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CLITORIA TERNATEA L. (BUTTERFLY PEA): FROM TRADITIONAL MEDICINE TO FUNCTIONAL FOOD AND PHARMACOLOGICAL APPLICATIONS – A COMPREHENSIVE REVIEW

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ABSTRACT:
Clitoria ternatea L. (butterfly pea) is a nitrogen-fixing legume widely renowned for its medicinal, nutritional, and functional food applications. Traditionally used as a memory enhancer, anxiolytic, anti-inflammatory, and antimicrobial agent, it is rich in bioactive compounds, including anthocyanins, flavonoids, triterpenoids, cyclotides, and phenolic compounds. Preclinical investigations have demonstrated several pharmacological activities, including antioxidant, neuroprotective, anti-inflammatory, antimicrobial, antidiabetic, hepatoprotective, and anticancer effects. In addition, the pH-sensitive anthocyanins present in its flowers have gained commercial importance as natural food colorants in beverages and functional foods. This review summarizes the current knowledge on the botany, ethnomedicinal significance, phytochemistry, pharmacological mechanisms, functional food applications, toxicity, and future therapeutic prospects of Clitoria ternatea L. It also highlights the recent advances, existing research gaps, and the need for standardized clinical studies. Overall, Clitoria ternatea L. shows considerable promise as a multifunctional medicinal plant and functional food resource with significant pharmaceutical, nutraceutical, and industrial potential.

KEYWORDS: *Clitoria ternatea*, Anthocyanins, Ternatins, Functional food, Phytochemistry

INTRODUCTION

Growing interest in plant-based therapeutics and natural products has been driven by their perceived safety, affordability, accessibility, and broad spectrum of biological activities. Medicinal plants play a vital role in traditional healthcare systems as well as in modern drug discovery, owing to their diverse array of bioactive compounds and significant pharmacological potential (Ashraf et al., 2024; Pandey et al., 2026). This increasing interest has further expanded their applications in the nutraceutical and functional food industries.

Clitoria ternatea L. (Fabaceae), commonly known as butterfly pea, is one such plant that has gained significant scientific and commercial importance. Native to tropical Asia, it has become widely distributed throughout tropical and subtropical regions worldwide and is valued for its ornamental, medicinal, and nutritional properties. The plant is particularly known for its vivid blue flowers, which contain anthocyanins (ternatins) that are widely used as natural colorants in foods and beverages. In traditional systems of medicine, it is described as a medhya rasayana (memory-enhancing herb) and has been used to manage stress, anxiety, inflammation, fever, and infectious conditions (Kaur et al., 2024; Sangeetha et al., 2026).

Recent scientific studies have demonstrated that C. ternatea exhibits a wide range of pharmacological activities, including antioxidant, neuroprotective, antimicrobial, anti-inflammatory, and antidiabetic effects. Despite its extensive traditional use and promising preclinical evidence, there is still a lack of well-designed clinical trials and standardized safety evaluations. Therefore, this review aims to comprehensively compile and analyze the available literature on the botany, phytochemistry, pharmacology, and traditional uses of C. ternatea, while also highlighting existing research gaps and future prospects (Jeyaraj, et al., 2021; Mayegowda, et al., 2022; Mukherjee, et al., 2008; Vidana Gamage, et al., 2021).

Unlike previous reviews, which have primarily focused on individual aspects such as phytochemistry, pharmacological activities, or traditional uses of Clitoria ternatea, the present review provides an integrated and updated overview of its botanical characteristics, ethnomedicinal significance, phytochemical composition, pharmacological mechanisms, functional food applications, and safety profile. In addition, this review critically discusses recent advances, identifies existing research gaps, and highlights future directions for clinical validation, standardization, and the development of C. ternatea-based pharmaceutical, nutraceutical, and functional food products. This comprehensive approach provides a broader perspective on the therapeutic and commercial potential of C. ternatea and its role in bridging traditional medicine with modern scientific applications.

Botanical description and taxonomy

Taxonomic Classification

Kingdom	:	Plantae
Infrakingdom	:	Streptophyta
Division	:	Tracheophyta
Subdivision	:	Spermatophytina
Clade	:	Tracheophytes
Clade	:	Angiosperms
Clade	:	Eudicots
Superorder		Rosanae
Order	:	Fabales
Family	:	Fabaceae (Leguminosae)
Sub family	:	Faboideae
Genus	:	Clitoria
Species	:	C. ternatea L.

The genus name Clitoria was assigned by Carl Linnaeus and is derived from the Latin term clitoris, referring to the female genital organ, owing to the resemblance of the flower's keel to female anatomy. The species epithet ternatea refers to the Ternate Islands of Indonesia, which are regarded as one of the probable centres of origin of the species (Quattrocchi, 2012; Press, 2018).

Botanical description

Clitoria ternatea L. (butterfly pea, Asian pigeonwings, Blue pea, Bluebell vine, Cordofan pea, Darwin pea) is a perennial, twining herbaceous climber belonging to the family Fabaceae. It is characterized by slender stems, pinnate leaves with 5–7 ovate leaflets, and distinctive papilionaceous flowers that are typically deep blue with a white or yellow throat, although white-flowered cultivars also occur. The plant produces flattened linear pods containing several yellowish-brown to black seeds.

Cytology

C. ternatea L. has a diploid chromosome number of 2n = 16, which is typical of many members of the Fabaceae. Cytogenetic studies point out a relatively stable chromosome complement, supporting its genetic stability and suitability for breeding, conservation, and biotechnological improvement (Fantz, 1991; Oguis et al., 2019).

