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Gmelina asiatica: exploring traditional uses, pharmacological insights, and phytoconstituents—a comprehensive review (1961–2023)

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Abstract *Gmelina asiatica* is one of medicinal plants that is famous in traditional medicines. It is known as Asian bushbeech under the family Lamiaceae. *Gmelina asiatica* is widely used in Indian folklore to treat many illnesses and disorders, such as treatment of jaundice, hemorrhoids, dysuria, arthritis, edema, liver diseases, neurological disorders, fever, heart diseases, dandruff, skin infections, acne, diabetes mellitus, catarrh of the bladder, syphilis, as antiseptic, astringent, demulcent, contraceptive and blood purifier. As well as, there are various reports on the pharmacological activities of this plant that scientifically support some of its traditional uses. These activities have been shown to include anticancer, anti-inflammatory, antioxidant, antihyperglycemic, antipyretic, nematicidal, anxiolytic, neuroprotective, anti-microbial, hepatoprotective, nephroprotective and analgesic activity. *Gmelina asiatica* is rich in furofuran lignans and flavonoids and contains many other secondary and primary metabolites, but only a few studies have been conducted to identify and isolate its phytoconstituents. The current review aims to provide the published information on *Gmelina asiatica*, its features, traditional uses, ethnobotanical uses by different tribes, pharmacological activities, and reported phytoconstituents, from 1961 to September 2023, which was collected from books and online databases such as Scopus, Google Scholar, PubMed, Science Direct, SpringerLink, and Wiley Online Library.

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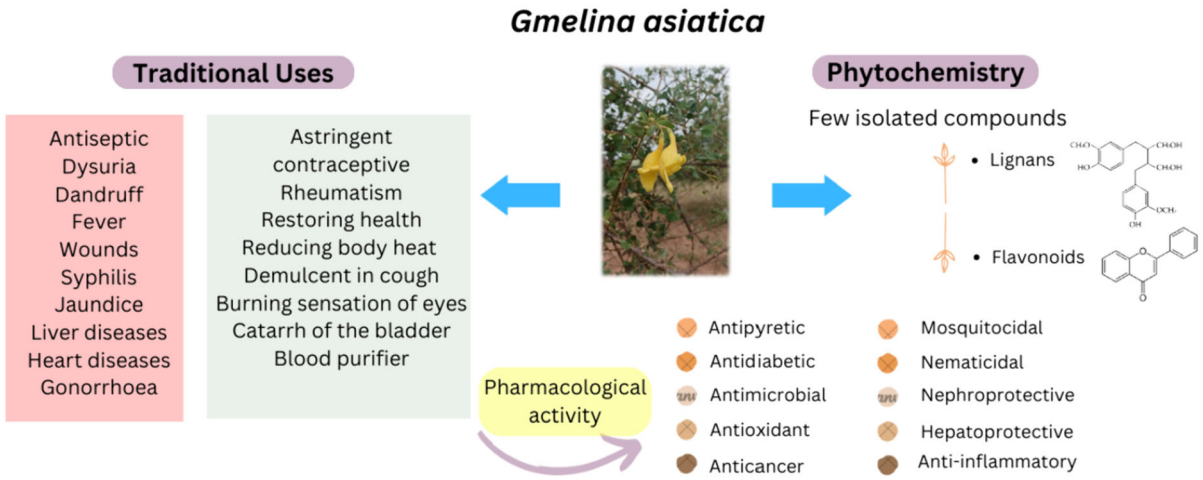
Graphical Abstract



Keywords *Gmelina asiatica* · *Gmelina parviflora* · Asian bushbeech · Badhara · Kumil · Lamiaceae

Abbreviations

ALP	Alkaline phosphatase
ALT	Alanine aminotransferase
APG	Angiosperm phylogeny group
AST	Aspartate transaminase
BHT	Butylated hydroxytoluene
CAT	Catalase
CBC	Complete blood count
CCL_4	Carbon tetrachloride
CMC-Na	Sodium carboxymethyl cellulose
DPPH	2,2-Diphenylpicrylhydrazyl
EPM	Elevated plus maze
FTC	Ferric thiocyanate
GAE	Gallic acid equivalent
G. arborea	*Gmelina arborea*
G. asiatica	*Gmelina asiatica*
g.b.w	Gram of body weight
GC–MS	Gas chromatography-mass spectrometry
GSH	Glutathione
IC_{50}	Half maximal inhibitory concentration
i.p.	Intraperitoneal injection
MCF-7	Michigan cancer foundation-7
MDA-MB-231	MD Anderson-metastatic breast 231
MIC	Minimum inhibitory concentration
MTT	3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide
OECD	Organisation for economic co-operation and development
P.O.	Per oral
ppm	Parts per million
QE	Quercetin equivalent
SOD	Superoxide dismutase
STDs	Sexually transmitted diseases
TBA	Thiobarbituric acid
UHPLC–HRMS	Ultra-high-performance liquid chromatography-high resolution mass spectroscopy

Introduction

Gmelina asiatica Linn. is an ornamental flowering (Chowdhuri and Deka 2019) woody shrub (Jayasingam et al. 1992), typically standing at a height of 2–4 m (de Kok 2012). At times, it can even resemble a small tree, but usually does not exceed 10 m in height (Chen and Gilbert 1994; Kannan et al. 2012). The plant is characterized by its straggling, climbing, and semi-evergreen nature with numerous branches and spines (Kannan et al. 2012; Rajesh et al. 2013). However, it can also occasionally take on a decumbent form (Girija and Ravindran 2011) and be deciduous (de Kok 2012). Initially, it classified under Bentham

and Hooker's system within the tribe Viticeae of the subfamily Viticoideae, under the family Verbenaceae, *Gmelina asiatica* then underwent a taxonomic shift. Phylogenetic analyses, forming the basis of the Angiosperm Phylogeny Group (APG) classification, led to the relocation of the subfamily Viticoideae to Lamiaceae. As a result, *Gmelina asiatica* is now recognized as a member of the family Lamiaceae (Kooiman 1975; Kannan et al. 2012; Vignesh 2020; Zhao et al. 2021).

Synonyms and vernacular names

Synonyms

Gmelina parvifolia Roxb., *Gmelina asiatica* f. *lobata* Moldenke, *G. attenuata* H. R. Fletcher, *G. paniculata* H. R. Fletcher (de Kok 2012).

International names according to the place or language name

English: Asian Bushbeach (Rajesh et al. 2013), Small Cashmere tree (Khare 2007), Asiatic beechberry (Sivapalan and Sanmugarajah 2019). *Chinese*: Ya zhou shi zi (Chen and Gilbert 1994; de Kok 2012). *Cambodia*: Köncaang (de Kok 2012), Agnchagn (Top et al. 2004). *Peninsular Malaysia (Malay language)*: Bulang, Bulongan (de Kok 2012). *Thailand:* Jo mae (Neamsuvan et al. 2015). *Philippines (Cebuano language):* Banganga (de Kok 2012). *Laos*: Phoung nou (de Kok 2012). *Indonesia*: in *Javanese language*: Wareng, in *West Timor (Dawan language):* Hau bako, in *Alor*: Lombaul (de Kok 2012). *Sri Lanka (Singhalese language)*: Demata (de Kok 2012).

Indian common names

Hindi: Badhara (Kannan et al. 2012), Bhedaira, Bhdara (Srivastava 1967). *Sanskrit:* Vikarini (Kannan et al. 2012), Gopabhandra (Rajesh et al. 2013), Biddari (Sivapalan and Sanmugarajah 2019). *Telugu:* Adavi Gummudu (Silvia and Satyanaraya 2014), Nelagummudu (Rajesh et al. 2013), Challa Gummudu (Kannan et al. 2012). *Oriya (Odia):* Gombhari, Gopogombhari, Nomdano (Jeeva et al. 2019). *Tamil:* Nilakumil, Kumil, Mulkumizh (Sivapalan and Sanmugarajah 2019). *Bengali:* Bhadra (Jeeva et al. 2019). *Malayalam:* Kumil (Kannan et al. 2012), Kumilamaram (Jeeva et al. 2019), Cherukumizh (Vignesh 2020). *Varanasi local language:* Nagphool (Kusuma and Joshi 2010).

Ayurveda and Siddha names

Ayurveda: Gambhaari, Gopabhadra, Vikarini (Khare 2007), Kshudragambhari (Murugeswaran et al. 2016). *Siddha*: Kumizham (Khare 2007).

Taxonomy

Gmelina asiatica, a species that originated in India, was used by Linnaeus to identify the genus *Gmelina* in 1753. Linnaeus classified this genus under the class 'Didynamia Angiospermea' without specification of its family. In 1806 the genus *Gmelina* was placed in the family Verbenaceae by de Jussieu. Further taxonomic refinements occurred as the family Verbenaceae underwent divisions into tribes and subfamilies. In 1829 and 1895, the genus *Gmelina* was successively included in the tribe Viticeae and the subfamily Viticoideae. More detailed classification emerged in 1895 when the genus *Gmelina* was divided into sections based on species characteristics by Briquet. *Gmelina asiatica* found its place under the section Microstromatae. Subsequent to phylogenetic analyses, several subfamilies, including Viticoideae, were transferred from Verbenaceae to the family Lamiaceae. Then, based on molecular studies, *Gmelina* and two other genera (Cornutia and Premna) have been removed from the subfamily Viticodeae and together they formed another subfamily called Premnoideae under the family Lamiaceae. Thus, *Gmelina asiatica* is now a part of the family Lamiaceae (Munir 1984; Li et al. 2016; Zhao et al. 2021).

