A Comprehensive Review on *Caesalpinia pulcherrima* (L.) Sw.: Phytochemistry, Pharmacological Activities, and Future Perspectives

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ABSTRACT

Caesalpinia pulcherrima (L.) Sw. (Fabaceae) is a medicinal and ornamental plant widely distributed throughout tropical regions and has long been used in Ayurveda, Siddha, and traditional folk medicine for the treatment of inflammatory disorders, fever, respiratory ailments, and menstrual irregularities. Despite extensive phytochemical and pharmacological investigations, a comprehensive and critical synthesis of its therapeutic potential and translational relevance remains limited. This review was conducted through a comprehensive literature search of PubMed, Scopus, ScienceDirect, and Google Scholar, covering studies published up to 2025, with evidence collected and synthesized according to the PRISMA 2020 framework. Current literature indicates that more than eighty secondary metabolites have been identified from *C. pulcherrima*, including cassane-type diterpenoids, flavonoids, triterpenoids, alkaloids, and phenolic compounds characterized using LC–MS, GC–MS, HPTLC, and NMR-based analytical techniques. Experimental studies consistently demonstrate antioxidant, anti-inflammatory, antimicrobial, anticancer, antidiabetic, hepatoprotective, wound-healing, and neuroprotective activities, while recent network pharmacology and molecular docking investigations suggest that these bioactivities involve modulation of oxidative stress, inflammatory, and apoptosis-related signalling pathways. Toxicological evidence indicates a favourable safety profile, with reported oral LD_{50} values exceeding 5 g/kg, although seed ingestion has been associated with mild gastrointestinal toxicity. Collectively, the available evidence highlights *C. pulcherrima* as a chemically diverse medicinal species with considerable pharmacological promise. Nevertheless, further progress toward clinical translation will require standardized phytochemical characterization, bioactivity-guided isolation of lead compounds, comprehensive ADME/Tox evaluation, mechanistic validation, and well-designed clinical studies to establish its therapeutic efficacy and long-term safety.

KEYWORDS: *Caesalpinia pulcherrima*, *cassane*-type diterpenoids, phytochemical characterization, pharmacological mechanisms, therapeutic potential.

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1. INTRODUCTION

Medicinal plants continue to serve as an important source of novel therapeutic agents and drug leads, with their diverse secondary metabolites providing valuable scaffolds for modern drug discovery and natural-product research. *Caesalpinia pulcherrima (L.) Sw.*, commonly known as Peacock flower, Mayilkondrai, Pride-of-Barbados, or Barbados pride, is a widely distributed ornamental and medicinal species found throughout tropical and subtropical regions. Besides its ornamental importance, the plant has been used extensively in Ayurveda, Siddha, and traditional folk medicine. Different plant parts, including the flowers, leaves, seeds, stem bark, root bark, and roots, have traditionally been employed to manage fever, respiratory disorders, gastrointestinal ailments, inflammatory conditions, skin diseases, and several other health disorders. This extensive ethnomedicinal use, together with accumulating experimental evidence, has attracted considerable scientific interest in *C. pulcherrima* as a potential source of biologically active phytochemicals for therapeutic development. [1,2] Taxonomically, *C. pulcherrima* belongs to the family Fabaceae and is characterized by bipinnate leaves and striking orange-, yellow-, or pink-coloured flowers. The species thrives under a wide range of environmental conditions and is commonly cultivated in disturbed habitats, gardens, and roadsides across Africa, Asia, the Americas, and the Caribbean. Its broad geographical distribution has facilitated both its traditional medicinal use and scientific investigation. Earlier ethnobotanical observations and preliminary pharmacological studies reported anti-inflammatory, analgesic, and

antimicrobial properties, providing the initial scientific basis for subsequent phytochemical and pharmacological investigations. [3] During the past decade, substantial advances in chromatographic, spectrometric, and computational techniques have accelerated research on *C. pulcherrima*. Modern analytical platforms, including LC–MS, GC–MS, and advanced spectroscopic methods, have enabled the identification of numerous bioactive constituents belonging to diverse chemical classes such as flavonoids, chalcones, rotenoids, terpenoids, glycosides, and phenolic compounds.[1,4] These findings have considerably expanded our understanding of the phytochemical diversity of the species and have generated new hypotheses regarding the molecular basis of its reported pharmacological activities.

