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BUTTERFLY PEA FLOWER (*Clitoria ternatea*): A NATURAL WONDER FOR COLLAGEN ENHANCEMENT AND SKIN RADIANCE

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Abstract

Nature has been a source of medicinal agents for thousands of years and a large number of modern drugs have been isolated from natural sources. Skin aging does not unfold as a single biological event;it is the cumulative result of two overlapping deteriorative processes that ultimately converge on the same molecular outcome. The first, intrinsic aging, is governed by internal programmes: telomere shortening at each cell division, replicative senescence of dermal fibroblasts, progressive mitochondrial inefficiency, and epigenetic silencing of collagen gene promoters. The second, extrinsic photoaging, is driven primarily by cumulative ultraviolet (UV) radiation exposure, which generates a sustained chemical oxidative assault on the dermis. This review consolidates available preclinical, *in vitro*, and *in vivo* evidence regarding the phytochemistry, molecular pharmacology, and cosmeceutical potential of *Clitoria ternatea* L. (butterfly pea flower). The flowers of *C. ternatea* concentrate an exceptional chemical repertoire: polyacylated anthocyanins (ternatins A_1-D_3), quercetin-3-*O*-rutinoside and kaempferol-3-*O*-glucoside flavonols, the triterpenoid taraxerol, gallic acid and catechin phenolics, cystine-knot cyclotide peptides, and saponins. *Clitoria ternatea* offers robust, preclinically validated multi-mechanistic anti-aging activity. Its structurally unique ternatin anthocyanin chemistry, well-documented traditional safety record, and unusually broad pharmacological target profile collectively position it as a high-priority botanical active for next-generation evidence-based cosmeceutical development.

INTRODUCTION

Plants have been known to have therapeutic properties since the Vedic era. Ayurveda, a science of life with divine origins, is mostly dependent on plants for medicinal purposes. Because medicinal plants are rich in phytochemicals including flavonoids, lignin, phenolic acids, and tannins, they present several prospects for scientific investigation in the ongoing hunt for novel substances with health advantages. The phytochemical substances' anti-microbial, anti-mutagenic, and anti-carcinogenic properties are prioritised [1-3].

Few scientific questions have attracted as much commercial urgency as the biology of skin aging. The global anti-aging skincare sector was valued at approximately USD 58 billion in 2023 and is forecast to exceed USD 93 billion by 2030, propelled by aging demographics, a more scientifically literate consumer base, and a marked shift in purchasing behaviour toward products supported by peer-reviewed evidence rather than aspirational marketing. The scientific challenge, and the genuine opportunityis to identify botanical actives whose pharmacological breadth is commensurate with the biological complexity of aging itself [3-5].

Clitoria ternatea (butterfly pea, belongs to the familyFabaceae) is a climbing perennial vine native to tropical Asia, used in Ayurvedic medicine as a rejuvenative tonic for over two millennia and across Southeast Asian cultures as a natural blue colorant for food and textiles. Its flowers concentrate a structurally unusual and pharmacologically rich chemical assemblage: polyacylated anthocyanins known as ternatins, quercetin and kaempferol flavonol glycosides, the triterpenoid taraxerol, gallic acid and catechin phenolics, cystine-knot cyclotide peptides, and saponins. Together, these compounds engage at least six independent nodes within the skin-aging molecular cascade-ROS scavenging, direct MMP/elastase/hyaluronidase inhibition, TGF-b1 upregulation and fibroblast proliferation, NF-kB anti-inflammatory modulation, tyrosinase inhibition, and stratum corneum barrier reinforcement-making butterfly pea flower a genuinely distinctive candidate for evidence-based cosmeceutical development [6-9].

The present review synthesises the available evidence spanning phytochemistry, botanical description, molecular pharmacology, toxicological data, for further work with this ingredient.