Ecology and distribution

G. asiatica can live in a variety of habitats, showcasing remarkable adaptability. It flourishes in different soil types, including sandy, clay, and poor soils (de Kok 2012). This resilient species can be found in both deciduous and evergreen forests, as well as dry thorn forests (de Kok 2012; Rajulu et al. 2021). Notably, it extends its presence to swamp shrubland and swamp forests in Cambodia and New Guinea (Giesen 2018). The adaptability of *G. asiatica* is further emphasized by its ability to thrive in diverse environments such as

Fig. 1 Pictures of different parts of *Gmelina asiatica* (flowers, leaves, stems, roots, and the whole plant) collected from Vallanadu, Thoothukudi District, Tamil Nadu, India

desert areas, coastal lands, barren regions, along roadsides, and in secondary and disturbed lands (de Kok 2012; Azhagumurugan and Rajan 2014b).

Its widespread presence is evident in various regions, including India, Sri Lanka (Ceylon), Thailand (east to the north), North Vietnam, south China, Peninsular Malaysia (de Kok 2012), New Guinea, Cambodia (Giesen 2018), Myanmar (Burma) (Collett and Hemsley 1890), Laos (Kato et al. 2008), Borneo, Java, Mauritius, Bengal, Sumatra and Philippine Islands (Lam 1919).

Description

Leaves: opposite, simple, papery leaves, occasionally alternate. The leaf morphology can take on shapes such as ovate, obovate, elliptical, or deltoid. The leaf size ranges from 5 to 50 (− 130) mm long, and 5–33 (− 60) mm wide. The leaf margin is entire to 3–5-lobed. Apex may be acuminate, acute, rounded, or obtuse. Base is cuneate or rounded. It has 3 or 4 pairs of veins and the nerves are covered with fine hairs. The upper side of the leaf (adaxis) is dark green, glossy, usually hairless, with a leathery texture. The lower side of the leaf (abaxis) is typically without hairs, sometimes covered by villi, involving glands (Lam 1919; Chen and Gilbert 1994; de Kok 2012; Kannan

et al. 2012). *Leaf stalk* (petiole): it is 0.5–3 cm long, glabrous or pubescent (de Kok 2012). *Inflorescence*: usually terminal, pendulous, and downy. The flowers are also pendulous. The morphology of inflorescence is either simple raceme or compound raceme (panicle) (Chen and Gilbert 1994; de Kok 2012; Kannan et al. 2012). Bracts and bracteoles are easily detached and leaf-like (Chen and Gilbert 1994; de Kok 2012). *Sepals (Calyx)*: consists of 4 to 5 lobes, pubescent, with numerous glands. The size of this calyx is up to 0.4 × 0.6 cm maximum. *Petals (Corolla)*: The corolla is yellow and long. It consists of 4 lobes and it is 2-lipped, the front lip consists of 3 lobes where the middle one is longer than the other two, while the back lip has just one lobe. It has some glands and is covered by hairs. *Fruits (Drupes)*: without hairs and has a yellow color when ripe (Chen and Gilbert 1994; de Kok 2012). *Heartwood*: light pinkish red (Anjaneyulu et al. 1975). *Roots*: brown with Superficial cracks (Krishnan and Gopi 2015). In addition, the anatomical studies of leaves and stems of *G. asiatica* has been reported by Florence and Domettila (2016). Figure 1 shows pictures of different parts of the plant.

Adulteration and substitution

While there are no reported adulterants for *Gmelina asiatica*, the roots of *Gmelina arborea* are documented by the ICMR to be adulterated with those of *Gmelina asiatica*, possibly due to the easier harvesting from the shrub-like *G. asiatica* compared to the tree-like *G. arborea*. Additionally, *G. asiatica* may offer better medicinal properties (Babu et al. 2010; Krishnan and Gopi 2015; Vignesh and Sumitha 2021).

Materials and methods

In the current review, a detailed report on *Gmelina asiatica* medicinal plant has been prepared based on related literature available from 1961 to 2023. All the inputs were gathered from books and electronic databases, such as Scopus, Google Scholar, PubMed, Science Direct, SpringerLink, and Wiley Online Library. The published articles related to *Gmelina asiatica* have been carefully reviewed to collect all information available on this plant, its traditional and tribal uses, pharmacological activities which have been proven through in vitro and in vivo studies, its

Table 1 Ethnomedicinal uses of different parts of *G. asiatica*

Part used	Ethnomedicinal uses
The whole plant	The plant is used for the purification of the blood, and in the treatment of gonorrhea and infections of the bladder (Jeeva et al. 2019). This plant is also considered a folkloric contraceptive plant (Farnsworth et al. 1975)
Leaves and aerial parts	They are used in rheumatism, catarrh of the bladder, STDs such as gonorrhea and syphilis, leucorrhea (Rathnam and Mudaliar 2002), restoring health (Khare 2007), jaundice, fever, reducing the body temperature, wounds, diabetes (Jeeva et al. 2019), to control the burning sensation in eyes and painful urination, in alleviating the anxiety, depression, yawning and lethargy (Rathnam and Mudaliar 2002), they are also used to relieve dandruff and employed as a blood purifier (Florence and Regini Balasingh 2016) and as anti-diarrheal agent (Rathnam and Mudaliar 2002)
Roots	The root is used as a demulcent in cough, astringent (Jeeva et al. 2019), antiseptic, blood purifier, and anticatarrhal, and it helps in restoring health (Khare 2007). The root is also used to treat heart disease (Ray and Saini 2021), rheumatism, burning sensation, diabetes, dandruff, wound, liver diseases, pyrexia, syphilis, gonorrhea, dysuria (Florence and Regini Balasingh 2016), diarrhea, anxiety, lethargy, and depression (Rathnam and Mudaliar 2002). In folkloric history, the root of this plant has been used to induce labor and thus facilitate childbirth or to induce abortion (Farnsworth et al. 1975)
Barks	The bark is used in the treatment of heart disease (Ray and Saini 2021) and other diseases mentioned in aerial parts

phytochemicals and the gaps which are needed to be filled. The structures presented in this report have been drawn using ChemDraw software, and ChatGPT was used to edit and improve language.

Results and discussion

Traditional uses

Gmelina asiatica holds significant importance in traditional medicinal practices due to its diverse therapeutic applications. Revered in folklore medicine, every part of the plant is recognized for its medicinal benefits. Despite its extensive use by traditional healers and individuals knowledgeable about herbal remedies, *G. asiatica* remains classified as an Anukta Dravya, signifying an "undocumented or extra-pharmacopeial medicinal plant" (Kusuma and Joshi 2010; Vignesh 2020).

Traditional medicine and formulations

G. asiatica finds application in Ayurvedic, Unani, Siddha, and Khmer traditional medicine, featuring prominently in various formulations (Kannan et al. 2012; Ali et al. 2014; Kapur 2016; Chassagne et al. 2017). Cambodian Khmer traditional therapists utilize *Gmelina asiatica* to treat liver diseases (Chassagne et al. 2017). In Siddha formulations, the powder of *G. asiatica* roots is internally administered for joint pain, while the leaves are included in external applications to alleviate headaches (Wilson et al. 2007; Esakkimuthu et al. 2021). Notably, an Ayurvedic drug, patented in 2005, incorporates *G. asiatica* to treat and repair the uncommon type of mullerian dysgenesis (Patil and Wadekar 2021). The Unani medicine formulation, Habb-e-Asgand, designed to address conditions such as gout, lumbago, arthritis, joint pain, and liver protection, features *Gmelina asiatica* stem as a key component (Ali et al. 2014). In general, traditionally, *G. asiatica* is used in the treatment of various ailments, including hemorrhoids, painful urination, neurological disorders, burning sensation, edema (Murugeswaran et al. 2016), arthritis (Choudhary et al. 2015), jaundice, pyrexia, diabetes mellitus, infections of the bladder (Jeeva et al. 2019), scalp and skin infections like dandruff and acne (Mahendra 2015).

Furthermore, *G. asiatica* serves as a blood purifier and has historically been employed in treating sexually transmitted diseases (STDs) such as syphilis and gonorrhea (Khare 2007; Florence and Regini Balasingh 2016). It is also reputed for their effectiveness in

Table 2 Summarization of herbal preparations of *G. asiatica* as used by local communities for addressing of some diseases

Type of disease	Preparation/method	References
Body heat	Soak 5–10 g of *G. asiatica* leaves in 200 ml of cool water for 2–3 h. Afterward, strain out the leaves, and consume the infused water orally twice daily for a period of 4–5 days	Vikneshwaran et al. (2008)
Dandruff	A blend is created by grinding the fruit pulp of *G. asiatica* and mixing it with *Sapindus emarginatus* fruit. Approximately 15–20 g of this mixture in form of paste is gently applied to the scalp during washing	Apparanantham et al. (1982); Jeyaprakash et al. (2011); Ganesh and Sudarsanam (2013); Murthy et al. (2020)
	Apply the fruit pulp alone for 4–5 days	
	Boil the fruits of *G. asiatica* with coconut oil to prepare a paste, and then apply it topically to the scalp	
	Apply a paste prepared from stem bark directly to the scalp of the head	
Earache	Make fresh juice from the fruits of the plant, and then administer 2 to 3 drops inside the affected ear	Bose et al. (2014)
Gonorrhea	Juice of the root administered internally	Murthy et al. (2020)
Eczema	Apply the fruit pulp topically on the eczema	Jeevan Ram et al. (2004)

Table 3 Outline of in vivo anti-inflammatory activity of *Gmelina asiatica* plant