Current research generally follows two complementary approaches. Experimental phytochemical investigations focus on the isolation, structural characterization, and biological evaluation of individual constituents, whereas pharmacological studies seek to validate traditionally claimed activities, including antioxidant, anti-inflammatory, antimicrobial, and cytotoxic effects through in vitro and in vivo models. In parallel, computational approaches such as network pharmacology, molecular docking, and molecular dynamics simulations have been increasingly employed to identify potential molecular targets and signalling pathways, thereby providing mechanistic explanations for the observed biological activities and highlighting possible translational applications, including anti-metastatic effects and modulation of angiogenesis- and matrix-remodelling-related pathways.[2] These multidisciplinary approaches have substantially improved our understanding of the relationship between phytochemical constituents and biological activity, allowing more rational prioritization of candidate compounds for further preclinical investigation. Nevertheless, several important limitations continue to hinder translational progress. Many published studies employ crude extracts prepared using different plant parts, extraction procedures, and dosing regimens, making direct comparison between investigations difficult. Likewise, although numerous phytochemical studies report the presence of specific compound classes, comprehensive structural characterization and quantitative standardization remain inconsistent. In addition, information regarding pharmacokinetics, bioavailability, metabolism, and long-term safety remains limited, restricting confidence in the clinical applicability of currently available findings. [1,3]

Recent advances in computational pharmacology have further expanded opportunities to investigate the therapeutic potential of *C. pulcherrima*. Network pharmacology integrated with molecular docking has identified several candidate phytochemicals and molecular targets associated with metastasis-related signalling pathways, providing a mechanistic framework for future anticancer investigations. [2] However, computational predictions primarily generate hypotheses and require rigorous validation through molecular, cellular, and whole-organism studies before clinical translation can be considered. Similarly, recent experimental investigations continue to demonstrate antioxidant, anti-inflammatory, and analgesic activities of flower and leaf extracts, reinforcing traditional medicinal claims while simultaneously emphasizing the need for standardized extract characterization and comprehensive dose–response evaluation.[3,4] The growing body of literature highlights the therapeutic promise of *C. pulcherrima* but also reveals considerable heterogeneity in experimental design, phytochemical characterization, and mechanistic validation. These inconsistencies make it difficult to critically evaluate the overall strength of evidence or identify priorities for future research. Consequently, a comprehensive synthesis integrating phytochemical composition, pharmacological evidence, toxicological findings, and emerging computational approaches is warranted to provide a clearer understanding of the species and its translational potential.

The present review therefore aims to (i) systematically collate and critically appraise the phytochemical profile of *C. pulcherrima*, (ii) synthesize pharmacological evidence from *in vitro*, *in vivo*, and *in silico* investigations, (iii) evaluate the available toxicological and safety data, and (iv) identify key knowledge gaps and future priorities for translational research and drug discovery. By integrating evidence from primary experimental studies, computational investigations, and recent review articles, this review provides an updated and critical assessment of the therapeutic potential of *C. pulcherrima*. The manuscript is structured according to the Create-a-Research-Space (CARS) framework, beginning with the botanical, ethnopharmacological, and phytochemical background, followed by a critical evaluation of current evidence, and concluding with recommendations to guide future pharmacological research and therapeutic development.

2. BOTANICAL DESCRIPTION & ETHNOPHARMACOLOGY

2.1 Botanical Description

Caesalpinia pulcherrima (L.) Sw., belongs to the family Fabaceae, subfamily Caesalpinioideae, one of the largest subfamilies comprising approximately 150 genera and 2,700 species. The species is an evergreen, perennial shrub or small thorny tree that typically grows 2–4 m in height under cultivation but may attain greater heights under favourable environmental conditions. It is characterized by sparsely prickly branches, bipinnate leaves measuring 20–40 cm in length, and 3–10 pairs of pinnae, each bearing 6–10 pairs of opposite leaflets that are approximately 15–25 mm long and 10–15 mm wide. Flowers are arranged in terminal racemes up to 20 cm long and exhibit striking yellow, orange, red, or occasionally pink petals. Each flower possesses five petals and ten elongated, bright-red stamens that extend well beyond the corolla, making the species readily

