenols and other phenolic compounds, which serve as free radical scavengers (25, 32, 40, 44).

Methanol extracts from different *G. superba* ecotypes reveal diverse phytoconstituents and correspondingly higher free radical scavenging activity. Quantitative DPPH assays on methanolic extracts of whole plant parts (shoot, flower and tuber) yielded IC_{50} values of 65.76 $\mu\text{g/mL}$ (shoot), 60.34 $\mu\text{g/mL}$ (flower) and 80.12 $\mu\text{g/mL}$ (tuber) (25). Ethanolic rhizome extracts showed DPPH scavenging with an IC_{50} of 77.20 $\mu\text{g/mL}$ (45), while chloroform : methanol and methanol rhizome extracts exhibited 89.94 $\pm$ 0.03 % and 90.16 $\pm$ 0.00 % scavenging at 500 $\mu\text{g/mL}$, with IC_{50} values of 2.0 $\mu\text{g/mL}$ and 1.5 $\mu\text{g/mL}$ respectively (46).

Rhizome extracts of *G. superba* with different solvents (ethanol, methanol, acetone, acetonitrile and distilled water) were evaluated for antioxidant activity by ABTS, DPPH and FRAP assay, which showed 3.54 $\pm$ 0.03 mM ascorbic acid equivalent (AAE)/100 g dry weight, 4.09 $\pm$ 0.01 mM AAE/100 g dry weight, 3.98 $\pm$ 0.01 mM AAE/100 g dry weight, 3.91 $\pm$ 0.02 mM AAE/100 g dry weight, 2.67 $\pm$ 0.03 mM AAE/100 g dry weight in ABTS assay, 4.42 $\pm$ 0.01 mM AAE/100 g dry weight, 4.58 $\pm$ 0.01 mM AAE/100 g dry weight, 3.66 $\pm$ 0.05 mM AAE/100 g dry weight, 1.24 $\pm$ 0.03 mM AAE/100 g dry weight, 1.64 $\pm$ 0.02 mM AAE/100 g dry weight in DPPH assay and 0.35 $\pm$ 0.02 mM AAE/100g dry weight, 0.41 $\pm$ 0.01 mM AAE/100 g dry weight, 0.54 $\pm$ 0.02 mM AAE/100 g dry weight, 0.42 $\pm$ 0.01 mM AAE/100 g dry weight, 0.16 $\pm$ 0.04 mM AAE/100 g dry weight in FRAP assay for ethanol extract, methanol extract, acetone extract, acetonitrile extract and distilled water respectively (43).

Methanol and ethyl acetate extracts from leaves and stems displayed moderate antioxidant activity in reducing power and ferric reducing antioxidant power assays (40). ABTS radical scavenging activity varies by phenological stage and plant organ, with aerial parts showing greater potency than subterranean ones (44). Phenolic compounds, a key class of plant secondary metabolites, underpin these bioactivities, particularly their antioxidant potential (44).

Anti-inflammatory activity

An innate defensive reaction to tissue damage brought on by harmful substances, microorganisms, or physical trauma is inflammation (47). It is a localised, non-specific response to infection regulated by the immune system (3, 48).

Numerous studies on the anti-inflammatory properties of various parts of glory lily have demonstrated, revealing its considerable potential for treating inflammation. The evaluation of the anti-inflammatory properties of glory lily was conducted (3). Methanolic extract derived from the tuber of the glory lily exhibits