Models	Method used/duration to see the result	Process/standard	Results	References
Male albino rats	Carrageenan-induced pedal edema/after 1, 2.5, and 5 h intervals	Suspension of powdered root in 2% acacia gum has been prepared and administered orally to the rats at different doses (50, 100, 150, 200 mg/100 g.b.w)/ phenylbutazone (10 mg/100 g.b.w) and hydrocortisone (1.5 mg/100 g.b.w)	Significant reduction in the volume of the paw (not dose-dependent decreasing)	Syed et al. (1997)
	Cotton pellet-induced granuloma/at the day number 8	Suspension of powdered root in 2% acacia gum (100 mg/100 g.b.w per day for 7 days) was administered by oral to rats/ hydrocortisone (1.5 mg/100 g.b.w)	Significant reduction in cotton pellet weight	
Male and female adult albino rats	Carrageenan induced paw edema/after 1, 2, 3, 4 h	Ethanolic extract of aerial parts (250 and 500 mg/kg p.o) were administered to rats (same in all methods)/indomethacin (10 mg/kg) as a standard in all methods	In all methods used, there was a significant inhibitory effect (reduction in edema volume or cotton pellet weight)	Merlin et al. (2009a)
	Histamine induced paw edema/after 1, 2, 3, 4 h	In the cotton pellet granuloma method, the dose of plant extract and the dose of the standard were given every day for 7 days		
	Dextran-induced paw edema/after 1, 2, 3, 4 h			
	Cotton pellet granuloma/on the 8th day			

g.b.w gram of body weight

addressing leucorrhea, an abnormal genital discharge in females. Moreover, this plant possesses anti-diarrheal properties, and is known to alleviate symptoms of anxiety, depression, yawning, and lethargy (Rathnam and Mudaliar 2002). Furthermore, the root bark of *Gmelina asiatica* is therapeutically valued for treating congenital heart disease in traditional medicine (Ray and Saini 2021). The details of ethnomedicinal uses of various parts of *G. asiatica* plant are listed in Table 1. Additionally, *Gmelina asiatica* plant is also found in the Military Medical Museum as this specimen was collected from Sri Lanka and was accompanied by medical notes often attributed to medical expertise or indigenous people. These notes emphasize the significance of the plant's leaves and roots in relieving swelling around the neck caused by infection of the lymph nodes (Kandamalai) (Cooper 1842).

Uses of G. asiatica by tribal communities

Saora tribe in Andra Pradesh employs the peel of *Gmelina asiatica*'s fruit topically to treat wounds and dandruff (Jeeva et al. 2019). In Chittoor villages, the Yanadi tribe uses a paste made from the fruits of *Gmelina asiatica* and the Soapnut tree to eliminate dandruff, applying it to the scalp before washing (Ganesh and Sudarsanam 2013).

Tribes in Tamil Nadu utilize the aerial parts of *G. asiatica* for addressing jaundice and liver problems, while other tribes in the same state consider it as an antipyretic to lower body temperature (Silvia and Satyanaraya 2014). Paliyar tribe in Virudhunagar district, Tamil Nadu, recommends *Gmelina asiatica* for dermatological ailments and uses its fruit juice as an ear drop for relieving ear pain (Bose et al. 2014; Mutheeswaran et al. 2021). In Theni district, Tamil Nadu, the Paliyar and Muthuvar tribes concoct a paste by boiling coconut oil and *Gmelina asiatica* fruits to

Table 4 Summary of antimicrobial activity of *G. asiatica* plant

Microorganisms	Method used	Extract/standard	Results	References
Staphylococcus aureus ATCC 25923, *Pseudomonas aeruginosa* ATCC 7853, *Bacillus subtilis* ATCC 6633, *Escherichia coli* ATCC 25922, *Micrococcus luteus* ATCC 10240 and *Salmonella typhi* ATCC 43579. The fungal species were *Candida albicans* ATCC 10231 and *Aspergillus niger* ATCC 16404	Agar disc diffusion test	Ethanol, ethyl acetate, chloroform, and petroleum ether extracts of aerial parts of the plant (500 µg/ml) / amikacin (10 µg/ml) as antibiotic standard and griseofulvin (20 µg/ml) for antifungal activity	All the extracts inhibited most of the tested microorganisms. Chloroform extract showed the highest antimicrobial activity. Ethanolic extract also exhibited significant activity	Merlin et al. (2009a)
Staphylococcus aureus, *Proteus vulgaris*, *Streptococcus faecalis*, enteropathogenic *Escherichia coli*, *Pseudomonas aeruginosa*, *Bacillus pumilus* and *Bacillus subtilis*	Well diffusion test Tube dilution test to define the Minimum Inhibitory Concentration (MIC)	Ethanolic extract of roots (40 µl at a concentration of 25 mg/ml in wells)/ampicillin (40 µg/ml)	The extract showed significant antibacterial activity compared with the standard	Sudhakar et al. (2006)
Streptococcus pneumoniae, *Klebsiella pneumoniae*, *Proteus mirabilis*, *Escherichia coli*, *Micrococcus luteus*, *Staphylococcus aureus*, *Bacillus subtilis* and *Pseudomonas aeruginosa*	Disc diffusion method	Acetone, benzene, chloroform, ethanolic, ether, and aqueous extracts of roots, leaves, and stems	All the extracts inhibited the pathogenic tested microorganism. Leaf and roots extracts showed the highest antibacterial activity against most of the bacteria	Shibu et al. (2012)
Bacillus circulans MTCC 9720, *Proteus vulgaris* MTCC 7299, *Actinomyces howelli* MTCC 3048, *Staphylococcus aureus* MTCC 3160, *Pseudomonas aeruginosa* MTCC 1688, *Escherichia coli* MTCC 9721 and *Streptococcus pyogenes* MTCC 1927	Agar disc diffusion assay	Essential oils and chloroform, acetone, petroleum ether, ethanolic and aqueous extracts of leaves (50 µl of 200 mg/ml solution) /kanamycin (10 µg) as a standard	The extracts showed antibacterial activity against all tested organisms. The highest efficacy was noted against *Actinomyces howelli* (inhibition zone 9.66 mm), followed by *Staphylococcus aureus*, *Bacillus circulans*, and *Streptococcus* pyogenes. The essential oils exhibited an insignificant effect against pathogens	Florence and Balasingh (2016)
Pseudomonas aeruginosa and *Staphylococcus aureus*	Disc diffusion test	Ethanolic extract (1500, 2500, and 5000 µg) /ampicillin (30 µg) as a positive control	The antibacterial activity of the plant was exhibited at concentrations of 2500 and 5000 µg with inhibition zones 8 mm and 10 mm, respectively	Jeevan Ram et al. (2004)
Escherichia coli, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Bacillus subtilis*, *Trichoderma viride* and *Candida albicans*	Disc diffusion method	Methanolic extract of barks (100, 200, and 300 µg/ml)/ ampicillin (10 µg) and ketoconazole (10 µg) as standards for antibacterial and antifungal activity, respectively	The extract was effective against all tested bacteria and fungi. The maximum antimicrobial activity had been shown against *Pseudomonas aeruginosa* for bacteria and *Trichoderma viride* for fungi at a concentration of 300 µg/ml	Vinitha and Prasanna (2019)

Table 4 continued

Microorganisms	Method used	Extract/standard	Results	References
Proteus vulgaris NCTC 8313, *Bacillus subtilis* ATCC 6633, *Salmonella typhimurium* ATCC 23564, *Pseudomonas pseudoalcaligenes* ATCC 17440 and *Staphylococcus epidermidis* ATCC 12228	Agar disc diffusion assay Well diffusion method	Methanolic and aqueous extracts of leaves	The methanolic showed antibacterial activity only against *Bacillus subtilis* (11 mm), while the aqueous extract exhibited an inhibitory effect only against *Pseudomonas pseudoalcaligenes* (11 mm)	Parekh et al. (2005)
Malassezia furfur	Broth dilution method to determine the MIC	Supercritical fluid extract of stems/climbazole as antifungal standard	*G. asiatica* extract showed a very high MIC (250 µg/ml) compared with the standard (1.95 µg/ml) and with another tested plant, *Rosemarinus officinalis* (15.6 µg/ml)	Mahendra et al. (2015)

combat dandruff (Jeyaprakash et al. 2011). Local tribes in the Eastern Ghats of Andra Pradesh use the fruits of *Gmelina asiatica* to treat eczema (Jeevan Ram et al. 2004), leprosy, dandruff, and toothache (Venkaiah et al. 2020). They use the stem bark in the form of a paste to treat dandruff and root juice for patients with gonorrhea (Murthy et al. 2020).

The local tribes of Telangana employ the leaves of *Gmelina asiatica* to stop nosebleeds and treat epistaxis (Suthari et al. 2018). The Irulas tribe in Tamil Nadu traditionally used the fruits of *Gmelina asiatica* as a substitute for soap (Ragupathy and Newmaster 2009). Additionally, indigenous groups in South India utilize *G. asiatica* for bacterial and viral throat infections, diabetes, and cough (JU et al. 2019). In some provinces of Sri Lanka, traditional practitioners rely on *Gmelina asiatica* to treat snakebites (Dharmadasa et al. 2016). It is also known that the Portuguese use this plant to get rid of all toxins in the body (Rathnam and Mudaliar 2002). The herbal preparations and their methods of use are summarized in Table 2.

Pharmacological activity

Studies have systematically investigated the biological activities of the *G. asiatica* plant in alignment with its traditional applications.