Floral Biology

The flowers are solitary, axillary, bisexual, zygomorphic, and complete, exhibiting the characteristic papilionaceous corolla of legumes. Each flower consists of a large standard petal (banner), two wing petals, and two fused keel petals enclosing the reproductive organs. The androecium comprises 10 stamens arranged in a diadelphous condition (9 + 1), while the gynoecium consists of a single superior ovary with marginal placentation. Flowering occurs throughout much of the year in tropical climates, with peak flowering generally observed during the warm and rainy seasons. Anthesis usually takes place during the morning hours, and flowers remain open for one day before senescence (Fantz, 1991; Aye & Lin, 2020).

Pollination

Clitoria ternatea is predominantly entomophilous (insect-pollinated). Large bees, particularly carpenter bees (Xylocopa spp.) and honeybees (Apis spp.), are the principal pollinators. Their foraging activity facilitates pollen transfer by depressing the keel petals and exposing the reproductive organs. Although the species is primarily cross-pollinated, self-pollination may also occur, contributing to successful seed production under varying environmental conditions (Oguis et al., 2019; Aye & Lin, 2020)

Seed Dispersal

The fruit is a dehiscent legume that splits open upon maturity, releasing the seeds through explosive (ballistic) dehiscence, the primary natural mechanism of seed dispersal. Seeds may also be dispersed over short distances by gravity, water, animals, and human activities, facilitating the establishment of new populations.

Adaptation to Different Agro-Climatic Conditions

C. ternatea is a hardy, drought-tolerant species widely adapted to tropical and subtropical regions. It grows well under temperatures ranging from 20–35°C and performs best in areas receiving 700–1,500 mm of annual rainfall. The species thrives in well-drained sandy loam to clay loam soils with a slightly acidic to neutral pH (approximately 5.5–7.5), although it tolerates moderately alkaline conditions. As a nitrogen-fixing legume, it improves soil fertility through symbiosis with rhizobial bacteria and can successfully grow in nutrient-poor soils. Its tolerance to drought, moderate salinity, and a wide range of environmental conditions makes it suitable for cultivation as an ornamental plant, forage crop, cover crop, medicinal herb, and functional food resource across diverse agro-climatic regions (Aye & Lin, 2020; Beevy & Dan, 2025).

Morphology and Distribution

Clitoria ternatea L. is a herbaceous, twining perennial climber belonging to the family Fabaceae that typically grows up to 3 m in length. The leaves are alternate and pinnately compound, consisting of five to seven elliptic to oblong leaflets. The flowers are solitary, axillary, and papilionaceous, with the characteristic deep blue corolla and a pale yellow or white

throat. White- and lilac-flowered cultivars also occur, while double-petalled forms are commonly grown as ornamentals. The fruit is a flattened, linear pod measuring approximately 5–12 cm in length and contains six to ten seeds, which are ovoid to nearly spherical and dark brown to black when mature (Mukherjee et al., 2008; Sangeetha et al., 2026).
Clitoria ternatea is widely distributed throughout tropical and subtropical regions of the world. Although it's precise centre of origin remains uncertain, the species is generally considered as native to tropical Asia and has become naturalized across South and Central America, the Caribbean, Madagascar, Africa, and Australia. The species is extensively cultivated in countries such as India, Thailand, Malaysia, Indonesia, the Philippines, and Sri Lanka for its ornamental, medicinal, agricultural, and forage purposes. As a member of the family Fabaceae, it forms symbiotic associations with nitrogen-fixing bacteria, making it an important cover crop, green manure, and fodder species that contribute to soil fertility and sustainable agriculture (Staples, 1992; Pitman et al., 2020).

Traditional and ethnomedicinal uses

Clitoria ternatea L., commonly known as Aparajita (meaning "the unconquered") in Ayurveda, is classified as a Medhya Rasayana, a group of rejuvenative herbs traditionally used to enhance memory, cognition, and mental well-being. The plant is described in classical Ayurvedic texts, including the Charaka Samhita and Sushruta Samhita, where it is recommended for improving intellect, promoting longevity, and managing a variety of ailments. Traditionally, different parts of the plant have been used as a memory enhancer, mild sedative, anxiolytic, antipyretic, anti-inflammatory, diuretic, and anthelmintic, as well as for the treatment of skin disorders, urinary diseases, respiratory ailments, fever, and snakebite (Fantz, 1991; Oguis, et al., 2019; Ashraf et al., 2024).

Beyond the Indian subcontinent, C. ternatea has been widely used in the traditional medicine of Southeast Asia. In Thailand, Malaysia, Indonesia, and neighbouring countries, flower infusions are commonly consumed as herbal tea to promote relaxation and general well-being, while decoctions prepared from the flowers and roots have traditionally been used to support postpartum recovery and stimulate lactation. The flowers are also used to prepare Nam Dok Anchan (blue butterfly pea tea), a traditional beverage valued for its distinctive natural blue colour and its perceived calming and health-promoting properties. In addition to its medicinal applications, C. ternatea is widely cultivated as an ornamental plant and holds cultural significance in several Southeast Asian communities (Al-Snafi, 2016; Sarma et al., 2023).