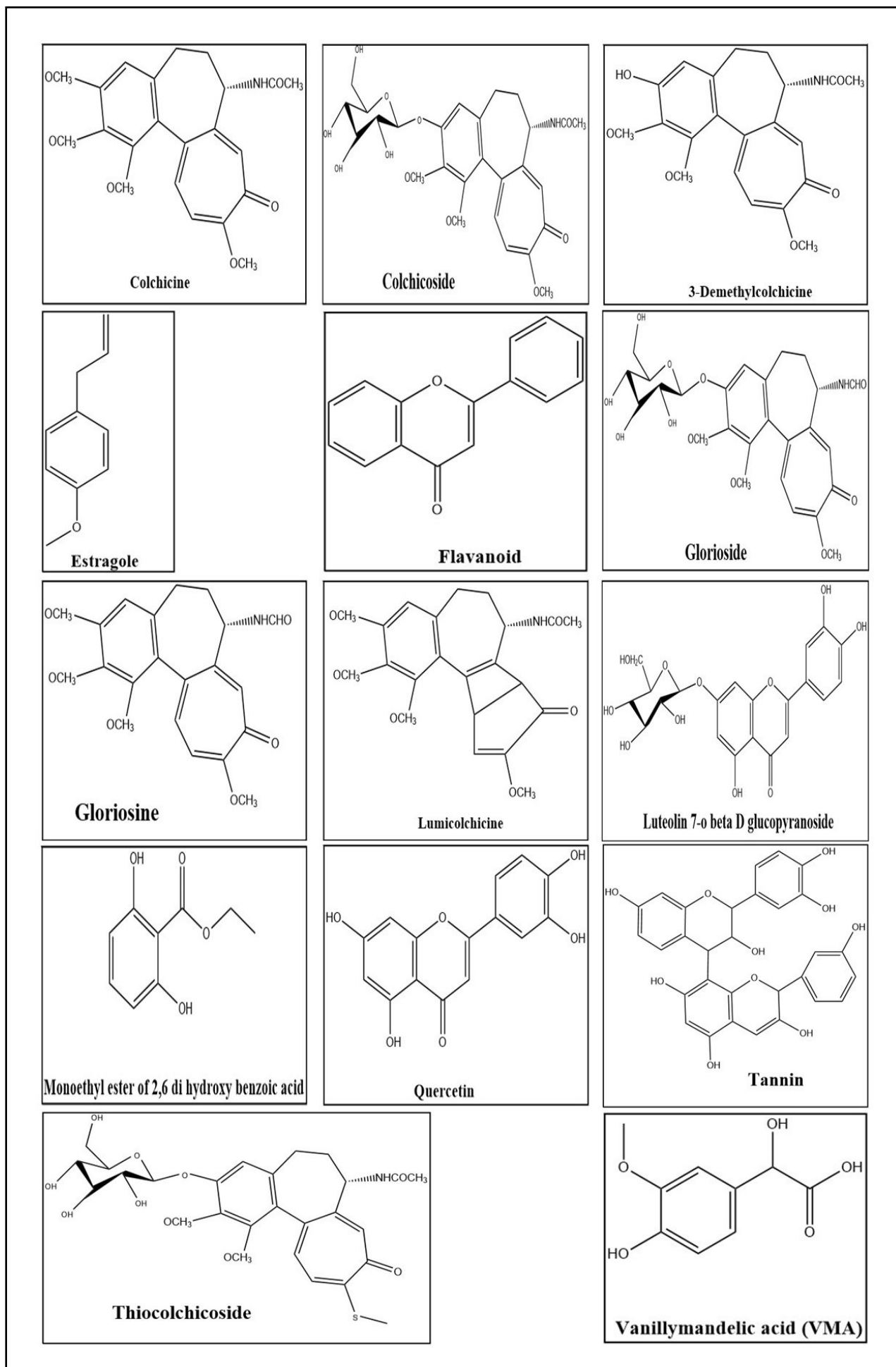


Fig. 3. Phytochemicals of *Gloriosa superba*. The chemical structures were originally prepared by the authors using Chemdraw Professional 16. These phytochemicals contain numerous pharmacological properties, including anti-inflammatory, anti-cancer and anti-gout (11, 83).

significant activity, as determined by LOX and COX assays (3).

The hydroalcoholic extract of *G. superba* rhizomes also demonstrated strong anti-inflammatory properties, supported by the suppression of peritoneal exudates in acute inflammation models and the inhibition of granuloma formation in sub-acute cotton wool granuloma models (2, 48). Quantitative pharmacological screening reveals that the primary alkaloid, colchicine, is exceptionally potent compared to standard treatments (49). Oral administration of colchicine at doses of 2, 4 and 6 mg/kg body weight resulted in inhibition of inflammation of 48.9 %, 68.7 % and 79.1 % respectively (1, 49). This significantly outperforms the standard drug phenylbutazone, which achieved only 30.9 % inhibition at a much higher dose of 100 mg/kg (1, 49).