Antipyretic activity

Ikram et al. (1987) reported the antipyretic activity of *G. asiatica* roots. The residues of chloroform, hexane, and water fractions of ethanolic extract were administered (150 mg/kg p.o.) to male and female rabbits with yeast-induced fever. A comparison with aspirin as a standard reference revealed a noteworthy antipyretic effect in the chloroform and hexane extracts, demonstrating no observable toxicity at the administered dose.

Anxiolytic and neuroprotective activity

Kamboj (2015) conducted an assessment of the anxiolytic properties of *G. asiatica* using the Elevated Plus Maze (EPM) test. Animal subjects were administered a methanolic extract of the leaves (400 mg/kg). The results revealed a significant increase in both the number of rodents entering the open arm and the duration spent in this arm, compared to the control group. This heightened activity in the open arm, as opposed to the closed arm, signifies the anxiolytic effects of *G. asiatica* leaves. Moreover, these findings suggest a potential neuroprotective role for this plant.

Antiulcer effect

A study to investigate the antiulcer activity of *G. asiatica* plant was conducted by Girija and Ravindhran (2014) using three models (pylorus ligation-, aspirin-, and cold stress-induced ulcer albino mice models). The aqueous and methanolic extracts of roots, leaves, and stems as well as the powder derived from these parts were evaluated at both low (100 mg/kg p.o) and high doses (400 mg/kg p.o). A standard

Table 5 Outline of antioxidant activity of *G. asiatica*

Research type	Extract/standard	Method used	Results	References
In vitro	Chloroform and ethanolic extracts of aerial parts/ascorbic acid	DPPH scavenging method	Results exhibited significant inhibition of free radicals indicating the antioxidant effect of the extracts. Ethanolic extract was more potent	Merlin and Parthasarathy (2011)
	Aqueous, ethanolic, methanolic, ethyl acetate, chloroform and hexane extracts of leaves, stems and roots/ Butylated hydroxytoluene (BHT) as a reference in reducing power assay	Quenching of Nitric oxide Scavenging of hydroxyl radical Hydrogen peroxide scavenging activity Scavenging of superoxide radical Ferric Thiocyanate (FTC) test Thiobarbituric acid (TBA) Method Reducing power method	All parameters measured exhibited a significant antioxidant effect of *G. asiatica* plant. The activity was higher in leaves and roots	Girija and Ravindhran (2011)
	Methanolic extract of stems/ascorbic acid	DPPH scavenging method Quenching of Nitric oxide Reducing power determination Total phenolics content determination (as gallic acid equivalent (GAE)/ g.) Total flavonoid content determination (as quercetin equivalent (QE)/g.)	The extract and standard reduced the free radicals content of DPPH and NO with IC_{50} values of 18.38 and 78.18 µg/ml for the extract respectively and 5.14 and 63.86 µg/ml for ascorbic acid respectively In the reducing power assay, the IC_{50} of plant extract and ascorbic acid were 84.15 and 64.47 µg/ml respectively It was found that these activities increased with increasing concentrations Total flavonoid and phenolics content in plant extract were 28.54 ± 0.18 QE/g and 4800 ± 24.537 GAE/g, respectively	Silvia and Satyanaraya (2014)
	Aqueous extract of *G. asiatica*/Butylated hydroxytoluene (BHT)	DPPH scavenging method Quenching of Nitric oxide Scavenging of superoxide radical Scavenging activity of hydrogen peroxide Determination of lipid peroxidation inhibition Thiobarbituric acid (TBA) assay Reducing power assay	IC_{50} values of DPPH radical, nitric oxide, superoxide, and hydrogen peroxide radicals scavenging activity were 206, 14.97, 199.2, and 67.8 µg/ml respectively, whereas the IC_{50} value of reducing power assay was 48.5 µg/ml The lipid peroxidation process has been significantly decreased, with IC_{50} value of lipid peroxidation inhibition assay being 135.5 µg/ml and IC_{50} value of TBA assay being 13.29 µg/ml	Kiruba et al. (2014)

Table 5 continued

Research type	Extract/standard	Method used	Results	References
	Hydro methanolic extract of flowers	Determination of total phenolics, total flavonoids, total carotenoid, and total anthocyanin contents Total antioxidant capacity Scavenging activity of DPPH radical Reducing power assay Lipid peroxidation inhibition by using thiobarbituric acid	Results showed a high amount of antioxidant metabolites present in flowers with good reducing capacity and ability to inhibit lipid peroxidation and scavenge free radicals	Janarny et al. (2021)
In vivo (CCl_4-treated rats)	Chloroform and ethanolic extracts of aerial parts/ silymarin	Measurement of the level of SOD, CAT, GSH, MDA, and hydroperoxides	The rats treated with extracts showed increasing in the level of GSH and antioxidant enzymes (SOD and CAT) with decreasing in the level of lipid peroxidation products (MDA and hydroperoxide). Ethanolic extract exhibited higher effect	Merlin and Parthasarathy (2011)

comparison was made using ranitidine (10 mg/kg i.p). The findings of this study revealed the effectiveness of *G. asiatica* roots and leaves in both the treatment and prevention of gastric ulcers. This effect was attributed to the reduction in acid secretion and an augmentation of the protective mucous lining in the stomach.

Antidiabetic activity

Kasiviswanath et al. (2005) investigated the hypoglycemic activity of *G. asiatica* root. The study employed normal and alloxan-induced diabetic rats distributed among nine groups. Ethanolic extract at different dosages of 100, 250, and 500 mg/kg were orally administered to the rats and compared with tolbutamide at a dose of 40 mg/kg p.o as a standard drug. A dose-dependent reduction in blood glucose level was observed among rats treated with the *G. asiatica* root extract. Notably, the study reported that the antidiabetic activity of *G. asiatica* surpassed that of the standard tolbutamide in diabetic rats, and no signs of toxicity were observed at therapeutic doses.

Anti-inflammatory activity

The anti-inflammatory activity of *G. asiatica* has been studied in vivo by Syed et al. (1997) and Merlin et al. (2009a), both utilizing the albino rat model. In the study conducted by Merlin et al., four methods with different agents were employed to assess the anti-inflammatory activity. The reports from these studies collectively indicate that *Gmelina asiatica* possesses significant anti-inflammatory effects, demonstrating efficacy in both acute and chronic inflammation, as succinctly detailed in Table 3.

Furthermore, the anti-inflammatory effect of *G. asiatica* was also evaluated in vitro by Kiruba et al. (2014). The study utilized albumin denaturation inhibition method, human erythrocyte membrane stabilization test, and inhibition of proteinase enzyme assay to investigate the in vitro anti-inflammatory effect of aqueous extract of *G. asiatica*. Aspirin served as the standard reference. The in vitro study exhibited the ability of this plant to suppress the denaturation of protein, inhibit red blood cells hemolysis and protect against proteinase activity. Thus, these findings indicate the potential anti-inflammatory activity of *G. asiatica* plant.

Antimicrobial activity

The pharmacological properties of *Gmelina asiatica* include demonstrated antibacterial and antifungal activities, as reported by various researchers who employed different parts of the plant and varied extraction solvents in their studies. In these investigations, antibacterial standards such as kanamycin, ampicillin, and amikacin, along with antifungal

Table 6 Summary of anticancer activity of *G. asiatica*

Cancer type/model	Method used	Extracts/dose/standard	Results	References
Breast cancer/ MCF-7 and MDA-MB-231 human cancer cell lines	MTT assay and IC_{50} value	Ethyl acetate extract of roots/ different concentrations (0.625, 1.25, 2.5, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100 µg/ml) for 2 days	Dose-dependent response of cell survival when the dose was between 4 and 80 µg/ ml in both MCF-7 and MDA-MB-231 cell lines, while the IC_{50} values were 32.9 ± 3.8 and 19.9 ± 2.3 µg/ml, respectively	Balijepalli et al. (2010)
Dalton Ascites Lymphoma in Swiss Albino mice	Biochemical tests such as complete blood count (CBC), liver function tests (ALT, AST, ALP), lipid profile (total cholesterol and triglycerides), as well as cancer cell count, tumor volume, body weight, and life span of animals were measured	Chloroform extract of aerial parts/200 and 400 mg/kg orally for 14 days/5-fluorouracil as a standard at a dose of 20 mg/kg	The effect of plant extract (at a dose of 400 mg/kg) was approximately similar to that of the standard drug: Abnormal levels of enzymes, lipids, and CBC were restored toward normal level. In addition, the life span was increased, while the number of cancer cells and tumor volume were decreased	Merlin and Parthasarathy (2010)
Breast cancer/ MCF-7 human cancer cell lines	MTT assay and cell morphological studies	Ethanol, Ethyl acetate, petroleum ether, and chloroform extracts of aerial parts/for MTT assay different concentrations were used (50, 100, and 200 µg/ml) for 2 days, while morphological studies were performed at a dose of 200 µg/ml after 24 h of incubation	Chloroform extract was found to be more potent than other extracts	Merlin et al. (2010)
Breast cancer/ MCF-7 cell lines	MTT assay and cell morphological studies	Ethanolic extract of leaves/various concentrations (7.8, 15.6, 31.2, 62.5, 125, 250, 500, and 1000 µg/ml) for 24 h	Dose-dependent response of cell survival with more than 80% of cell viability inhibition at a dose of 1000 µg/ml	Florence and Jeeva (2016b)
Cervical cancer/SiHa cell line	MTT assay, IC_{50} value, and fluorescence imaging	Methanol, ethyl acetate, chloroform, and hexane extracts of leaves/for MTT assay various concentrations from each extract (10, 50, 100, and 200 µg/ml followed by incubation for 24, 48, and 72 h, while for fluorescence imaging the concentration used was 50 µg/ml	a gradual reduction in the viability of SiHa cells with both time and rising concentrations of the extracts In terms of IC_{50} and fluorescence imaging, the methanolic extract demonstrated the highest potency, showcasing increased cytotoxic activity against the SiHa cell line	Ksirri et al. (2023)