distinguishable. The fruit is a flat, oblong legume measuring 6–12 cm in length and contains several compressed, hard-coated brown seeds that are released upon dehiscence. [6] The species is widely cultivated throughout tropical and subtropical regions because of its ornamental value and adaptability to diverse environmental conditions. It thrives in disturbed habitats, arid soils, gardens, roadsides, and landscapes across the Caribbean, South America, Central Africa, South Asia, and Southeast Asia, where it is frequently planted as a hedge or ornamental shrub. [7,8] This broad ecological adaptability has contributed significantly to its widespread distribution and long-standing use in traditional medicine.

Anatomical investigations have demonstrated that the leaves and stems possess abundant secretory cells and glandular trichomes containing phenolic deposits, features that are consistent with defensive phytochemical accumulation observed in other members of the Caesalpinioideae.[9] Recent metabolomic investigations have further revealed a chemically diverse profile comprising flavonoids, chalcones, diterpenoids, alkaloids, and other secondary metabolites, with flowers and seeds representing the principal sites of metabolite accumulation.[10] The localization of these metabolites within glandular trichomes and epidermal tissues supports their ecological roles in pathogen defence, herbivore deterrence, and environmental adaptation. Although genomic information remains limited, recent transcriptomic studies have identified putative biosynthetic genes associated with flavonoid and lignan biosynthesis, providing preliminary insights into the molecular pathways responsible for secondary metabolite production in *C. pulcherrima*.[11] Collectively, the species exhibits a combination of distinctive morphological characteristics, ecological adaptability, and phytochemical diversity that underpins both its medicinal significance and its potential as a valuable source of bioactive natural products.

(A) Whole Plant
(B) Flowering Twig
Figure 1: Morphological features of *Caesalpinia pulcherrima (L.)* Sw.

2.2 Ethnopharmacology

Ethnomedical evidence demonstrates that *C. pulcherrima* has been deeply integrated into traditional health systems across Asia, Africa, and the Caribbean. Classical Ayurvedic and Siddha texts describe its use as a febrifuge, anti-inflammatory agent, and uterine

stimulant; decoctions of flowers and leaves have historically been prescribed for respiratory ailments, including cough, bronchitis, and asthma, as well as gastrointestinal complaints such as dysentery and abdominal pain[12] In folk systems of Central America and the Caribbean, preparations from bark and seeds have also been employed for wound healing, menstrual regulation, and as abortifacients, reflecting potent bioactive properties and necessitating safety considerations in reproductive contexts[13] Contemporary ethnobotanical surveys reinforce these traditional

claims. In rural Southeast Asian communities, flower infusions continue to be used for fever, skin irritation, and microbial infections, while leaf poultices are applied topically to alleviate inflammation and pain[14] Across West Africa, the plant is frequently included in polyherbal formulations for malaria, indicating perceived antipyretic and antiplasmodial activity. Importantly, these community-level uses align with reported pharmacological activities such as antimicrobial, antioxidant, and anti-inflammatory effects, lending translational relevance to traditional knowledge systems. In recent years, global interest in natural therapies has revitalized ethnomedicinal research on *C. pulcherrima*. However, variability in extraction methods, dosage forms, and plant parts used across traditional practices highlights the need for standardized phytopharmacological validation. Furthermore, anecdotal records of abortifacient activity underscore the importance of rigorous toxicological evaluation prior to therapeutic application[13,15] As bioprospecting and integrative medicine evolve, *C. pulcherrima* represents a compelling model for bridging traditional knowledge with evidence-based drug discovery, provided that scientific inquiry remains sensitive to cultural context, sustainability, and bioethical considerations.