The mechanism behind this potent anti-inflammatory action is attributed to colchicine's ability to inhibit the production of tumor necrosis factor- α by macrophages and its capacity to reduce the surface expression of TNF-receptors on both macrophages and endothelial cells (49). Additionally, hydroalcoholic extracts from the tubers have been shown to downregulate other key inflammatory mediators, including interleukin-1 β and IL-6, further substantiating the plant's efficacy in treating joint pain and rheumatoid arthritis (21, 50).

Anti-microbial activity

The antimicrobial efficacy of *G. superba* is characterised by significant variations depending on the plant organ used, the extraction solvent and the target pathogen. Comparative analyses consistently demonstrate that the rhizomes and tubers are the most pharmacologically active parts of the plant compared to aerial sections (51, 52). For instance, ethanolic tuber extracts exhibit a zone of inhibition of 19 mm against *Staphylococcus aureus* and 18 mm against *Escherichia coli*, statistically outperforming shoot and flower extracts (51). This heightened activity in subterranean organs is correlated with a higher concentration of secondary metabolites, including alkaloids, tannins and flavonoids (51).

The choice of solvent significantly modulates the potency of these extracts. In comparative bioassays, chloroform fractions of the rhizome exhibit superior antibacterial activity (88 %) against *S. aureus* compared to crude methanol extracts (59 %) (53). Similar trends are observed in gram-negative pathogens, while chloroform extracts show a ZOI of 13 ± 0.00 mm against *Klebsiella pneumoniae* comparable to the standard antibiotic gentamicin (15.86 ± 4.67 mm) isolated compounds like desmosterol and 3-hydroxy-5-methoxy-benzoic acid demonstrate even more targeted potency against *Pseudomonas aeruginosa* at concentrations as low as 100 $\mu\text{g/mL}$ (22, 54). Generally, gram-negative bacteria such as *E. coli* require lower concentrations (500 $\mu\text{g/mL}$) for inhibition compared to gram-positive strains like *S. aureus* (1000 $\mu\text{g/mL}$) when using root tuber extracts (2).

Recent advancements in green nanotechnology have further enhanced the antimicrobial profile of *G. superba* by reducing the required inhibitory concentrations. Silver nanoparticles synthesised from tuber extracts produce substantial ZOI values against *Enterococcus faecalis* (29 mm) and *B. subtilis* (24 mm) at only 40 $\mu\text{g/mL}$ (55). Furthermore, bioengineered TiO_2 nanocatalysts from rhizome extracts show a statistically significant improvement in antibiofilm activity compared to crude extracts, achieving a 30.8 % inhibition rate for *P. aeruginosa* biofilms at 50 $\mu\text{g/mL}$ (35). Similarly, CuO nanoparticles (30–70 nm) synthesised using *G. superba* as fuel demonstrate potent effectiveness against *K. aerogenes* (15.67 mm

ZOI) and *E. coli* (13.67 mm ZOI) at 1000 $\mu\text{g}/50 \mu\text{L}$ (56–58).

Beyond antibacterial properties, the plant exhibits broad-spectrum antifungal and anthelmintic activity. Tuber extracts are significantly more effective than aerial parts against fungal pathogens, recording ZOI values of 20.17 mm against *Rhizopus oryzae* (51). Methanol tuber extracts also demonstrate high specificity, with inhibition rates reaching 99.33 % against *Rhizoctonia solanii* and 98.13 % against *Alternaria* sp. (13, 59). Finally, the rhizome's potency extends to parasitic management, where quantitative assays show it induces up to 100 % juvenile (J2) mortality in the nematode *Meloidogyne incognita* in only 12 hr of exposure (60).

Ecological significance

Microbial communities and plant-microbe interactions

Plant roots host diverse microbial communities, especially beneficial *Bacillus* species that boost plant health and growth. These act as plant growth-promoting rhizobacteria, producing hormones like indole-3-acetic acid, solubilising phosphate and synthesising enzymes for nutrient access and stress tolerance. Strains such as *Bacillus subtilis* and *Bacillus velezensis* control charcoal rot caused by *Macrophomina phaseolina* via hydrolytic enzymes and secondary metabolites, aiding disease suppression and plant growth (18).