Phytochemistry

Clitoria ternatea L. is a rich source of diverse phytochemicals that contribute to its medicinal and functional food properties. The plant contains anthocyanins, flavonoids, phenolic acids, triterpenoids, cyclotides, alkaloids, tannins, saponins, steroids, and fatty acids (Oguis et al., 2019; Jeyaraj et al., 2022; Li et al., 2021; Chen et al., 2023).
Among these, ternatins, a group of polyacylated delphinidin-based anthocyanins, are the major pigments responsible for the characteristic deep blue colour of the flowers. These compounds exhibit remarkable colour stability and possess potent antioxidant properties, making them valuable as natural food colourants (Kazuma et al., 2003; Escher et al., 2020). Other important phytochemicals include flavonoids such as quercetin, kaempferol, myricetin, rutin, and catechin, along with phenolic acids including gallic, caffeic, ferulic, and p-coumaric acids, which contribute to the antioxidant, anti-inflammatory, antimicrobial, and antidiabetic activities of the plant (Jeyaraj et al., 2022; Sarma et al., 2023).
The biosynthesis of ternatins follows the phenylpropanoid–flavonoid pathway. The pathway begins with phenylalanine, which is converted to cinnamic acid by phenylalanine ammonia-lyase (PAL). Through the sequential action of enzymes including chalcone synthase (CHS), chalcone isomerase (CHI), flavanone 3-hydroxylase (F3H), flavonoid 3′,5′-hydroxylase (F3′5′H), dihydroflavonol 4-reductase (DFR), and anthocyanidin synthase (ANS), delphinidin is produced. Subsequent glycosylation and acylation reactions catalysed by glycosyltransferases and acyltransferases result in the formation of ternatins, which are responsible for the stable blue pigmentation of the flowers (Kazuma et al., 2003; Terahara et al., 1998).
The distribution of phytochemicals varies among different plant parts. Flowers are particularly rich in ternatins, anthocyanins, flavonoids, and phenolic compounds, whereas leaves contain abundant flavonoids, tannins, triterpenoids, and phenolic acids. Roots are reported to contain flavonoids, triterpenoids, and alkaloids associated with neuroprotective and anti-inflammatory activities. Seeds are characterized by the presence of cyclotides, cyclic peptides with antimicrobial, insecticidal, and cytotoxic properties (Oguis et al., 2019; Mukherjee et al., 2008). The diverse phytochemical composition of C. ternatea underpins its extensive therapeutic applications and growing importance in the pharmaceutical, nutraceutical, and functional food industries (Jeyaraj et al., 2022; Sarma et al., 2023; Goh et al., 2022).

Pharmacological activities

Extensive pharmacological investigations have demonstrated that Clitoria ternatea L. possesses a broad spectrum of biological activities. Experimental evidence from in vitro assays and in vivo animal models indicates that extracts and isolated phytochemicals from different plant parts exert antioxidant, anti-inflammatory, antimicrobial, antidiabetic, neuroprotective, hepatoprotective, immunomodulatory, and anticancer effects. These findings provide scientific support for the plant's widespread traditional use and underscore its potential as a source of therapeutic agents (Havananda & Luengwilai, 2019; Jaafar et al., 2020 ; Vidana Gamage et al., 2021).
A substantial body of preclinical research has further characterized the pharmacological activities of extracts obtained from the flowers, leaves, roots, stems, and seeds of C. ternatea. The major pharmacological properties reported in the literature are summarized below.

a. Neurological and psychological effects

Root and the whole-plant extracts have demonstrated nootropic activity, improving learning and memory retention in experimental animal models. In addition, these extracts have exhibited anxiolytic, antidepressant, anticonvulsant, and sedative effects in various preclinical studies. These pharmacological activities provide scientific support for the plant's traditional Ayurvedic classification as a Medhya Rasayana (Medhya herb), a group of rejuvenating herbs traditionally used to enhance cognitive and promote mental well-being (Suna et al., 2025).

b. Antioxidant and anti-inflammatory Activity

Flavonoid- and anthocyanin-rich extracts of Clitoria ternatea L. exhibit considerable antioxidant potential through free-radical scavenging and reducing activities demonstrated in various in vitro assays. The polyacylated anthocyanins (ternatins), flavonoids, and other phenolic constituents present in the flowers contribute significantly to reactive oxygen species (ROS) neutralization and protection against oxidative damage. Recent investigations have reported that anthocyanin-enriched fractions of C. ternatea flowers possess strong antioxidant activity, with ternatins identified as key phytoconstituents responsible for these effects. In addition, ethanolic extracts of C. ternatea have demonstrated significant anti-inflammatory activity in experimental models, including carrageenan- and histamine-induced paw oedema, along with anti-arthritic effects in inflammatory models. These findings indicate that the antioxidant properties of C. ternatea may contribute to the regulation of oxidative stress-mediated inflammatory pathways, supporting its traditional application in inflammatory disorders (Jeyaraj et al., 2022).

c. Antimicrobial activity

Clitoria ternatea L. exhibits significant antimicrobial potential, largely attributed to its diverse phytochemical profile, which includes flavonoids, phenolic compounds, tannins, terpenoids, and bioactive proteins. Various extracts derived from its leaves, seeds, and flowers have demonstrated inhibitory activity against a wide range of pathogenic microorganisms. Among these, methanolic leaf extracts have shown notable antibacterial efficacy against both Gram-positive and Gram-negative bacteria, including Bacillus cereus, Staphylococcus aureus, Klebsiella pneumoniae, Proteus vulgaris, and Salmonella typhi. The superior antimicrobial activity of methanolic extracts compared with petroleum ether and aqueous extracts is likely due to the enhanced extraction of bioactive compounds with intermediate polarity (Raza & Tahseen, 2024; Islam et al., 2023).