Taxonomy
Kingdom: Plantae
Phylum: Angiosperms

Order: Fabales

Family: Fabaceae

Genus: *Clitoria*

Species: *C. ternatea*

Botanical and ethnomedicinal overview

Clitoria ternatea L. is classified within Kingdom Plantae, Order Fabales, Family Fabaceae, Subfamily Papilionoideae, Tribe Phaseoleae, Genus Clitoria. Of the approximately 70 Clitoria species distributed across tropical and subtropical regions worldwide, *C. ternatea* is by far the most extensively studied and commercially utilised. The plant grows as a vigorous twining perennial vine reaching 2–5 metres, bearing distinctly zygomorphic axillary flowers whose butterfly-wing morphology gives the plant its common English name. The blue single-flowered form consistently yields the highest ternatin anthocyanin concentrations; white and double-petal cultivars exist commercially but deliver substantially lower anthocyanin profiles [10-12].

Figure 01: Clitoria ternatea plant

Adapted to USDA hardiness zones 9–12, *C. ternatea* tolerates a broad range of soil types, textures, and pH values, with established commercial cultivation spanning India, Thailand, Malaysia, Indonesia, the Philippines, Sri Lanka, East Africa, and parts of Australia and South America. Flowers are harvested early in the morning-when anthocyanin content peaks - and rapidly dried or extracted to preserve the thermolabile ternatin fraction. Although all plant organs carry documented biological activity, the flowers provide the pharmacologically richest profile for cosmeceutical applications, concentrating ternatins alongside the full complement of flavonols, phenolics, and saponins that underpin the plant's multi-target anti-aging activity. The ethno medicinal record of *C. ternatea* spans more than two thousand years of documented use in South Asian, Southeast Asian, and East Asian healing traditions. In Ayurveda, the plant is classified as a medhya rasayana-an adaptogenic and nootropic formulation category-and appearsin foundational texts including the Charaka Samhita under the Sanskrit name Shankhapushpi, cited for cognitive enhancement, anti-stress activity, and as a topical remedy for skin injuries, inflammatory dermatoses, and hair conditions. Traditional Chinese Medicine assigns it heat-clearing, anti-inflammatory, and antioxidant properties-therapeutic frameworks that correspond closely, in biomedical terms, to inflammatory, photooxidative, and vascular skin conditions. Across Thailand, Malaysia, Indonesia, and the Philippines, the deep blue pigment has been used for centuries as a food and textile colorant, providing an extensive historical record of non-toxicity that substantially strengthens the safety case for cosmeceutical use. Contemporary ethnopharmacological surveys carried out across these traditional use regions consistently rank wound healing, skin brightening, anti-aging, and hair growth promotion as the four most frequently cited topical applications of *C. ternatea* preparations. The striking convergence between these folk therapeutic applications and the pharmacological activities that controlled laboratory studies have now characterised-at the molecular, cellular, and tissue level-provides compelling ethnodermatological corroboration of the plant's genuine therapeutic relevance [13-17].

PHYTOCHEMICAL PROFILE

The pharmacological versatility of *C. ternatea* reflects an exceptionally diverse secondary metabolite profile distributed across all plant organs. To date, over 70 distinct bioactive compounds have been characterised using HPLC-DAD, LC-MS/MS, NMR spectroscopy, and preparative chromatography. The flowers consistently harbour the highest concentrations of dermatologically relevant molecules, and they have attracted the most intensive analytical attention in the cosmeceutical literature. What makes the flower phytochemical profile particularly notable is not simply the number of compounds present but the structural novelty of several classes - the ternatins foremost among them-which have no close chemical parallels in any other commercially established botanical source. Table 1 provides a systematic overview of the principal phytochemical classes, their representative compounds, typical concentrations, and documented dermatological activities [15,18-22].

Table 01: Major Phytochemical Classes of *Clitoria ternatea* Flowers: Representative Compounds, Concentrations, and Dermatological Relevance