3. METHODOLOGY

A systematic and structured review methodology was followed to ensure a comprehensive and unbiased compilation of scientific literature related to *Caesalpinia pulcherrima*. The search strategy was designed to capture both classical ethnopharmacological knowledge and the latest advancements in phytochemical and pharmacological research. Major scientific databases including PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar were extensively searched. Additional specialized repositories such as NAPRALERT, AYUSH Research Portal, and Plants of the World Online were consulted to trace traditional medicinal usage and botanical records. The search employed a combination of relevant keywords and Boolean operators such as "*Caesalpinia pulcherrima*", "Peacock flower", "Barbados Pride", "phytochemistry", "bioactive compounds", "pharmacological activity", "anti-inflammatory", "antioxidant", and "neuroprotective". Medical Subject Headings (MeSH) terms were incorporated where applicable to further enhance the precision of search outcomes. Studies published from inception until January 2025 were screened, and additional articles were retrieved by manually scanning the references of eligible papers to ensure completeness of data collection. To maintain scientific rigor, strict inclusion and exclusion criteria were applied. Eligible studies included peer-reviewed original research articles, theses, and herbal monographs that provided empirical data on the phytochemical composition, biological activities, or safety profile of *C. pulcherrima*. Articles reporting traditional medicinal knowledge verified by documented ethnobotanical evidence were also included. Only studies published in English and those focusing directly on *C. pulcherrima* were considered. Conversely, articles without reliable botanical identification, non-research commentaries, anecdotal reports, and duplicates across search databases were excluded. Review articles were not included as primary evidence, but their reference lists were examined to identify additional relevant primary studies. Studies that lacked sufficient methodological details or presented inconsistent data without reproducible outcomes were excluded in order to maintain methodological transparency and scientific credibility. Following study selection, data extraction was performed independently by two reviewers to minimize bias. A standardized data extraction template was used to record key information including authors, year of publication, experimental models, plant parts used, extraction solvent or technique, identified phytoconstituents, pharmacological assays, outcome measures, and toxicity observations. Emphasis was placed on studies that clearly described extraction and analytical protocols, including chromatographic and spectroscopic methods. Discrepancies in data interpretation were resolved through consensus, and when necessary, a third reviewer was consulted. To ensure quality assessment, established systematic review standards such as PRISMA guidelines were consulted as a methodological reference framework, enhancing transparency in study selection and assessment[16,17] The extracted data were synthesized through a narrative approach due to the heterogeneity in research designs, experimental models, and reported outcomes. Quantitative results, where available, such as IC50 values for antioxidant assays, cytotoxicity parameters, and pharmacokinetic insights, were highlighted to provide detailed insight into the therapeutic potential of the plant. Ethnobotanical records were compared with contemporary pharmacological evidence to trace validation of traditional uses through modern scientific studies. The final synthesis highlighted major research trends, knowledge gaps, and future research directions, particularly focusing on phytochemical standardization, mechanistic pharmacological studies, and translational research to bridge preclinical findings with clinical application potential.

4. PHYTOCHEMISTRY

The phytochemical profile of *Caesalpinia pulcherrima* (L.) Sw. is distinguished by a diverse spectrum of secondary metabolites, predominantly flavonoids, phenolic acids, diterpenoids, triterpenoids, alkaloids, and glycosides, contributing to its wide pharmacological spectrum. Among these, flavonoids and diterpenoids emerge as the most pharmacologically significant classes, particularly contributing to the plant's anti-inflammatory, antioxidant, neuroprotective, and anticancer properties. Flavonoids isolated from *C. pulcherrima* include quercetin, rutin, kaempferol, apigenin, luteolin, and fisetin, with quercetin and rutin consistently reported in methanolic leaf and flower extracts (18,19). Rutin concentrations from leaf extracts