In addition to its antibacterial properties, C. ternatea possesses considerable antifungal activity mediated through both phytochemical constituents and protein-based defense mechanisms. A seed-derived antimicrobial protein isolated from C. ternatea has demonstrated broad-spectrum antifungal activity against clinically important fungal pathogens, particularly Cryptococcus neoformans, highlighting its potential therapeutic significance. Furthermore, extracts rich in phenolic and flavonoid compounds have exhibited inhibitory effects against several fungal species, suggesting that the antimicrobial action of C. ternatea may involve multiple mechanisms, including disruption of microbial cell membranes, inhibition of cellular growth and metabolism, and induction of oxidative stress within microbial cells (Yolin Angel et al., 2024).

Collectively, these findings provide strong scientific evidence supporting the antimicrobial and antifungal properties of C. ternatea. The observed bioactivities validate its traditional medicinal uses and underscore its potential as a valuable source of natural bioactive compounds for the development of novel pharmaceutical, nutraceutical, and antimicrobial formulations (Rajeena & Raga, 2025).

d. Antidiabetic, cardiovascular, and metabolic effects

Clitoria ternatea L. has gained considerable attention for its potential antidiabetic, cardiovascular, and metabolic health-promoting properties. Preclinical studies have demonstrated that its extracts can improve glycaemic control by reducing postprandial blood glucose levels through inhibition of carbohydrate-hydrolyzing enzymes, enhancement of insulin secretion and sensitivity, and protection of pancreatic β-cells against oxidative stress. These effects are primarily attributed to its rich content of anthocyanins, flavonoids, and other phenolic compounds (Lucianus et al., 2024; Dewi et al., 2023)

In addition to its antidiabetic activity, C. ternatea exhibits promising cardioprotective and metabolic effects. Its potent antioxidant properties inhibit lipid peroxidation and cholesterol oxidation, thereby reducing oxidative stress associated with dyslipidaemia and atherosclerosis. Animal studies have further demonstrated improvements in lipid profiles and attenuation of inflammatory biomarkers, suggesting a protective role against metabolic syndrome and cardiovascular complications (Rupadani et al., 2024)

Furthermore, C. ternatea has been reported to possess vascular smooth muscle relaxant, antiplatelet, and mild diuretic activities, which may contribute to improved vascular function, regulation of blood pressure, and reduced risk of thrombotic events. Collectively, these findings indicate that C. ternatea is a promising natural therapeutic agent for the prevention and management of diabetes, metabolic syndrome, and cardiovascular diseases. However, further well-designed clinical studies are required to establish its long-term efficacy and safety in humans (Widowati et al., 2024)

e. Anticancer, immunomodulatory, and other effects

Clitoria ternatea L. has demonstrated promising anticancer potential in preliminary studies, with extracts exhibiting tumour-suppressive, antiproliferative, and pro-apoptotic activities against various cancer cell lines. These effects are largely attributed to its rich content of flavonoids, anthocyanins, phenolic compounds, and other bioactive phytochemicals, which can modulate oxidative stress, inhibit cellular proliferation, and induce programmed cell death. In addition, C. ternatea has shown significant immunomodulatory properties by enhancing both humoral and cell-mediated immune responses. Its antioxidant and anti-inflammatory constituents are believed to play a key role in regulating immune function and strengthening the body's defence mechanisms against diseases (Deepika et al., 2018; ALshamrani 2022).

Beyond its anticancer and immunomodulatory activities, C. ternatea exhibits several other pharmacological effects. Studies have reported hepatoprotective activity through the prevention of oxidative liver damage and protection against toxin-induced hepatic injury. The plant has also demonstrated anthelmintic, insecticidal, and local anaesthetic properties, supporting its diverse traditional medicinal applications. Collectively, these findings highlight the broad therapeutic potential of C. ternatea as a source of natural bioactive compounds for pharmaceutical, nutraceutical, and agricultural applications. However, further mechanistic studies and clinical investigations are required to validate these effects and establish their therapeutic efficacy in humans (Maia et al., 2025; Rahayu et al., 2025).

f. Nutritional and culinary applications

Clitoria ternatea L. (butterfly pea) is widely recognized as a natural food colourant because of its deep blue flowers, which are rich in ternatin-type anthocyanins. These pigments provide an attractive blue colour and exhibit pH-dependent colour changes, turning purple or pink under acidic conditions. Traditionally, the flowers have been used in Southeast Asian cuisine to colour rice, desserts, confectioneries, and beverages. Today, butterfly pea flower tea, commonly known as "blue tea," has become a popular functional beverage due to its antioxidant properties and appealing natural colour (Adisakwattana et al., 2020; Handayani et al., 2024).

The growing demand for clean-label and plant-based food ingredients has increased the use of C. ternatea in the food and nutraceutical industries. Flower extracts are incorporated into bakery products, dairy products, beverages, confectioneries, and functional foods because they contain bioactive compounds such as anthocyanins, flavonoids, and phenolic compounds. Although the flower extract has shown considerable commercial potential, further research is needed to improve its stability during processing, standardize extraction methods, and evaluate its long-term safety and bioavailability for wider food applications (Aripin et al., 2024; Setiawati et al., 2025).

g. Toxicity and safety considerations

Clitoria ternatea L. has a long history of traditional dietary and medicinal use, with no widespread reports of severe adverse effects when consumed at customary levels. Available experimental and clinical observations suggest that C. ternatea-based preparations are generally well tolerated. For example, topical formulations containing C. ternatea extract, including herbal shampoo preparations evaluated against conventional antifungal treatments such as 2% ketoconazole for dandruff management, have demonstrated good tolerability with fewer reported adverse effects. These findings indicate the potential safety of C. ternatea in certain therapeutic applications; however, comprehensive toxicological investigations remain limited (Assegaf et al., 2024; Djunet & Rizkawati, 2023)