Table 7 Outline of toxicity studies of *G. asiatica* plant

Plant part/Extract	Model used	Process with dose/duration	Results	References
Leaves, roots, and stems powder	Wistar Albino mice	Suspensions of the plant parts' powder in water were prepared using a 1% CMC-Na suspending agent. Oral administration of a series of doses (50, 500, 1000, and 2000 mg/kg) was conducted on overnight fasting animals for acute toxicity assessment, with observations made over a 28-day period	By monitoring changes in mice body weight and feed consumption over the 28-day period, alongside conducting different functional tests on major organs (liver, kidney, blood), and histopathological examinations, the study concluded that *G. asiatica* parts are safe and non-toxic within the tested dose range (50–2000 mg/kg), with no observed mortality	Girija and Ravindhran (2014)
Chloroform and ethanolic extract of aerial parts	Wistar albino rats and mice	The extracts were orally administered to the animals. The administration involved escalating doses, reaching a maximum of 2000 mg/kg, for the purpose of acute toxicity assessment	The study demonstrated the safety of the plant at the given doses, as no mortality or toxic symptoms were observed	Merlin and Parthasarathy (2011)
Chloroform extract of aerial parts	Male Swiss albino mice	The chloroform was orally administered to the albino mice via gastric intubation at doses of 5, 50, 300, and 2000 mg/kg. The animals were observed for acute toxicity for 14 days, with mortality assessed on the 14th day, along with behavioural changes and other toxic symptoms	The extract was well-tolerated in male mice up to the dose of 2000 mg/kg, as no mortality or toxicity was observed during the observation period	Merlin and Parthasarathy (2010)
Alcoholic extract of barks	Mice	Various doses of the extract (250, 500, 750, 1000 mg/kg) were administered orally as a single dose for acute toxicity study. Behavioural changes and mortality were observed for 2 days after administration For the short-term toxicity evaluation, doses of 200 and 400 mg/kg of the alcoholic extract were administered orally daily for 14 days. Different parameters and toxic symptoms were monitored during this period	Both acute and short-term studies showed no signs of toxicity. There were no significant changes in the observed parameters, and no mortality was recorded. Therefore, the alcoholic extract of the bark is considered safe up to 1000 mg/kg	Kasiviswanath et al. (2005)
Chloroform, hexane, and water fractions of ethanolic extract of the roots	Rabbits and albino rats	The different fractions at different doses (200, 400, 800, and 1600 mg/kg) were suspended in 0.25% agar and orally administered to the rabbits and albino rats using a gastric tube. The mortality and toxic symptoms were monitored for 7 days for toxicity assessment	The extracts were non-toxic in both rabbits and mice up to the dose of 1600 mg/kg	Ikram et al. (1987)

CMC-Na Sodium carboxymethyl cellulose

Table 8 Chemical classes present in different parts of *G. asiatica*

Plant part	Extract	Chemical classes available in the part	References
Stems	Aqueous, methanol, chloroform, and hexane extracts	Flavonoids, tannins, phenolic compounds, triterpenoids, alkaloids, glycosides, carbohydrates, amino acids, proteins, fats and oils	Silvia and Satyanaraya (2014)
Leaves	Petroleum ether, acetone, chloroform, ethanol, and aqueous extracts	Saponins, flavonoids, tannins, terpenoids, coumarins, alkaloids (absent in all extracts except aqueous extract), glycosides (absent only in aqueous extract), steroids, quinones, phytosterols, carbohydrates, and proteins	Florence and Regini Balasingh (2016)
Leaves	Powdered leaves	Flavonoids, tannins, phytosterols, cardiac glycosides, carbohydrates, and proteins	Merlin et al. (2009a)
Aerial parts	Ethanol, chloroform, ethyl acetate, and petroleum ether extracts	Flavonoids, saponins, phenolic compounds, phytosterols, glycosides, carbohydrates, amino acids, and proteins	Merlin et al. (2009a)
Barks	70% methanolic extract	Coumarins, tannins, phenolic compounds, glycosides, phytosterols, and carbohydrates	Vinitha and Prasanna (2019)
Roots, stems, and leaves	Powdered leaves, stems, and roots	Flavonoids, coumarins, tannins, phenolic compounds, quinones, triterpenoids, phytosterols, steroids, furan, and carbohydrates	Girija and Ravindran (2011)
Flowers	Hydro-methanolic extract	Phenolic compounds, flavonoids, anthocyanins, carotenoids (β-carotene)	Janarny et al. (2021)

standards griseofulvin, climbazole, and ketoconazole, were employed. The reports revealed that *Gmelina asiatica* extracts exerted an inhibitory effect against a spectrum of bacteria, including *Pseudomonas aeruginosa*, *Escherichia coli*, *Bacillus subtilis*, *Salmonella typhi*, *Staphylococcus aureus*, *Bacillus pumilus*, *Streptococcus faecalis*, *Micrococcus luteus*, *Streptococcus pneumoniae*, *Klebsiella pneumoniae*, *Proteus mirabilis*, *Proteus vulgaris*, *Actinomyces howelli*, *Bacillus circulans*, and *Streptococcus pyogenes*. Additionally, these extracts demonstrated efficacy against various fungi, such as *Candida albicans*, *Aspergillus niger*, and *Trichoderma viride* as presented in Table 4. These results support the plant's traditional use as an antiseptic agent and in wound healing (Merlin et al. 2009a).

Mosquito larvicidal activity

Muthukumaran et al. (2015) demonstrated the mosquito larvicidal activity of the aqueous extract of *G. asiatica* leaves and the silver nanoparticles synthesized from the same extract. The study targeted *Aedes aegypti*, *Anopheles stephensi*, and *Culex quinquefasciatus*, significant vectors of human diseases. Various concentrations of the aqueous extract (50, 100, 150, 200, and 250 ppm) were tested and the LC_{50} and the LC_{90} were determined. The results showed the effectiveness of *G. asiatica* extract in larvae mortality compared to the control group.

Similarly, Florence and Solomon (2016) reported the larvicidal activity of *G. asiatica* leaves against *Culex quinquefasciatus* and *Aedes aegypti* by exposing the species to different concentrations of four distinct extracts of *G. asiatica* leaves. These findings suggest the potential of *G. asiatica* as a natural insecticide, holding promise in the control of mosquito-borne illnesses such as malaria, dengue, and lymphatic filariasis.

Nematicidal effect

Two studies were carried out by Azhagumurugan et al. in 2014 and 2015 to investigate the nematicidal effect of *G. asiatica* leaves against *Meloidogyne incognita,* a significant species of root-knot nematode notorious for infesting a wide range of plants and causing crop destruction. The host plants for the nematode, namely the tomato plant and black gram plant, were utilized, and various concentrations of acetone extract from *G.*

Table 9 Phytoconstituents identified in different parts of *G. asiatica* through GC–MS and UHPLC–HRMS analysis

Plant part	Technique used	Extract	Major compounds (peak area %)	References
Leaves	UHPLC–HRMS	Methanolic extract	The top fifteen most abundant constituents are: L-α-Palmitin, 1-stearoylglycerol, erucamide, 2-(3,4-dihydroxyphenyl)ethyl 3-O-(6-deoxy-β-L-mannopyranosyl)-6-O-[(2E)-3-(3,4-dihydroxyphenyl)-2-propenoyl]-β-D-glucopyranoside, 2-[[(5S,6R,9S)-14-[[(2-fluoroanilino)-oxomethyl]amino]-5-methoxy-3,6,9-trimethyl-2-oxo-11-oxa-3,8 diazabicyclo[10.4.0]hexadeca-1(12),13,15-trien-8 yl]methyl]benzoic acid, 7-hydroxycoumarine, 4-ethoxy ethyl benzoate, (4S,4aR,7S,7aR)-7-[(1R)-1,2-Dihydroxyethyl]-4a-hydroxy-4-(4-hydroxyphenyl)tetrahydro-2H-furo[3,4-b]pyran-2,5(3H)-dione, choline, valerophenone, 8-(1,2-dihydroxyethyl)-9-hydroxy-4-(4-hydroxyphenyl)-1,7-dioxaspiro[4.4]nonane-2,6-dione, ethyl paraben, DL6498000 (6-Ethoxy-2-mercaptobenzothiazole), 2,3-dihydroxypropyl 12-methyltridecanoate, and piperine	Ksirri et al. (2023)
Leaves	GC–MS	Ethanolic extract	Ethyl α-D-glucopyranoside (22%), 9,12,15-octadecatrienoic acid (15%), 3,7,11,15-tetramethyl-2-hexadecen-1-ol (15%), pentadecanoic acid (11%), (9Z, 12Z)-ethyl-9,12-octadecadienoate (7%) and 45 other compounds are present in trace amounts	Florence and Jeeva (2015)
Leaves	GC-MS	Mthanolic extract	Methyl tridecanoate (84%), methyl 10-octadecenoate (61.6%), 16-octadecenoic acid methyl ester (26%), spiro (androstane-3,2-thiazolidine) (5a) (16%), pregnane-3,11,12,14,20-pentol, 3,12,20, triacetate 11(hydroxyacetate), (3a,11a,12a,14a) (12.4%) and 2,7-diphenyl-1,6-dioxopyridazino (4,5:2,3) pyrrolo (4,5,-d) pyridazine (10%)	Azhagumurugan and Rajan (2014b)
Leaves	GC-MS	Essential oil	(E)-9-Octadecenoic acid ethyl ester (56.65%), ethyl linoleate (14.57%), ethyl hexadecanoate (synonym: ethyl palmitate) (14.1%), ethyl heptadecanoate (10.1%), ethyl E-11-hexadecenoate (3.69%), cholesterol trimethylsilyl ether (0.37%), 1,2-benzenedicarboxylic acid diisooctyl ester (0.27%) and benzene (1-butylhexadecyl) (0.24%)	Florence and Jeeva (2016a)
Aerial parts (leaves)	GC-MS	Ethyl acetate extract	Alpha-N-normethadol (22.88%), stigmasterol (6.51%), oleyl alcohol, trifluoroacetate (5.68%), 3,7,11,15-tetramethyl-2-hexadecen-1-ol (5.5%), cyclohexanol, 5-methyl-2-(1-methylethyl)-, (1α,2β,5α) (synonym: menthol) (5.08%), 2,6,6-trimethyl-bicyclo[3.1.1]heptane (4.41%), butyl 4,7,10,13,16,19-docosahexaenoate (4.31%), betulin (4.1%), beta-amyrin (3.91%), ethyl 13-methyl-tetradecanoate (3.68%), 2-((octan-2-yloxy)carbonyl)benzoic acid (2.47%), 2-hexyl-1-decanol (2.61%), dl-alpha-tocopherol (2.06%) and 11 other compounds with a percentage not exceeding 17%	Hassan Mohammad et al. (2021)
Aerial parts	GC-MS	Chloroform and ethanolic extract	1, 2-Benzenedicarboxylic acid diisooctyl ester, pentyl 2-hydroxybenzoate (synonym: amyl salicylate), (Z,Z)-9,12-octadecadienoic acid, nonadecane, n-hexadecanoic acid, heptacosane, 1-monolinoleoylglycerol trimethylsilyl ether, phytol, 3,7,11,15-tetramethyl-2-hexadecen-1-ol, (Z,Z)-9,12-octadecadienoyl chloride (synonym: linoleoyl chloride), spathulenol, patchoulane, 1,1-diethoxy-2-methylbutane, and various other compounds present in minute proportions	Merlin et al. (2009b)