were reported up to 14.8 mg/g dry weight, indicating a high flavonol abundance (20). Anthraquinone derivatives such as emodin and chrysophanol have also been identified, particularly from root and bark extracts (21). Phenolic acids including gallic acid, caffeic acid, ferulic acid, and protocatechuic acid contribute to antioxidant potential, with gallic acid quantified at 3–6 mg/g extract depending on solvent system (22). A defining phytochemical hallmark of *C. pulcherrima* is its diterpenoid and cassane-type nor-diterpenoid skeleton compounds, notably caesalpinins (A–Q), pulcherrins, pulcherrimalins, and pulcherrins A–F, primarily isolated from seeds and heartwood (23,24). For example, caesalpinins A and B have demonstrated cytotoxic effects against breast and lung cancer cell lines with IC_{50} values ranging 5–12 μM (25). Additionally, β-sitosterol, lupeol, stigmasterol, campesterol, and oleanolic acid form part of the triterpenoid fraction, contributing to anti-inflammatory and hepatoprotective effects (26). Several glycosylated flavonoids and lignan glycosides, including syringaresinol-O-β-D-glucoside, have also been reported (27). Alkaloids such as pulcherriminine and pulcherrimidine analogues have been identified in seeds and pods, although available literature suggests relatively low abundance compared to phenolics and terpenoids (28). Recent metabolomic profiling using LC-MS and UHPLC-QTOF has expanded the phytochemical catalogue, identifying over 75 metabolites, including new cassane diterpenoids and flavonoid glycosides (29). GC-MS studies of seed oil have detected fatty acids such as linoleic acid, oleic acid, palmitic acid, and stearic acid, supporting potential nutraceutical interest (30). High-resolution NMR, including 1D and 2D NMR (^{1}H, ^{13}C, HSQC, HMBC, COSY), remains the gold standard for structural elucidation of newly found diterpenoid frameworks (31). Chromatographic techniques frequently applied include TLC and HPTLC for preliminary profiling and chemotaxonomy, HPLC-UV/DAD for phenolic quantification, and LC-MS/MS for targeted metabolite discovery. Notably, HPTLC fingerprints have been established for rutin, quercetin, gallic acid, and caffeic acid, aiding standardization efforts (32). However, despite advanced profiling, significant variability in reported phytochemical content exists due to differences in plant part, geographical source, extraction solvents, and seasonal variation, underscoring the need for standardized phytochemical benchmarking protocols (33). Overall, the phytochemical richness of *C. pulcherrima* positions it as a promising natural candidate for drug development. The abundance of flavonoids, phenolic acids, and diterpenoids, complemented by emerging reports on glycosides and alkaloids, provides a diverse chemical base that warrants deeper mechanistic and pharmacokinetic studies. Future research should prioritize bioactivity-guided fractionation, metabolomic-genomic correlation studies, and quantitative standardization, particularly focusing on cassane diterpenoids and flavonoid glycosides as lead scaffolds for anti-inflammatory and neuroprotective drug discovery.

Table 1. Phytochemical Class, Active Constituents and Reported Pharmacological Activities of *Caesalpinia pulcherrima (L.)* Sw.

Phytochemical Class	Active Constituents (s)	Molecular Formula / MW	Plant Part(s)	Biological / Pharmacological Activity	Analytical Method(s)	Reference(s)
Flavonoids	Quercetin, Rutin, Kaempferol, Luteolin, Apigenin	$C_{15}H_{10}O_7$ (Quercetin)	Leaves, Flowers	Potent antioxidant and anti-inflammatory effects; inhibition of ROS, TNF-α, and IL-6; contributes to antimicrobial and hepatoprotective actions	LC–MS, HPLC, HPTLC, UV-Vis spectroscopy	18-20,32,34
Phenolic acids	Gallic acid, Caffeic acid, Ferulic acid, Protocatechuic acid	$C_7H_6O_5$ (Gallic acid)	Leaves, Bark, Roots	Free radical scavenging, cytoprotective, and hepatoprotective activities; supports anti-diabetic effects via oxidat	HPLC, LC–MS, UV spectrophotometry	20,22,43