Despite its promising nutritional and pharmacological applications, detailed safety assessments, including long-term toxicity, reproductive safety, pharmacokinetics, and dose-dependent effects, are still required. Particular attention has been given to cyclotides, a group of cyclic peptides naturally present in C. ternatea, due to their bioactive properties and potential implications for food safety evaluation. Regulatory agencies, including the European Food Safety Authority (EFSA), have emphasized the need for further characterization and safety evaluation of cyclotide content before wider approval of C. ternatea as a food ingredient. Therefore, cautious use is recommended, particularly among pregnant and lactating women, children, and individuals with underlying health conditions until more comprehensive clinical safety data become available (Vettorazzi et al., 2020; Precup et al., 2024; Le Bloch et al., 2024).

Mechanisms underlying the pharmacological activities

The pharmacological activities of Clitoria ternatea L. are primarily attributed to its bioactive constituents, including anthocyanins (ternatins), flavonoids, phenolic compounds, triterpenoids, and cyclotides. These phytochemicals act through multiple molecular pathways to produce diverse therapeutic effects. The antioxidant activity is mainly mediated by scavenging reactive oxygen species (ROS), enhancing endogenous antioxidant enzymes, and inhibiting lipid peroxidation, thereby protecting cells from oxidative damage. Anti-inflammatory effects are associated with suppression of the NF-κB signaling pathway and downregulation of pro-inflammatory mediators such as TNF-α, IL-1β, IL-6, COX-2, and iNOS. The antidiabetic activity is attributed to inhibition of α-amylase and α-glucosidase, improved insulin sensitivity, enhanced glucose utilization, and protection of pancreatic β-cells. Antimicrobial activity results from disruption of microbial cell membranes and inhibition of microbial growth by flavonoids, phenolics, and cyclotides. Preliminary studies also suggest that C. ternatea exhibits anticancer potential by inducing apoptosis, inhibiting cell proliferation, and causing cell-cycle arrest in cancer cells. Collectively, these mechanisms support the plant's traditional medicinal uses and highlight its potential as a multifunctional therapeutic agent, although further mechanistic and clinical studies are needed to confirm these effects (Sowmya et al., 2023; Ramesh et al., 2025).

Toxicity and safety considerations

Clitoria ternatea L. is generally considered safe for consumption and has been used for centuries in traditional medicine and as a food ingredient without reports of serious adverse effects. Experimental studies indicate that its extracts exhibit low toxicity and are well tolerated at commonly used doses. However, most available evidence is based on preclinical studies, and comprehensive data on long-term toxicity, reproductive safety, pharmacokinetics, and herb–drug interactions are still limited. Therefore, further well-designed clinical studies and standardized safety evaluations are required to confirm its long-term safety and support its wider therapeutic and functional food applications (Shambhawi et al., 2022; Vaishnav et al., 2023; Chandini & Navuduri, 2025).

AGRICULTURE

Fodder crop

Clitoria ternatea L. is an important multipurpose legume widely cultivated as a high-quality fodder crop because of its high biomass production, excellent nutritional value, and adaptability to tropical and subtropical regions. The protein-rich forage is highly palatable to cattle, sheep, and goats, making it suitable for grazing, hay production, and sustainable livestock farming. Owing to its rapid growth and abundant biomass, the plant is also used as a green manure to improve soil fertility by adding organic matter and biologically fixed nitrogen. As a nitrogen-fixing legume, it forms symbiotic associations with Bradyrhizobium species, reducing the dependence on synthetic nitrogen fertilizers and promoting sustainable agricultural practices (Barro & Ribeiro, 1983; Mahala et al., 2012; Oblisami, 1974; Duangkhet et al., 2018; Oguis et al., 2019).

Enhancement of soil fertility

Clitoria ternatea L. is an efficient nitrogen-fixing legume that forms symbiotic associations with rhizobial bacteria in its root nodules, enabling the conversion of atmospheric nitrogen into forms available for plant growth. This process enhances soil fertility by increasing nitrogen availability and improving the levels of essential nutrients such as phosphorus and potassium. Studies have shown that C. ternatea improves soil organic matter and nutrient content, making it a valuable cover crop and intercrop in sustainable agricultural systems. The plant is compatible with several Bradyrhizobium species, particularly Bradyrhizobium elkanii and Bradyrhizobium japonicum, which enhance nodulation, nitrogen fixation, and plant growth. Consequently, C. ternatea is widely recommended for crop rotation, green manuring, and soil conservation to improve soil health and reduce dependence on synthetic nitrogen fertilizers (Oblisami, 1974; Duangkhet et al., 2018; Oguis et al., 2019).

Clitoria ternatea is widely used as a cover crop because its dense canopy suppresses weeds, conserves soil moisture, and reduces soil erosion caused by wind and rain. Its extensive root system improves soil structure, enhances water infiltration, and supports long-term soil conservation. The attractive blue flowers provide nectar and pollen for honeybees, carpenter bees, and other pollinators, thereby supporting biodiversity and improving pollination in nearby crops. These combined benefits make C. ternatea a valuable component of sustainable farming, agroforestry, crop rotation, and conservation agriculture (Fantz, 1991; Aye & Lin, 2020; Pitman & Vendramini, 2020).