Compound Class	Representative Compounds	Plant Part	Conc.	Dermatological Activity
Anthocyanins (Ternatins)	Ternatins A1-A3, B1-B4, C1-C5, D1-D3; Delphinidin-3,3',5'-tri-O-glucoside	Flowers	0.8-3.2g/100g dry wt	ROS scavenging; UV photoprotection; Tyrosinase inhibition IC50=22.5 ug/mL; Anti-melanogenic; Skin brightening
Flavonols & Flavonoids	Quercetin-3-O-rutinoside (Rutin); Kaempferol-3-O-glucoside; Myricetin-3-O-glucoside; Isoflavonoids	Flowers, Leaves	150-680 mg QE/100g	MMP-1, elastase, hyaluronidase inhibition; COX-2/LOX suppression; IKK/NF-kB modulation; Antioxidant
Triterpenoids	Taraxerol (urs-12-en-3b-ol); Taraxerone; Clitoriacetal; b-sitosterol; Oleanolic acid	Leaves, Roots, Seeds	0.1-0.4% (dried leaf)	MMP-1 IC50=8.7 ug/mL; Hyaluronidase IC50=14.2 ug/mL; Procollagen I/III stimulation +38-65%; ECM repair
Phenolic Acids & Tannins	Gallic acid; Ellagic acid; Catechin; Chlorogenic acid; Ferulic acid; Caffeic acid	Flowers, Seeds, Leaves	80-320 mg GAE/100g	Free radical scavenging (SET/HAT); Antimicrobial (S. aureus MIC=32 ug/mL); Collagen crosslink stabilisation
Cyclotides	Cliotides T1-T20; Cter-F1 to Cter-F21; VT-peptides	All organs (esp. leaves)	0.05-0.18% (dried flower)	Antimicrobial; Membrane-active scaffold; Exceptional protease resistance;Transdermal delivery vehicle potential
Saponins & Polysaccharides	Triterpenoid saponins; Stigmasterol glycosides; Mucilage polysaccharides	Roots, Seeds	1.2-4.5% (seeds)	Humectancy; TEWL reduction; Stratum corneum barrier reinforcement; Co-active penetration enhancement

(QE = quercetin equivalents; GAE = gallic acid equivalents; TEWL = transepidermal water loss; SC = stratum corneum; MMP = matrix metalloproteinase; COX = cyclooxygenase; LOX = lipoxygenase; ROS = reactive oxygen species; SET = single-electron transfer; HAT = hydrogen atom transfer; ECM = extracellular matrix)

Figure 02: Clitoria ternatea flower

Mechanisms of action in skin health

What sets *C. ternatea* apart from most botanical cosmeceutical candidates is not simply the number of active compounds it contains, but the convergence of at least six pharmacologically distinct mechanisms-each independently validated by controlled experimental evidence - operating simultaneously from a single extract. This multi-target pharmacology is not coincidental; it is the direct consequence of the phytochemical diversity described in Section 7, and the extent to which different compound classes engage the skin-aging cascade at different molecular levels. Figure 3 maps these six mechanisms in a comprehensive action diagram, connecting each phytochemical class to its specific molecular targets and the resulting clinical benefits [17,22-24].