				ive stress modulation		
Cassane-type diterpenoids	Caesalpinins A–Q, Pulcherrins A–F, Pulcherrimalins, Norcassane derivatives	$C_{20}H_{30}O_5$ (typical cassane skeleton)	Seeds, Stem bark, Heartwood	Cytotoxic and antiproliferative effects in breast, lung, and glioblastoma cell lines; anti-inflammatory, antiplasmodial, and insect-deterrent properties	LC–MS/MS, NMR (^{1}H, ^{13}C, HMBC, HSQC), X-ray crystallography	23-25,29,31,40–42,47,51
Triterpenoids / Sterols	β-Sitosterol, Lupeol, Oleanolic acid, Stigmasterol, Campesterol	$C_{30}H_{50}O$ (Lupeol)	Bark, Leaves	Anti-inflammatory and hepatoprotective activity; membrane-stabilizing and antioxidant effects	GC–MS, LC–MS, HPLC	26,30,44
Anthraquinones	Emodin, Chrysophanol	$C_{15}H_{10}O_5$ (Emodin)	Roots, Bark	Exhibits antimicrobial, laxative, and cytotoxic effects; supports purgative and traditional use claims	LC–MS, HPLC, UV	21,48
Lignans / Glycosides	Syringaresinol-O-β-D-glucoside, New lignan glycosides	Variable	Whole plant	Antioxidant, neuroprotective, and anti-inflammatory potential	LC–MS/MS, NMR	27,28
Alkaloids	Pulcherrimine, Pulcherrimidine derivatives	Variable	Seeds, Pods	Exhibits antiparasitic, antimicrobial, and possible CNS activity; moderate abundance in seeds	GC–MS, LC–MS	28,42,46
Fatty acids	Oleic acid, Linoleic acid, Palmitic acid, Stearic acid	Variable	Seeds	Nutraceutical relevance; antioxidant and lipid-regulating properties	GC–MS, FTIR	30
Lignin polymer fractions	Lignin isolate from leaves	Polymer	Leaves	Demonstrated antioxidant, antifungal, and immu	FTIR, NMR	36

				nomodulatory effects		
Novel diterpenoids (recently identified)	Caesalpin in derivatives	Variable	Aerial parts	Newly characterized cassane diterpenoids with *in silico* anti-inflammatory and anticancer potential	LC–MS, HR-MS, 2D NMR	[51]

5. PHARMACOLOGICAL ACTIVITIES

Caesalpinia pulcherrima exhibits a broad and well-documented preclinical pharmacological profile spanning antimicrobial, anti-inflammatory/analgesic, antioxidant, anticancer, antidiabetic/metabolic, cardioprotective, neuroprotective, hepatoprotective, wound-healing, and several other bioactivities. Antimicrobial and antifungal effects are among the most frequently reported: multiple studies from 2019–2024, shows that polar and mid-polarity extracts (methanol, ethyl acetate) of leaves, flowers, and roots inhibit Gram-positive and Gram-negative bacteria (including food-borne and urinary pathogens), dermatophytes, and *Candida* spp., with MIC and zone-of-inhibition values suggesting flavonoid- and phenolic-mediated activity[34–36] Early antiviral screening also demonstrated broad *in vitro* antiviral activity of aqueous extracts and related flavonoids (notably quercetin), indicating potential antiviral breadth that warrants modern reassessment using contemporary viral models[37] Anti-inflammatory and analgesic properties have robust *in vivo* support: ethanolic and aqueous extracts reduced carrageenan-induced paw oedema and acetic-acid-induced writhing in rodents and lowered pro-inflammatory cytokines (TNF-α, IL-6) and oxidative stress markers in treated animals, supporting traditional uses for pain and inflammatory disorders[3,38] Antioxidant activity is consistently strong across DPPH, ABTS, and other assays, and correlates with total phenolic and flavonoid content measured by modern LC–MS and spectrophotometric methods. Antioxidant effects also underpin several downstream protective activities such as hepatoprotection and neuroprotection[10,39] Anticancer potential has been highlighted by the isolation of cassane-type diterpenoids and flavonoid derivatives that show antiproliferative, pro-apoptotic, and anti-metastatic effects in multiple cancer cell lines (breast, lung, squamous carcinoma, etc.). Several recent reports (2020–2024) document cassane diterpenoids with low-micromolar cytotoxicity and induction of apoptotic markers, though selective toxicity and *in vivo* efficacy require further validation[40,41] Antiplasmodial activity has also been reported for stem-bark fractions and isolated pulcherrimin-type compounds in preclinical malarial assays, supporting ethnomedical antimalarial claims[42] Metabolic benefits, especially antidiabetic effects, are supported by STZ-diabetic rodent studies showing improved glycaemic indices, attenuation of diabetic peripheral neuropathy, cardiomyopathy, and cognitive decline following prolonged extract treatment. HPLC fingerprinting in these studies repeatedly detected gallic and protocatechuic acids as recurring markers. Cardioprotective and neuroprotective endpoints have been observed in diabetes-associated models, where extracts improved myocardial markers, motor coordination, and cognitive function[43] Hepatoprotective activity has also been supported by evidence from CCl_4- and paracetamol-induced liver injury models, showing dose-dependent normalization of SGOT/SGPT levels and histological protection with ethanolic or methanolic extracts (2024–2025 reports)[44]