Clinical evidence and research gaps

Despite the promising pharmacological activities of Clitoria ternatea L. demonstrated in numerous in vitro and in vivo studies, clinical evidence in humans remains limited. Most published studies have focused on its antioxidant, cognitive-enhancing, antidiabetic, and functional food properties, with only a few small-scale human investigations available. Furthermore, there is a lack of standardized extract formulations, optimal dosage recommendations, long-term safety assessments, pharmacokinetic studies, and large randomized controlled clinical trials. Future research should therefore prioritize well-designed human clinical studies, standardization of bioactive compounds, evaluation of bioavailability and mechanisms of action, and assessment of long-term efficacy and safety to facilitate the development of C. ternatea-based pharmaceutical, nutraceutical, and functional food products

Future Perspectives

Clitoria ternatea L. has considerable potential for development as a pharmaceutical, nutraceutical, and functional food ingredient. Future research should focus on conducting well-designed human clinical trials to confirm its efficacy and safety, standardizing extraction methods and bioactive compounds, and improving the bioavailability and stability of its phytochemicals. Further investigations into molecular mechanisms, nanoformulation-based drug delivery systems, and herb–drug interactions are also needed. In addition, expanding its applications in natural food colourants, functional beverages, and value-added food products, supported by regulatory approval and quality control standards, will facilitate the wider commercialization and global acceptance of C. ternatea

CONCLUSION

Clitoria ternatea L. represents a valuable link between traditional ethnomedicinal knowledge and modern pharmacological research. Its diverse phytochemical composition, particularly anthocyanins, flavonoids, triterpenoids, and cyclotides, contributes to a broad range of biological activities, including nootropic, antioxidant, anti-inflammatory, antimicrobial, and antidiabetic effects. In addition to its therapeutic potential, the plant's naturally occurring blue anthocyanin pigments have enhanced its importance as a natural food colourant and functional ingredient in beverages and nutraceutical products. However, the current scientific evidence is largely based on preclinical investigations, and further well-designed human clinical trials, standardized extract characterization, bioavailability studies, and comprehensive toxicological evaluations are required to establish its efficacy, safety, and mechanisms of action. These efforts will facilitate the translation of C. ternatea from traditional use and experimental research into validated pharmaceutical, nutraceutical, and functional food applications. Future research should focus on clinical trials, metabolomic standardization, nanoformulation approaches, and evaluation of synergistic effects with conventional therapies. Relevant literature was collected from major scientific databases, including PubMed, Scopus, Web of Science, and Google Scholar, to provide a comprehensive overview of the current knowledge on Clitoria ternatea L

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Table 1. bioactive phytochemicals identified in Clitoria ternatea L.

Phytochemical	Chemical class	Plant part	Biological activities	References
1. Ternatins	Polyacylated anthocyanins	Flowers	Natural blue pigment, antioxidant, anti-inflammatory	Kazuma et al., 2003; Vidana Gamage et al., 2021
2. Delphinidin	Anthocyanin	Flowers	Antioxidant, anti-inflammatory	Vidana Gamage et al., 2021
3. Quercetin	Flavonoid	Leaves, flowers	Antioxidant, antimicrobial, anticancer	Jeyaraj et al., 2022
4. Kaempferol	Flavonoid	Flowers	Antidiabetic, cardioprotective	Sarma et al., 2023
5. Myricetin	Flavonoid	Leaves	Antioxidant	Oguis et al., 2019
6. Catechin	Flavanol	Flowers	Antioxidant, antimicrobial	Oguis et al., 2019
7. Gallic acid	Phenolic acid	Flowers	Antioxidant, hepatoprotective	Jeyaraj et al., 2022
8. Caffeic acid	Phenolic acid	Leaves	Anti-inflammatory	Sarma et al., 2023
9. Cyclotides	Cyclic peptides	Seeds	Antimicrobial, insecticidal, cytotoxic	Oguis et al., 2019
10. Triterpenoids	Terpenoids	Roots, leaves	Anti-inflammatory	Mukherjee et al., 2008
11. Saponins	Glycosides	Whole plant	Immunomodulatory, antimicrobial	Ashraf et al., 2024

Table 2. Traditional ethnomedicinal uses of different parts of Clitoria ternatea L.

Plant part	Traditional use	Reported therapeutic applications	References
1. Roots	Ayurvedic medicine	Memory enhancement, anxiolytic, antipyretic, anti-inflammatory, diuretic, anthelmintic	Mukherjee et al., 2008; Oguis et al., 2019
2.Flowers	Herbal tea, natural food colourant	Antioxidant, relaxation, cognitive support, functional beverage	Al-Snafi, 2016; Sarma et al., 2023
3. Leaves	Herbal decoction	Wound healing, antimicrobial, anti-inflammatory, skin disorders	Ashraf et al., 2024
4. Seeds	Traditional remedies	Anthelmintic, antimicrobial, insecticidal	Oguis et al., 2019
5. Whole plant	Ayurvedic formulations	General tonic, Medhya Rasayana, fever, respiratory disorders	Fantz, 1991; Mukherjee et al., 2008

Table 3. Pharmacological activities and proposed mechanisms of Clitoria ternatea L.