asiatica leaves were tested. These concentrations were subsequently compared with the control group by assessing different parameters. The results from these studies underscored the potential nematicidal effect of *G. asiatica*, emphasizing its agricultural significance and the prospect of employing it to safeguard crops from the detrimental impact of agricultural pests (Azhagumurugan and Rajan 2014a; Azhagu Murugan and Rajan 2015).

Nephroprotective potential

The nephroprotective activity of *G. asiatica* plant has been investigated in vitro using gentamicin-induced cytotoxicity in Vero cell line. To assess its potential for nephroprotection, the aqueous extract (50 µl of a 500 mg/ml solution) was applied, with Vitamin E serving as the reference compound in the experiment. The inhibition of nephrotoxicity was evaluated by two methods; the MTT assay and epifluorescence microscopy technique. The MTT assay demonstrated a dose-dependent response in cell survival following treatment with the *G. asiatica* extract. Moreover, the epifluorescence staining assay revealed a green color under the microscope, indicating the viability of treated cells. These findings collectively suggest the potential of the *G. asiatica* plant to act as a cytoprotective agent (Kiruba et al. 2014).

Fig. 3 Lignans and flavonoids isolated from *G. asiatica* plant ▶

Hepatoprotective potential

Merlin and Parthasarathy (2011) assessed the hepatoprotective potential of *G. asiatica* extracts in the context of carbon tetrachloride (CCl_4)-induced hepatotoxicity in Wistar albino rats and mice. Chloroform

Table 10 Isolated compounds from *G. asiatica*

Plant part	Extract	Compounds	References
Heartwood	Methanolic extract	Paulownin, gmelinol, methyl p-methoxycinnamate, sitosterol, methyl p-hydroxycinnamate, and cycloolivil	Anjaneyulu et al. (1975)
Leaves, flowers, and fruits	Ethanolic extract	Quercetagetin, kaempferol, apigenin, luteolin and their glycosides (apigenin-7-rutinoside, luteolin-7-glucuronide, apigenin-7-glucuronide, kaempferol-3-rutinoside)	Nair and Subramanian (1975)
Roots	Ethanolic extract	Lignans: (+) Sesamin, (+) pinoresinol, (−) piperitol Flavonoids: sakuranetin, ovalifolin	Satyanarayana et al. (2007)

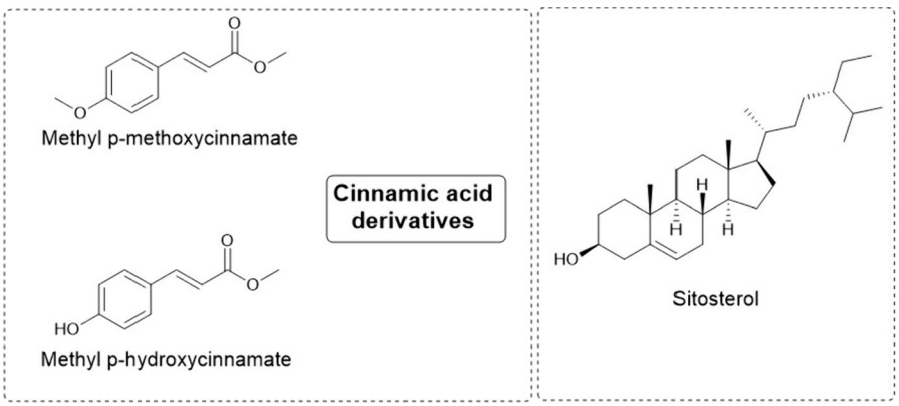
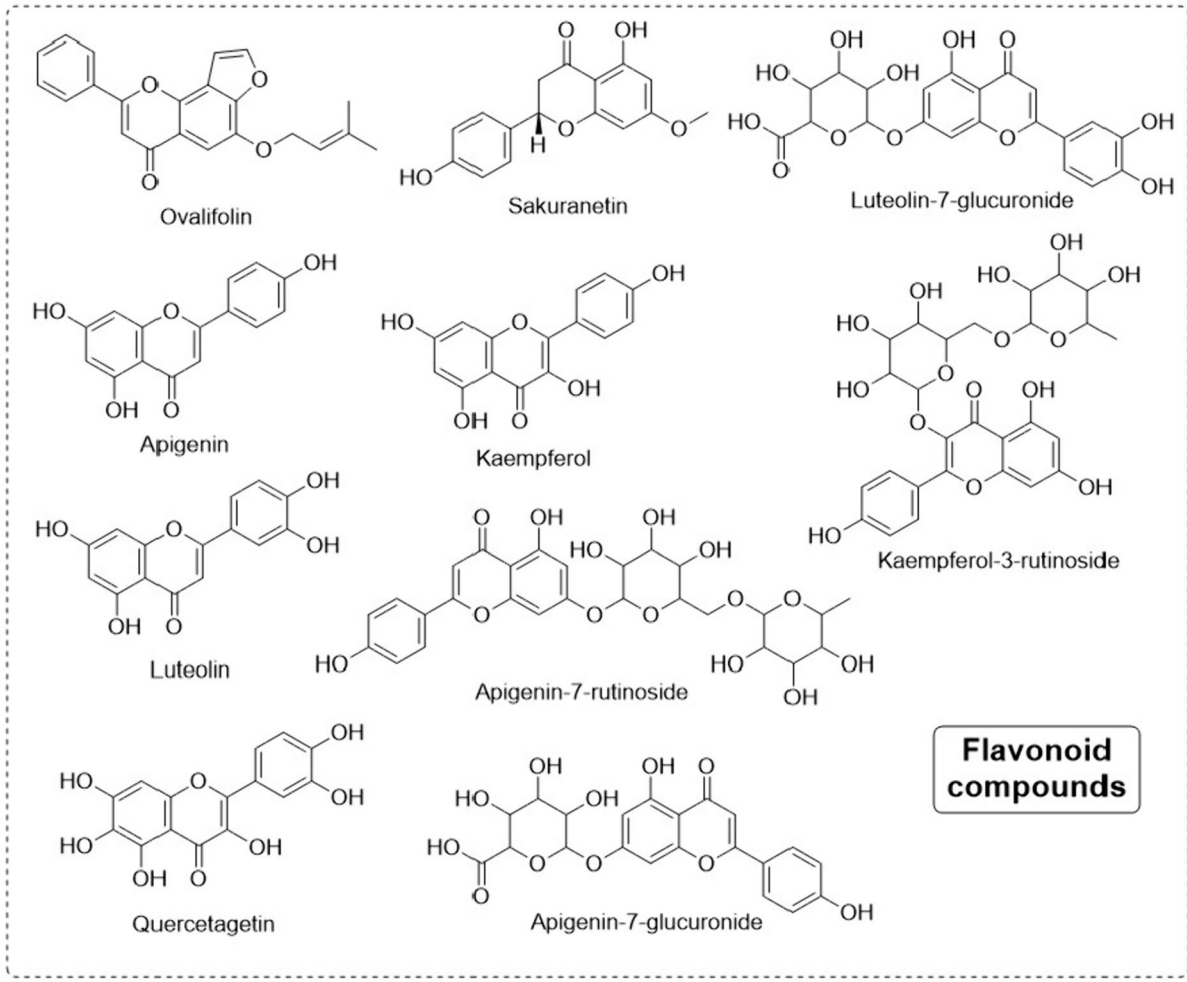