Plant metabolites link to associated microbes (61). In medicinal plants, endophytic and ectophytic microbes alter bioactive levels, enhance stress tolerance and support growth (61). Endophytic *Bacillus* strains colonising glory lily rhizomes and shoots raise colchicine and gloriosine levels while promoting growth (17).

Pollination systems

Plants hold ecological importance due to its specialised pollination strategies, role in supporting pollinator diversity and value as a source of bioactive compounds. These features support ecosystem functions, while its medicinal properties aid conservation.

Pollination systems and pollinators influence glory lily productivity, including seed colchicine content, fruit set, pod length, test weight and germination (62). Three main pollinator types melittophilus, sphisophilus and psychophilus efficiently pollinate *G. superba* (62).

The plant favours cross-pollination, aided by small birds, butterflies and large insects like bumblebees due to its open flower structure. Butterflies, especially the pierid *Eronia cleodora* and birds like *Nectarinia zeylonica* and *Nectarinia asiatica* with long beaks are the most effective visitors (2, 4). This reliance on few pollinators limits widespread cross-pollination.

Studies highlight butterflies from Pieridae and Papilionidae families as ideal pollinators due to their size and wing-based pollen transfer (63). In India, large bumblebees and sunbirds pollinate the plant (63), while in South Africa's Eastern Cape, butterflies are common visitors (63, 64).

Insect visitors include allotrophous, hemitrophous and eutrophous types from 6 orders, 14 families and 16 genera. Hymenopterans dominate, followed by dipterans, lepidopterans, coleopterans, orthopterans and hemipterans; changes in frequency link to weather variations (62). Families such as Apidae, Vespidae, Nymphalidae, Pieridae and Papilionidae also act as

pollinators under Nauni conditions (62).

The glory lily's flowers are adapted for butterfly pollination. Butterfly wings, as dynamic structures, enhance pollen attachment and transfer. This floral design influences butterfly behaviour, reducing self-pollination and promoting cross-pollination (63).

Cultural importance

Throughout history, plants have been vital to the progress and evolution of human life. From providing essential nutrients and medicinal compounds to fostering cultural practices and economic growth, plants have been indispensable to human progress. Every tribe on the globe has its own customs, traditions, religious ceremonies, taboos, totems, folktales, folk music, feasts and mythology and other cultural elements, which are intimately connected with vegetation. The tribes regularly use a diverse flora for food and medicine and for various daily activities (65).

In numerous nations, glory lilies play a significant role in different rituals and cultural celebrations. In India, the glory lily holds a special place in the cultural fabric and is frequently linked to the Goddess Saraswati, representing knowledge and purity (66). In Tamil Nadu, it is considered the state flower (67). According to folklore regarding the plant's name, if its blossom is thrown onto a neighbor's roof, arguments will ensue within three days. Therefore, when playing during the flowering season, tribal children would gather the flowers from their surroundings and throw them onto each other's roofs. The flowers are used in sacred celebrations, especially those dedicated to deities such as Dongarya Dev (28).

The flame lily stands as Zimbabwe's national flower, symbolising resilience, strength and the enduring spirit of its people. This flower is a source of national pride and is highlighted in cultural narratives and official insignias (68, 69).

Throughout several African nations, *G. superba* is employed in magical rituals and traditional ceremonies. The flowers of this plant are used in religious rituals and offerings across various cultures, illustrating its significance as a connector between the natural realm and the divine (70).

Conservation efforts

The glory lily, valued for its medicinal benefits, faces significant overexploitation through indiscriminate harvesting from wild populations by local communities and pharmaceutical industries for its colchicine content, contributing to its endangered status (2). This excessive harvesting, along with poor propagation, caused by decreased viability and reduced seed germination, has resulted in the plant being classified as endangered as documented in 2024–25 literature (56, 62).

Propagation of the glory lily occurs through seeds and by the separation of fully developed plants from rhizomes (71). Common vegetative plant propagules, such as root tubers, can survive as dormant structures in arid or chilly conditions (2, 72). Additionally, tubers are easier to store and transport, facilitating the exchange of germplasm across international borders; however, this limitation often arises because of low germination rates, as seeds can stay dormant for 6 to 9 months (12, 10, 73). limits regeneration because of their low germination rates, as seeds can stay dormant for 6 to 9 months (10,12,73).