Pharmacological activity	Bioactive compounds	Proposed mechanism of action	References
1.Antioxidant	Anthocyanins, flavonoids, phenolics	Free radical scavenging, inhibition of lipid peroxidation, enhancement of antioxidant enzymes	Jeyaraj et al., 2022; Li et al., 2021
2. Anti-inflammatory	Flavonoids, triterpenoids	Inhibition of NF-κB pathway, suppression of TNF-α, IL-6, COX-2 and iNOS	Jeyaraj et al., 2022
3. Neuroprotective	Flavonoids, anthocyanins	Reduction of oxidative stress, enhancement of neurotransmission, protection of neurons	Mukherjee et al., 2008; Vidana Gamage et al., 2021

4. Antimicrobial	Cyclotides, flavonoids, phenolics	Disruption of microbial cell membrane and inhibition of microbial growth	Raza & Tahseen, 2024; Islam et al., 2023
5. Antidiabetic	Anthocyanins, flavonoids	α-Amylase and α-glucosidase inhibition, improved insulin sensitivity	Dewi et al., 2023; Lucianus et al., 2024
6. Hepatoprotective	Phenolics, flavonoids	Prevention of oxidative liver damage and lipid peroxidation	Maia et al., 2025
7. Anticancer	Anthocyanins, flavonoids	Induction of apoptosis, inhibition of cell proliferation and cell-cycle progression	Deepika et al., 2018; ALshamrani, 2022
8.Immunomodulatory	Flavonoids, phenolics	Enhancement of humoral and cell-mediated immune responses	Deepika et al., 2018

Table 4. Recent preclinical and clinical studies on Clitoria ternatea L.

Study type	**Plant part/ extract**	**Findings**	**Limitations**	**References**
1. Review	Flowers, roots and leaves	Reported antioxidant, neuroprotective, antimicrobial and antidiabetic activities	Mostly preclinical evidence	Vidana Gamage et al., 2021
2. In vivo	Ethanolic flower extract	Significant antioxidant and anti-inflammatory activities	Animal model	Jeyaraj et al., 2022
3.Experimental	Flower extract	Improved glucose metabolism and inhibition of carbohydrate-hydrolysing enzymes	Preclinical study	Dewi et al., 2023
4. In vitro	Methanolic leaf extract	Broad-spectrum antibacterial activity against Gram-positive and Gram-negative bacteria	Laboratory study	Islam et al., 2023
5. Human dietary intervention	Butterfly pea flower beverage	Reduced postprandial glycaemic response and improved antioxidant status	Small sample size and short duration	Adisakwattana et al., 2020
6. Clinical topical evaluation	Butterfly pea herbal shampoo	Good tolerability with improvement in dandruff symptoms	Single-centre study with limited participants	Assegaf et al., 2024
7. Food application study	Flower extract	Confirmed suitability as a natural blue food colourant	Not a therapeutic clinical study	Handayani et al., 2024
8. Experimental	Flower extract	Cardioprotective and metabolic health-promoting effects	Animal model	Widowati et al., 2024
9. Regulatory review	Butterfly pea-derived food ingredients	Highlighted need for comprehensive toxicological evaluation before wider approval	No efficacy assessment	Precup et al., 2024