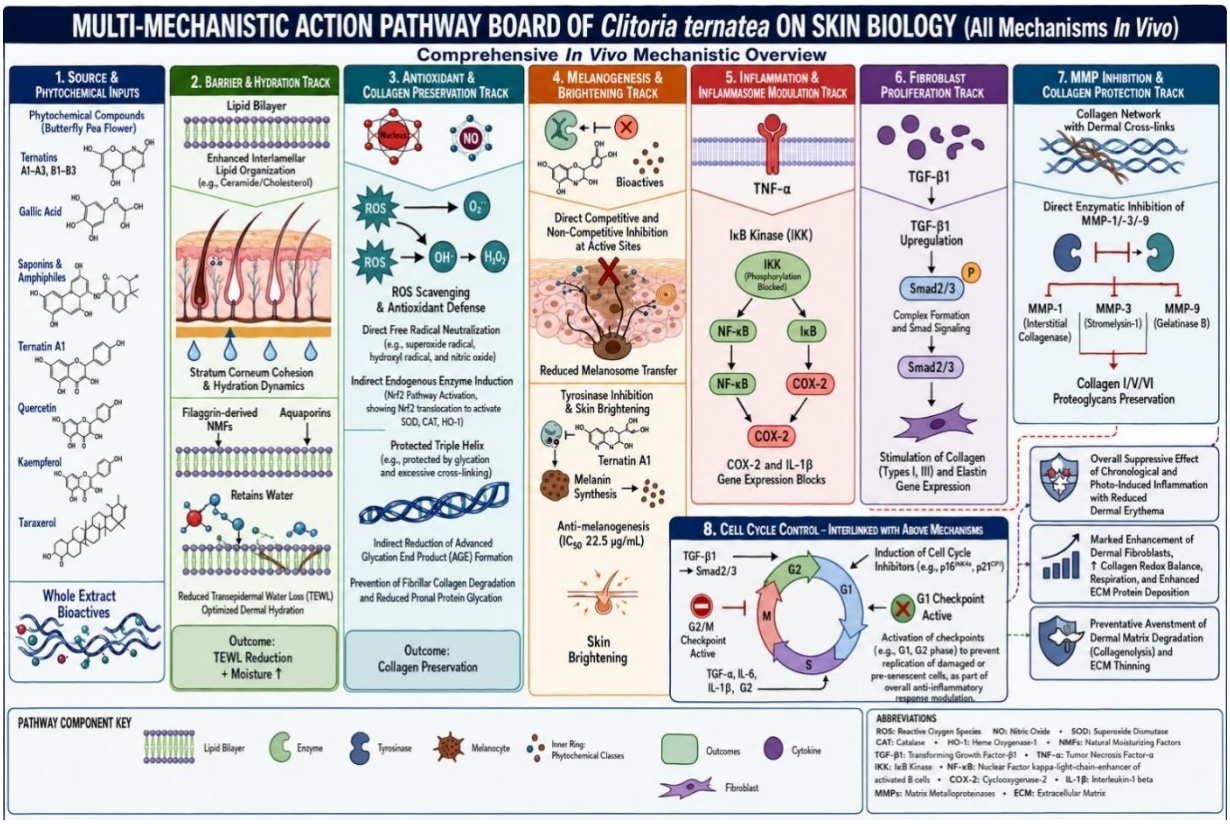

Figure 03: Comprehensive mechanism of action diagram for *Clitoria ternatea* flower extract on skin health. Left column: molecular events in UV-B-damaged untreated skin. Centre: the six phytochemical classes driving each intervention. Right column: the six specific pharmacological mechanisms, with quantitative data, active compounds, and resulting clinical outcomes.

ANTIOXIDANT ACTIVITY

The chemical composition of the flowers of *C. ternatea* suggest that they may have antioxidant activity, ethanopharmacological evidences shows that 15 the extracts of *C. ternatea* flowers are used in Thailand as a component of cosmetics. The aqueous and ethanolic extract of *C. ternatea* was found to have antioxidant potential. Aqueous extracts were shown to have stronger antioxidant activity than ethanol extracts (IC_{50} values were 2 mg/mL and 5 mg/mL, respectively). This was assessed by performing DPPH scavenging activity test. The total phenolic content was 2.0 mg/g extract as gallic acid equivalents. The data from this study support the use of *C. ternatea* extracts as anti-oxidant inclusions in cosmetic products.

ANTI-INFLAMMATORY ACTIVITY

The effects of a blue petal extract of *C. ternatea* on inflammation induced in C57BL/6 mice. The extract was found to be rich in flavonoids, with nine compounds tentatively identified. Male C57BL/6J mice were fed either a standard diet (SD) or a high-fat, high-fructose diet (HFFD) for 16 weeks, with the HFFD groups receiving 0.25%, 0.5%, or 2% (w/w) of the aqueous extract in their drinking water. Treatment significantly improved oxidative stress parameters and inflammatory mediators, indicating that the anthocyanins present in the blue petals exerted substantial anti-inflammatory effects while promoting reverse cholesterol transport [16-21].

DISCUSSION

Taken together, the evidence reviewed in this article positions *Clitoria ternatea* as one of the most pharmacologically credible and commercially differentiated botanical actives to emerge in cosmeceutical science in the past decade. Its distinctiveness rests not simply on the breadth of its claimed activity but on the mechanistic depth and chemical novelty of its primary bioactive class - the ternatin anthocyanins-which have no structural precedent in any other commercially established botanical ingredient. An extract that simultaneously quenches ROS, inhibits MMP-1 directly, restores TGF-b1 biosynthetic signalling, suppresses NF-kB inflammaging, inhibits tyrosinase anti-melanogenically, and reinforces the stratum corneum barrier delivers pharmacological coverage across six

independent skin-aging nodes that established actives achieve only in combination [18,25-27].