The traditional propagation method presents several drawbacks, including the necessity to reserve 50 % of the yield for the cultivation of the subsequent crop, the movement of soil-

borne diseases not only between various crops but also across different sites and it can also take place during the 2-3 month interval of storage that occurs between the harvest and the subsequent crop's planting (74).

Biotechnological techniques could be a keystone for the protection, conservation and propagation of this significant plant, making it necessary to implement *in vitro* propagation and micropropagation methods to accomplish this (11).

Two approaches for the clonal propagation of *G. superba* were devised, employing apical buds and nodal segments cultured on B5 or MS media with a range of plant growth regulators. The first approach involved culturing apical buds in 6-benzyladenine (BA) and indole-3-butyric acid (IBA), which were subsequently transferred to media for shoot proliferation and rooting. The second approach allowed shoot tips to generate adventitious buds, achieving high shoot proliferation in liquid MS medium. Effective rooting was achieved in Murashige and Skoog (MS) media with IAA, IBA, or naphthaleneacetic acid (NAA), where 0.1 mg/L IAA provided the optimal results. Acclimatised plantlets survived in soil but did not flower, resulting in the production of only small corms during the initial vegetative phase (75).

A different and efficient way to quickly and continuously multiply species to satisfy the demand for commercial exploitation is through *in vitro* methods of propagation. Without requiring any acclimation, *in vitro* tubers can be planted directly in the soil (73).

The conservation of *G. superba* is no longer merely a biological necessity but a critical ethical imperative. The plant's current "endangered" status in nations across Asia and Africa is a direct consequence of a commercial-ecological conflict, where industrial demand for colchicine outweighs the species' natural regenerative capacity (56, 62). Ethical bioprospecting demands a paradigm shift away from the current trend of indiscreet reaping and imprudent harvesting from wild habitats, which treats the species as an infinite industrial resource rather than a fragile biological entity (2, 11).

The ethics of harvesting are particularly sensitive due to the plant's natural reproductive bottlenecks. *Gloriosa superba* is characterised by a naturally low seed set and a reliance on a narrow range of specific pollinators, such as sunbirds and large butterflies (4, 63). When tubers are harvested prematurely or extensively from the wild to satisfy the pharmaceutical market, such harvesting essentially halts the natural germplasm cycle, leading to local extinctions in regions like the Darjeeling Himalaya (2, 56).

Conclusion and future perspectives

A critical synthesis of the reviewed literature reveals that *G. superba* is a plant of significant pharmacological complexity, yet its transition to clinical applications is currently hindered by a narrow therapeutic index and ecological vulnerabilities. Rather than a uniform medicinal resource, it exhibits organ-specific metabolic trade-offs: tubers remain the industrial standard for colchicine, while leaves demonstrate superior antioxidant potential through higher phenolic accumulation (67, 76). Furthermore, extraction yields do not always correlate with biological potency; for example, while methanol achieves high bulk yields of 5.56 %, chloroform fractions offer superior targeted antimicrobial sensitivity against pathogens like *S. aureus* (22, 53).

A clear distinction must be drawn between reported ethnomedicinal uses and validated clinical effects. Traditional systems like Ayurveda employ over 158 formulations for varied ailments via detoxification processes (*Shodhana*), yet modern validation remains predominantly at the *in vitro* and murine levels (21, 77). Potent anti-cancer activities such as an IC₅₀ of 0.12 g/mL against colon cancer cells have yet to be replicated in human clinical trials (22). Application safety is further constrained by colchicine's lethal threshold, necessitating a shift from traditional purification to precise modern dosage standardisation (1, 49).

Regarding ecological status, evidence confirms *G. superba* as a priority conservation species rather than one facing immediate global extinction. Vulnerability arises from industrial over-harvesting and reproductive bottlenecks, including naturally low seed set and reliance on specialist pollinators like sunbirds and butterflies (4, 56, 63). Its economic importance ties to the high-demand colchicine market, which relies on wild-sourced materials (33).