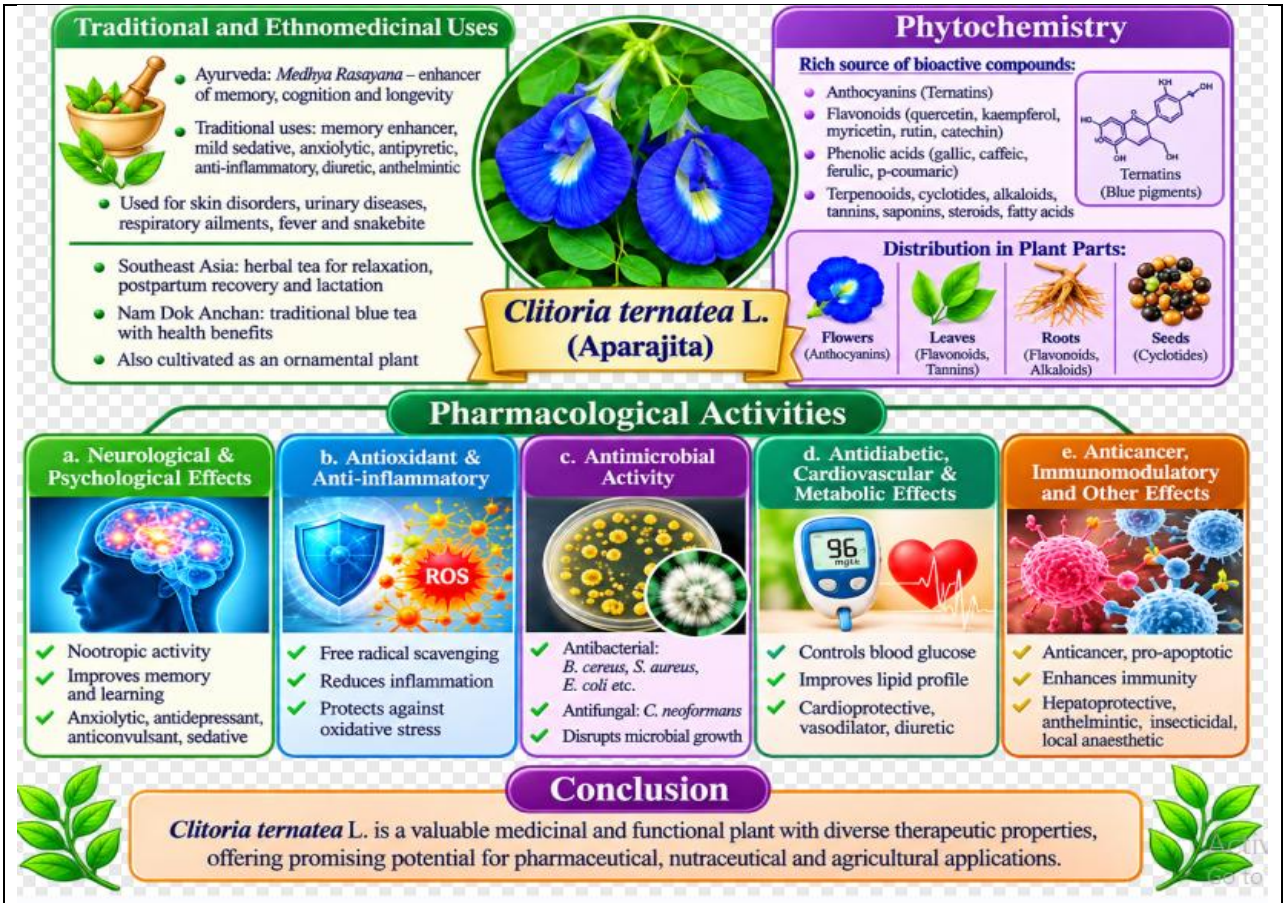


Fig. 1. Overview of the traditional uses , phytochemical constituents and pharmacological activities of Clitoria ternatea L.

Table 5. Commercial Food, Nutraceutical and Industrial Applications of Clitoria ternatea L.

Product category	Commercial products	Plant part used	Primary application	Representative references
1. Herbal tea (Blue tea)	Tea bags, dried flower tea, herbal infusions	Flowers	Functional beverage rich in antioxidants	Mukherjee et al., 2008; Maia et al., 2025
2. Natural food colourant	Liquid and powdered flower extracts	Flowers	Natural blue food colourant replacing synthetic dyes	Handayani et al., 2024
3. Functional beverages	Ready-to-drink beverages, mocktails, kombucha	Flower extract	Natural colouring and antioxidant enrichment	Maia et al., 2025
4. Bakery products	Bread, cakes, muffins, biscuits	Flower extract	Functional ingredient and natural colouring	Maia et al., 2025
5. Dairy products	Yogurt, ice cream, flavoured milk	Flower extract	Colour enhancement and antioxidant fortification	Maia et al., 2025
6. Confectionery	Gummies, jelly, chocolates, candies	Flower extract	Natural colouring and antioxidant enrichment	Jeyaraj et al., 2021
7.Traditional foods	Nasi Kerabu, Pulut Tai Tai, coloured rice, desserts	Fresh or dried flowers	Traditional natural blue colouring	Mukherjee et al., 2008
8. Nutraceuticals	Capsules, powders, dietary supplements	Flower extract	Antioxidant and cognitive health supplementation	Ashraf et al., 2024; Maia et al., 2025
9. Functional foods	Breakfast cereals, noodles, nutrition bars	Flower extract	Functional ingredient and natural colourant	Maia et al., 2025
10. Food packaging	Anthocyanin-based edible films and freshness indicators	Flower extract	pH-sensitive freshness indicator and active packaging	Handayani et al., 2024
11.Cosmeceuticals	Herbal shampoo, soaps, creams, facial masks	Flowers	Hair-care and skincare applications	Assegaf et al., 2024; Maia et al., 2025

Table 6. Agricultural importance of Clitoria ternatea L.

Agricultural Application	Benefit	References
1. Green manure	Improves soil fertility	Barro & Ribeiro (1983); Mahala et al. (2012); Oguis et al. (2019)
Cover crop	Weed suppression, conserves soil moisture, and reduces soil erosion	Staples (1992); Pitman & Vendramini (2020); Aye & Lin (2020)
Nitrogen fixation	Forms symbiotic association with Bradyrhizobium spp., reducing nitrogen fertilizer requirement	Oblisami (1974); Duangkhet et al. (2018); Oguis et al. (2019)
Fodder crop	Provides high-protein, highly digestible forage for livestock	Barro & Ribeiro (1983); Mahala et al. (2012); Cook et al. (2005)
Pollinator plant	Flowers provide nectar and pollen for honeybees and carpenter bees	Fantz (1991); Aye & Lin (2020); Oguis et al. (2019)
Soil conservation	Extensive root system improves soil structure and reduces erosion	Staples (1992); Pitman & Vendramini (2020)
Agroforestry	Suitable as a forage legume and cover crop in integrated farming systems	Cook et al. (2005); Pitman & Vendramini (2020)
Sustainable farming	Enhances soil health, supports biodiversity, and reduces dependence on synthetic fertilizers	Oguis et al. (2019); Duangkhet et al. (2018); Cook et al. (2005)

Table 7. Future research priorities and knowledge gaps in Clitoria ternatea L. research

Research area	Current limitations	Future priorities
1. Clinical validation	Limited human clinical trials	Large multicentre randomized controlled trials
2. Standardization	Variation in phytochemical composition	Standardized extracts and quality control protocols
3. Safety evaluation	Limited long-term toxicity and pharmacokinetic data	Chronic toxicity, reproductive toxicity and herb–drug interaction studies
4. Molecular pharmacology	Mechanisms not completely elucidated	Multi-omics, transcriptomics, metabolomics and molecular docking studies
5. Functional foods	Stability of anthocyanins during processing	Nanoencapsulation and improved formulation technologies
6. Pharmaceutical development	Low bioavailability of bioactive compounds	Novel drug delivery systems and nanoformulations
7. Agricultural applications	Limited breeding and genetic improvement	Marker-assisted breeding and climate-resilient cultivars
8. Industrial commercialization	Regulatory approval and standardization challenges	Regulatory harmonization and commercialization of value-added products



Fig. 1. Clitoria ternatea L. (Butterfly pea) plant