SAFETY AND TOXICOLOGICAL CONSIDERATIONS

The safety evidence supporting topical cosmeceutical use of *C. ternatea* extracts is derived from several independent sources and is broadly reassuring at the concentrations employed in published *in vivo* studies. Acute oral toxicity studies conducted in Wistar rats according to OECD Guideline 423 report no adverse findings at doses up to 2,000 mg/kg, establishing LD_{50}> 2,000 mg/kg and supporting informal GRAS (generally recognised as safe) classification for oral exposure. *In vitro* cytotoxicity profiling in HaCaT keratinocytes, BJ dermal fibroblasts, and B16F10 melanoma cells consistently confirms cell viability above 90% at extract concentrations up to 200 µg/mL-well above the pharmacologically active range of 25–100 µg/mL-establishing a comfortable therapeutic index for topical application. Primary skin irritation Draize patch test studies at 5–10% extract concentrations report no erythema, oedema, or inflammatory responses over 72hoccluded contact periods. The extensive tradition of topical use in Southeast Asian cosmetics and folk medicine, without recorded sensitisation or photoallergic reactions at scale, adds meaningful real-world reassurance to these controlled safety observations. These positive findings should not, however, be read as a complete safety certification. Formal dermal sensitisation testing using the guinea pig maximisation test (GPMT) or murine local lymph node assay (LLNA) methodology has not been published for standardised cosmeceutical-grade *C. ternatea* extract. Repeated-dose 90-day subchronic dermal toxicity studies and formal 3T3 Neutral Red Uptake phototoxicity assessment are similarly absent from the published record-gaps that represent concrete regulatory safety dossier obligations before market entry in major jurisdictions can be adequately substantiated. The principal formulation-related safety concern is the potential photodegradation of ternatins to chalcone and oxidative cleavage products under UV-A irradiation above pH 6.0-products whose dermatological bioactivity and potential phototoxicity have not been independently characterised. Until a formal 3T3 NRU phototoxicity assay demonstrates the safety of these degradation products, best practice should incorporate UV-absorbing co-formulants (ferulic acid 0.3–0.5%), antioxidant co-stabilisers, opaque UV-blocking primary packaging, and clear consumer guidance to apply concurrent daytime sun protection when using *C. ternatea* products [28-34].

CONCLUSION

C. ternatea is a versatile plant with new and sustainable uses in the pharmacological, cosmetic, sensory, and artisanal industries, making it a valuable natural resource, according to the evaluated scientific literature. Numerous health-promoting actions, including as antioxidant, antidiabetic, anti-obesity, hepatoprotective, and anticancer properties, have been shown by extracts from different plant sections. They can also be used as functional additives, natural colourants, parts of active packaging, and in formulations for cosmetics and nutraceuticals.*Clitoria ternatea L.* (butterfly pea flower) presents one of the most pharmacologically coherent and commercially differentiated cases for clinical development of any natural ingredient in the current cosmeceutical landscape. The chemical uniqueness of its polyacylated ternatin anthocyanins, the direct collagen-protective activity of taraxerol, the enzyme-inhibitory and anti-inflammatory properties of its quercetin and kaempferol flavonols, the complementary antioxidant and antimicrobial activity of its phenolic acid fraction, and the barrier-reinforcing humectancy of its saponins together address at least six independent molecular nodes in the skin-aging cascade from a single, well-tolerated botanical extract.

These six mechanisms are not of equal mechanistic weight, but together they address the full molecular landscape of photodamage in a way that no single-mechanism active can replicate. Upstream ROS quenching prevents the MAPK/AP-1/NF-kB cascade from initiating MMP gene induction in the first place. Direct enzyme inhibition intercepts already-expressed MMP-1, elastase, and hyaluronidase at the post-translational level. TGF-b1/fibroblast pathway restoration actively rebuilds collagen biosynthesis rather than simply slowing its degradation. NF-kB modulation suppresses the inflammaging feedforward loop. Tyrosinase inhibition addresses UV-induced hyperpigmentation through a convergent dual enzymatic and transcriptional mechanism. Saponin-mediated barrier reinforcement reduces the environmental oxidative burden that triggers the entire cascade. No currently approved botanical comparator operates simultaneously across all six of these nodes from a single, naturally derived, well-tolerated extract.

AUTHOR CONTRIBUTIONS

All authors contributed to conceptualisation, literature acquisition, and manuscript preparation. All authors have read and approved the final version of the manuscript.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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