Fig. 2 Cinnamic acid derivatives and sterols isolated from *G. asiatica* plants


Ovalifolin
Sakuranetin
Luteolin-7-glucuronide
Apigenin
Kaempferol
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Luteolin
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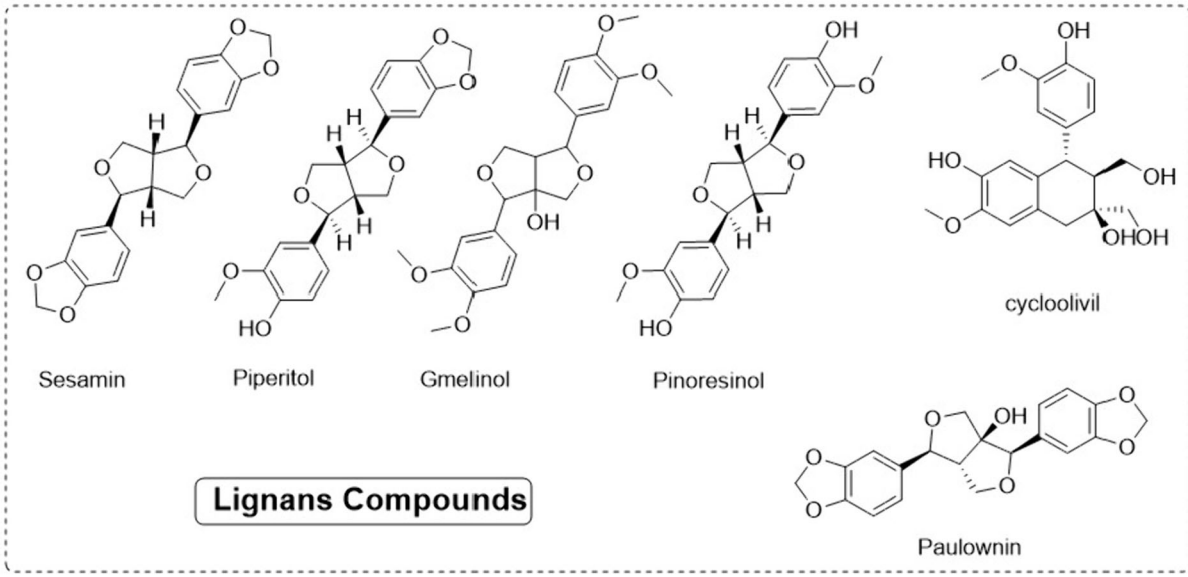
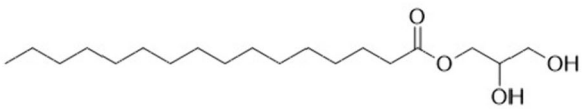
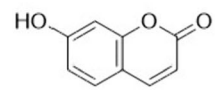
Quercetagetin
Apigenin-7-glucuronide
Flavonoid compounds

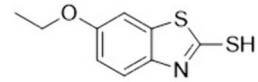

Sesamin
Piperitol
Gmelinol
Pinoresinol
cycloolivil
Lignans Compounds
Paulownin



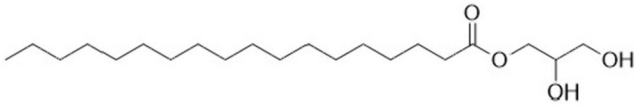
L-α-Palmitin



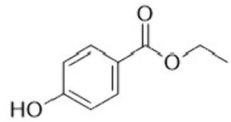
7-Hydroxycoumarine



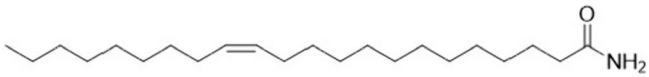
6-Ethoxy-2-mercaptobenzothiazole



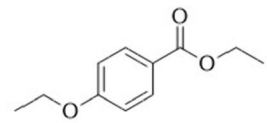
1-Stearoylglycerol



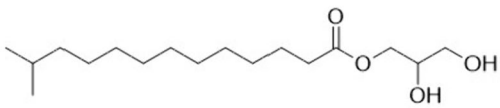
Ethyl paraben



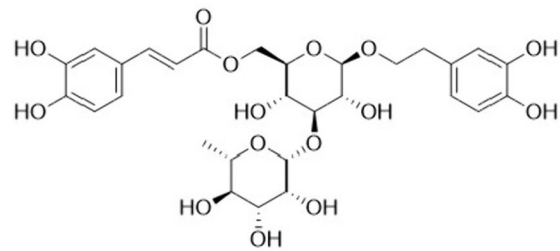
Erucamide



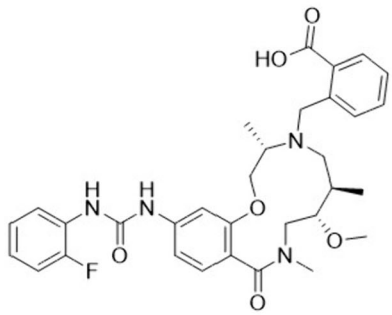
4-Ethoxy ethylbenzoate



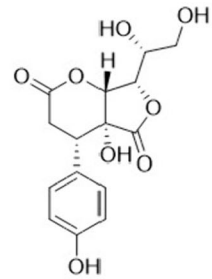
2,3-dihydroxypropyl 12-methyltridecanoate



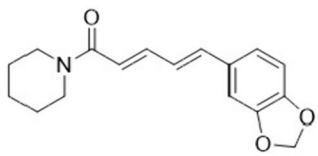
2-(3,4-Dihydroxyphenyl)ethyl 3-O-(6-deoxy-β-L-mannopyranosyl)-6-O-[(2E)-3-(3,4-dihydroxyphenyl)-2-propenoyl]-β-D-glucopyranoside



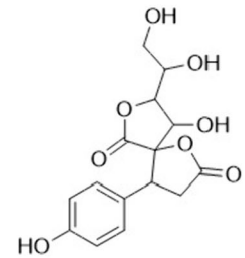
2-[[(5S,6R,9S)-14-[[(2-fluoroanilino)-oxomethyl]amino]-5-methoxy-3,6,9-trimethyl-2-oxo-11-oxa-3,8-diazabicyclo[10.4.0]hexadeca-1(12),13,15-trien-8-yl]methyl]benzoic acid



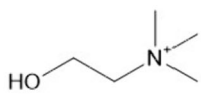
(4S,4aR,7S,7aR)-7-[(1R)-1,2-Dihydroxyethyl]-4a-hydroxy-4-(4-hydroxyphenyl)tetrahydro-2H-furo[3,4-b]pyran-2,5(3H)-dione



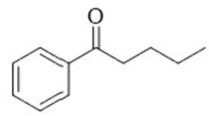
Piperine



8-(1,2-Dihydroxyethyl)-9-hydroxy-4-(4-hydroxyphenyl)-1,7-dioxaspiro[4.4]nonane-2,6-dione