Medicinal plants like *G. superba* are vital sources of bioactive compounds for traditional and modern medicine. This economically important endangered species has treated diverse ailments throughout history, offering medicinal, ecological and cultural value, yet faces extinction risks from habitat loss, overexploitation and poor propagation (2). Biotechnological innovations are essential for its conservation and commercial cultivation.

This review positions *G. superba* as a high-value resource and Ayurvedic "*Upavisha*" (6, 21). Ethnopharmacological uses by 35 Indian tribes target conditions like labor induction and infections (9, 23), while clinical studies validate alkaloid-based anti-inflammatory and antimicrobial effects outperforming some NSAIDs (non-steroidal anti-inflammatory drugs) (49, 78).

Despite 158 Ayurvedic formulations relying on it (21, 56), gaps hinder standardised colchicine production amid rising demand (56, 67). Now endangered in Asia and Africa (56, 62) prioritised in India and extinct in parts of the Darjeeling Himalaya (56) its risks stem from low seed set and limited pollinators (62, 63).

Future efforts should prioritise *in vitro* micro-tuber production and elicitor-enhanced yields (67, 79), blending biotechnology with Ayurvedic heritage for sustainable supply (21, 56).

Critical discussion

The pharmacological profile of *G. superba* reveals a complex interplay between organ-specific secondary metabolism, extraction chemistry and modern nanotechnological interventions. A critical synthesis of current research indicates that the plant's therapeutic value is not uniform, but highly dependent on the physiological source and the methodological approach to bioactive recovery.

Organ-specific bioactivity and metabolic trade-offs

A fundamental observation across the literature is the metabolic "trade-off" between aerial and subterranean organs. While the rhizomes and tubers remain the primary industrial source for alkaloid extraction (colchicine), they are often outperformed by the leaves and stems in antioxidant capacity (65, 76). Specifically, leaves demonstrate a significantly higher accumulation of phenolic compounds and greater ABTS radical scavenging activity compared to tubers, a phenomenon observed in both *in vivo* and *in vitro* cultivated specimens (38, 76). This suggests that the leaves represent an underutilised resource for managing oxidative stress-

related pathologies, while the subterranean organs should remain the focus for potent antimicrobial and anti-inflammatory alkaloid production (23, 49).

Interpretation of extraction dynamics: Yield vs. potency

The choice of solvent introduces a critical variable in drug standardisation. Quantitatively, methanol is the superior solvent for bulk extraction, achieving root yields of 5.56 % (17.78 g from 320 g), which drastically exceeds yields from n-hexane (0.17 %) or chloroform (0.90 %) (23). However, a critical interpretation of antimicrobial sensitivity suggests that higher yield does not always equate to higher potency. For example, while methanolic extracts provide broader phytochemical recovery, chloroform fractions of the rhizome exhibit higher targeted sensitivity (88 %) against *S. aureus* compared to crude methanol extracts (59 %) (51). This indicates that industrial applications must distinguish between "high-yield" crude preparations and "high-potency" purified fractions depending on the clinical target.

The nanotechnology paradigm and reactive oxygen species (ROS) modulation

The integration of green nanotechnology represents a significant leap in maximising the plant's biological efficacy while potentially reducing the dosage required for therapeutic effect. Comparative data shows that bioengineered nanoparticles achieve inhibitory results at concentrations far below those of crude extracts. For instance, silver nanoparticles synthesised from tuber extracts produce a 29 mm zone of inhibition against *Enterococcus faecalis* at only 40 µg/mL (53). Furthermore, the mechanism of action shifts from simple chemical inhibition to active biological modulation; bioengineered TiO₂ nanocatalysts have been shown to induce mitochondrial depolarisation and increase ROS levels in cancer cell lines, leading to a 30.8 % inhibition rate of *P. aeruginosa* biofilms (34). This suggests that nanotechnology is essential for transitioning *G. superba* from traditional ethnomedicine to precise, targeted modern therapies.

Ethical and ecological considerations for drug development

Finally, the transition from research to clinical application faces a significant barrier: the plant's endangered status. Despite its immense pharmacological potential, *G. superba* is currently prioritised by the National Medicinal Plant Board for conservation due to over-exploitation (54). The synergy between Ayurvedic traditional knowledge (where the plant is known as Langali) and modern molecular docking studies validates its use for inflammatory conditions (23, 27). However, future pharmaceutical development must shift toward biotechnological interventions, such as micropropagation or the use of arbuscular mycorrhizal fungi, to enhance alkaloid content and growth without further depleting wild populations (19, 67).