The methanolic extract of *Caesalpinia pulcherrima* exhibited significant immunosuppressive potential in animal models by inhibiting delayed-type hypersensitivity and antibody titers, indicating suppression of both humoral and cell-mediated immune responses. The extract was found to reduce lymphocyte proliferation and modulate macrophage function, suggesting regulation of cytokine production and immune-cell activation. This immunomodulatory effect supports the plant's traditional use in inflammatory and autoimmune conditions. The findings highlight *C. pulcherrima* as a potential source of natural immunosuppressants for controlling hyperactive immune responses without marked cytotoxicity, warranting further mechanistic and dose–response evaluation. Methanolic leaf and flower extracts of *C. pulcherrima* demonstrated marked vasorelaxant activity on isolated rat aortic rings pre-contracted with phenylephrine, suggesting endothelium-dependent relaxation mediated through nitric oxide release and calcium-channel blockade. The effect was concentration-dependent and reversible, indicating direct smooth-muscle interaction. Such vascular smooth-muscle relaxation contributes to lowered peripheral resistance and improved microcirculation. These results rationalize the plant's traditional use in circulatory and febrile disorders and imply antihypertensive potential. The observed vasodilatory effect could also explain reported improvements in blood flow and tissue oxygenation associated with the plant's extracts. Extracts and isolated constituents from *C. pulcherrima* displayed pronounced antiproliferative effects in cell-based assays. Ethanolic extracts inhibited the proliferation of mitogen-stimulated lymphocytes and certain tumour cell lines in a dose-dependent manner. The activity was attributed to flavonoids and diterpenoids capable of interfering with DNA synthesis

and cell-cycle progression, leading to growth arrest and apoptosis. These results confirm that the antiproliferative property is not limited to neoplastic cells but may also modulate immune-cell proliferation, explaining its concurrent immunosuppressive action. The study supports the dual role of *C. pulcherrima* compounds in controlling hyperplastic and neoplastic processes. *C. pulcherrima* leaf extract inhibited ADP-induced platelet aggregation *in vitro*, suggesting interference with thromboxane-A_2 synthesis or calcium-mobilization pathways. This inhibition occurred in a concentration-dependent manner without causing haemolysis or cytotoxicity to erythrocytes. The observed effect points to potential cardiovascular benefits by reducing platelet activation and thrombus formation. The findings are consistent with the vasorelaxant and antioxidant properties of the plant, which together may contribute to improved vascular health and reduced atherothrombotic risk. Such natural antiplatelet activity underscores its therapeutic relevance in cardiovascular and inflammatory disorders. Petroleum-ether and methanolic extracts of *C. pulcherrima* leaves and flowers exhibited strong acaricidal properties against *Rhipicephalus (Boophilus) microplus* ticks *in vitro*. The extracts caused high mortality and reduced oviposition in treated adult females, indicating interference with the reproductive physiology of the parasite. The activity was attributed to lipophilic secondary metabolites, including terpenoids and flavonoids. This demonstrates the plant's potential in developing eco-friendly biopesticides for veterinary and agricultural use. The study emphasized that *C. pulcherrima* could serve as a sustainable botanical alternative to synthetic acaricides, minimizing resistance and environmental toxicity concerns. *C. pulcherrima* extracts improved peripheral blood flow and tissue perfusion in animal models through vasodilation and antiplatelet mechanisms. These effects were linked to flavonoid-induced nitric oxide release and inhibition of vascular constrictors. Enhanced circulation supports wound healing and tissue regeneration, aligning with its ethnomedicinal use for fever and inflammation. The improved hemodynamic response suggests cardiovascular regulatory potential, complementing its vasorelaxant and antioxidant actions. Thus, *C. pulcherrima* contributes to maintaining vascular integrity and promoting oxygen delivery, reinforcing its traditional application in disorders associated with poor circulation or stagnation. Methanolic extracts of *C. pulcherrima* demonstrated specific antibacterial activity against *Clostridium perfringens*, a pathogenic bacterium responsible for gastrointestinal infections and food poisoning. The extract produced significant inhibition zones in agar-diffusion assays and reduced bacterial growth comparable to standard antibiotics at higher concentrations. The activity was mainly attributed to phenolic and flavonoid constituents that disrupt bacterial cell-wall integrity. This targeted antimicrobial potential suggests that *C. pulcherrima* could serve as a source of natural inhibitors against anaerobic enteropathogens, supporting its ethnomedicinal use for treating intestinal disorders and infections associated with food spoilage. *C. pulcherrima* extracts enhanced glucose uptake in L6 myotubes and adipocytes by up-regulating GLUT4 translocation through phosphoinositide-3-kinase (PI3K) pathway activation. This insulin-mimetic mechanism improves peripheral glucose utilization and supports glycaemic control in diabetic conditions. The presence of phenolic acids such as gallic and protocatechuic acids was linked to this effect. This mechanistic insight provides molecular evidence for its traditional antidiabetic use and expands its pharmacological profile from antioxidant protection to metabolic regulation, suggesting potential as a natural insulin sensitizer or adjuvant for diabetes management[45]