Choline



Valerophenone

Fig. 4 *G. asiatica* compounds identified by UHPLC–HRMS

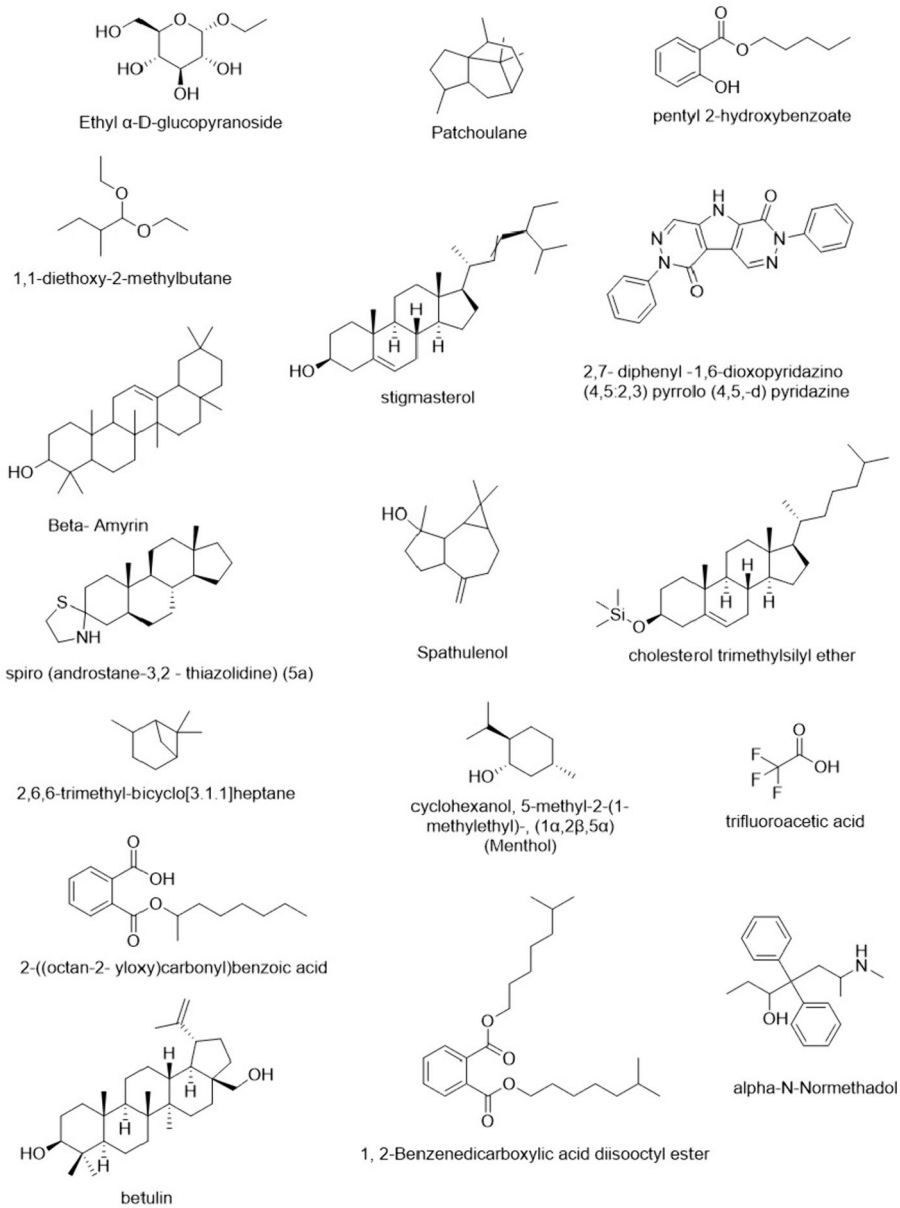


Fig. 5 *G. asiatica* compounds identified by GC–MS

and ethanolic extracts of *G. asiatica* aerial parts were administered orally at a dose of 400 mg/kg per day for 5 days. A standard reference, silymarin at 50 mg/kg, was also administered orally for 5 days. Liver biochemical tests and histological study were conducted to examine the liver protective effect of both plant extracts and the standard. Following treatment with either plant extracts or silymarin, there was a significant decrease in the elevated levels of alanine aminotransferase (ALT), aspartate transaminase (AST), bilirubin, and alkaline phosphatase (ALP). Notably, the ethanolic extract exhibited a more pronounced effect compared to the chloroform extract. These results, corroborated by the histological study, confirm the hepatoprotective activity of *G. asiatica* extracts against CCl_4-induced hepatotoxicity in rats.

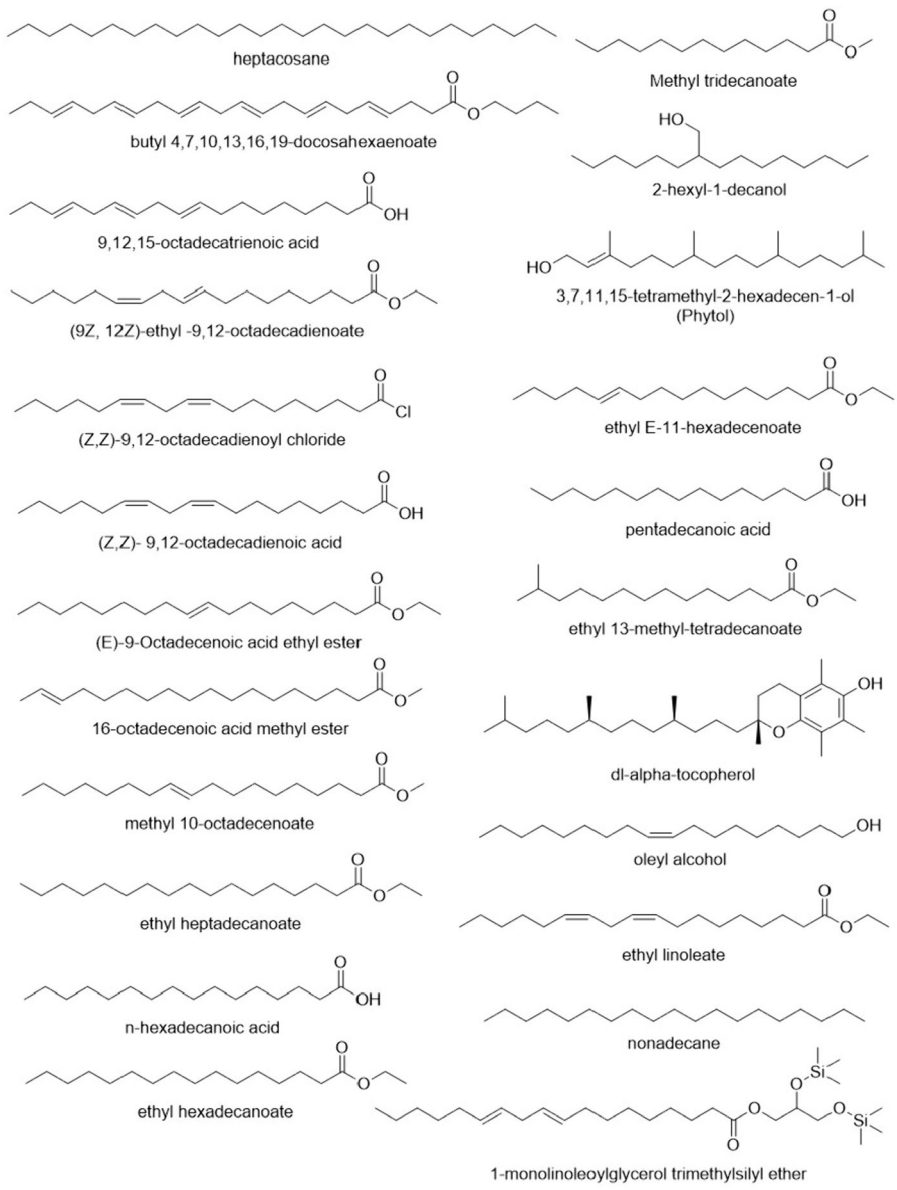


Fig. 5 continued

Antioxidant activity

In vitro and in vivo studies have been conducted by different researchers to study the antioxidant activity of different parts of *G. asiatica* plant, as elaborated in Table 5. In vitro assessments utilized methods such as free radical scavenging test, reducing power assay, lipid peroxidation inhibition assay, and total antioxidant capacity method. For in vivo antioxidant activity evaluation, levels of reduced glutathione (GSH), superoxide dismutase (SOD), catalase (CAT), malondialdehyde (MDA), and hydroperoxides were assessed in CCl_4-treated Wistar albino rats. The reports revealed that *G. asiatica* has a significant antioxidant effect which could be the reason of many other therapeutic activities related to this plant.

Anticancer activity and cytotoxic potential

Various researchers have undertaken studies to investigate the anticancer activity of the *G. asiatica* plant. These investigations encompassed both in vitro assessments against human breast cancer and cervical cancer, with a singular in vivo study targeting lymphoma, as summarized in Table 6. The studies utilized different plant parts, including roots, leaves, and aerial parts. The collective results indicate that *G. asiatica* exhibits a noteworthy antiproliferative effect and cytotoxic activity. These findings suggest the potential of *G. asiatica* as a valuable candidate for further exploration and development as an anticancer agent.

Toxicity studies of *G. asiatica* plant

Toxicity studies on *G. asiatica* were conducted by various researchers, examining different parts of the plant (roots, stems, barks, leaves, and aerial parts), and utilizing diverse animal models such as rats, mice, and rabbits. Various extracts were employed and a range of doses was tested, as summarized in Table 7. The studies were performed according to OECD guidelines.

Phytochemistry

The examination of phytochemistry plays a crucial role in identifying the potential medicinal applications of plants, as certain secondary metabolites can indicate their suitability for specific medical fields. In the case of *G. asiatica*, extensive studies have utilized diverse solvents to scrutinize the phytoconstituents across its various parts, aiming to forecast its therapeutic value. Preliminary phytochemical screening, extensively detailed in Table 8, has been a cornerstone of many of these investigations. Identification of these phytoconstituents predominantly relied on the GC–MS technique, as elucidated in Table 9. Notably, a singular study employed LC–MS (UHPLC–HRMS) for a more nuanced analysis, also detailed in Table 9. While these analytical approaches have provided valuable insights, the isolation of compounds from *G. asiatica* has been somewhat limited, as summarized in Table 10. These isolated compounds predominantly include flavonoids, lignans, and a few other compounds, as showed in Figs. 2 and 3. On the other hand, Figs. 4 and 5 present the structures of compounds identified through LC–MS and GC–MS, respectively.

The initial attempts to analyze the components of this plant focused on seed oils, employing chromatographic techniques in 1961 and 1965 (Gunstone and Sykes 1961; Gunstone and Qureshi 1965). These investigations unveiled a rich composition, including high levels of saturated fatty acids such as palmitic and stearic acids (Gunstone and Qureshi 1965), cis-11-eicosenoic, oleic, linoleic, ricinoleic acids (Gunstone and Sykes 1961) alongside the presence of sitosterol (Nair and Subramanian 1975).

Conclusion and future perspective

G. asiatica, an invaluable medicinal plant, holds a significant place in traditional medicine due to its numerous therapeutic benefits. Local practitioners and healers have long utilized its properties to address various ailments, contributing to its esteemed status in folklore medicine. However, despite its extensive use, scientific efforts to validate these traditional uses have been limited. Moreover, there is a crucial need for in-depth studies on *G. asiatica* to unlock its full potential. Current gaps in research include the insufficient exploration of its phytoconstituents, the validation of their therapeutic values, and a comprehensive understanding of their mode of action. Addressing these gaps will not only contribute to the scientific understanding of this plant but also pave the way for harnessing its valuable therapeutic properties. Given the increasing demand for more effective medicines to combat diverse diseases, dedicating attention to the systematic study of *G. asiatica* is imperative. Through rigorous scientific investigation, we can capitalize on the medicinal benefits of this plant, offering new and improved treatment options.

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Author contributions RK: design, literature review, writing, and editing-original manuscript. MK: reviewed, and provided

critical comments. KB: reviewed, edited, and provided critical comments, SH: design, supervision, review, and editing.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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