Identification of knowledge gaps and future research directions

While the pharmacological potential of *G. superba* is well-documented, several critical gaps remain that hinder its transition from laboratory research to standardised clinical application. Addressing these gaps is essential for the sustainable development of this endangered medicinal resource. Clinical validation is lacking, as *in vitro* potency (e.g., IC₅₀ 0.12 µg/mL vs. colon cancer (22)) has not progressed to human trials and should expand beyond murine models (50). Metabolic standardisation is required due to colchicine variation (0.15–0.9 % (33)); elite chemotypes must be fingerprinted amid ecotype differences (16). Pollination/

seed-set is low owing to specific pollinators (sunbirds, butterflies (63)); cross-pollination improvement is essential (64). Safety profiles demand comparison of crude (Ayurvedic Upavisha (21)) vs. purified extracts, assessing synergies modulating colchicine toxicity (49). Microbial enhancement via endophytes/AMF boosts metabolites (18), but signalling pathways need elucidation for sustainable production (61).

Toxicological profile and clinical risk management

The pharmacological utility of *G. superba* is inextricably linked to its systemic toxicity, rooted in its Ayurvedic classification as an Upavisha (semi-poisonous drug) (21). This status necessitates traditional detoxification (Shodhana) where tubers are processed in media like cow's milk to mitigate irritant alkaloids while preserving therapeutic efficacy (21). Despite these ancient safety protocols, the plant's narrow therapeutic index remains a major concern; accidental ingestion often induces symptoms mirroring arsenic poisoning, including gastrointestinal distress that can progress to cardiovascular collapse and respiratory failure (2, 56).

A critical analysis of its presence in over 158 documented traditional formulations reveals a significant standardisation gap (21). While traditional use targets conditions like inflammation and labor induction, the lethal threshold of colchicine (2–6 mg/kg) requires precise dosing that current ethnomedicinal practices may lack (1, 21). Modern research suggests that while colchicinoids are potent anti-inflammatories, their cytotoxic nature poses severe risks, such as bone marrow suppression and alopecia (49). Consequently, the clinical future of *G. superba* depends on bridging the gap between traditional purification methods and modern quantitative safety standards to mitigate the inherent risk of misuse and accidental poisoning (2).

Responsible bioprospecting and benefit-sharing

The commercial expansion of *G. superba* necessitates a transition from "extractive" harvesting to ethical bioprospecting frameworks that safeguard its endangered wild populations (2, 56). This shift is governed by the Nagoya protocol's access and benefit-sharing mechanism, which recognises the 35 tribal communities in India as the primary custodians of the plant's ethnomedicinal knowledge (9, 21). Responsible bioprospecting requires pharmaceutical entities to obtain prior informed consent and ensure the equitable distribution of technological or financial benefits to these indigenous groups (4, 56).

To move beyond purely extractive models, the industry should prioritise contract farming and the transfer of biotechnological propagation methods, such as micro-tuber production, to local communities (67, 79). By integrating modern industrial demand with sustainable, community-led cultivation, the global trade of *G. superba* can support both pharmaceutical innovation and the socio-economic welfare of traditional practitioners (16, 33).

Conclusion

The notable developments in hydrological modelling since the establishment of the initial Hydrological Research Unit (HRU) at Wallingford in the 1960s have not occurred in isolation. They have coincided with rapid technological advancement. Complex mathematical computations that take hours or days to complete on a PC or laptop can now be performed in seconds. New instruments

and data recording tools allow for more precise and frequent observations. Recent significant flood occurrences have led to the development of real-time flood forecasting systems with sophisticated data processing algorithms, real-time updating of model parameters and the estimation of prediction uncertainty. These systems use data from multi-parameter weather radars.

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Authors' contributions

RK has written the whole manuscript. RK carried out the conceptualisation and literature review, biochemical structure designing, data collection and analysis of this paper. S and AP participated in review and editing and providing technical support to write the manuscript. DKP supervised the writing of the manuscript in a proper format and approved the final manuscript. All authors have read and approved the final manuscript.

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