Other reported activities include wound-healing and topical antiseptic effects (supported by traditional use and experimental wound models), purgative/laxative activity in older pharmacological reports, anthelmintic activity in *in vitro* and *in silico* screens, insecticidal/herbivore deterrent effects of cassane diterpenoids, and potential contraceptive/anti-sperm effects in recent hydro-ethanolic sperm assays — all suggesting diverse bio-functionalities beyond classical pharmacology and indicating areas for targeted development or safety evaluation[2, 5, 46–49] Notably, some ethnomedical uses (e.g., abortifacient/uterotonic actions) flag reproductive-safety concerns and warrant caution and rigorous toxicological assessment before therapeutic application. Across activities, recurrent limitations include heterogeneity in extract preparation, inconsistent dose reporting, limited pharmacokinetic data, and a shortage of well-controlled *in vivo* and clinical studies. While the preclinical evidence up to 2025 is substantial and diverse, translating these activities into therapeutics will require standardized extracts, bioactivity-guided isolation of lead compounds, comprehensive ADME/Tox profiling, and early-phase clinical evaluation.

6. *IN SILICO* STUDIES

In silico investigations have increasingly supported the pharmacological profiling of *Caesalpinia pulcherrima*, using molecular docking, ADMET prediction, and network-based approaches to elucidate potential mechanisms and prioritize candidate phytochemicals. Network pharmacology linked several flavonoids and diterpenoids from the plant to key cancer and inflammation-related pathways, identifying interactions with metastasis-associated proteins (MMP-2, AKT1, EGFR) with favourable binding affinities, suggesting multi-target anticancer and anti-inflammatory mechanisms[2] Further computational analyses reinforced this polypharmacology profile by mapping *C. pulcherrima* constituents to apoptosis and immune-modulation pathways, providing system-level mechanistic insight[50] LC-MS-guided metabolite identification has enhanced the reliability of docking studies by ensuring only experimentally verified phytoconstituents are screened, improving target prediction accuracy[10] ADME/Tox modelling revealed

that several glycosylated flavonoids exhibit drug-likeness, while some lipophilic *cassane* diterpenoids show low predicted oral bioavailability and possible hepatotoxicity risks, indicating the need for careful safety evaluation[51] Additionally, newly isolated *cassane* diterpenoids demonstrated promising computational affinity toward inflammatory and cancer-associated targets, further supporting their therapeutic relevance[52] Overall, these computational findings provide a rational basis for biomolecular validation and drug-development pipelines; however, *in vitro* confirmation of target binding, metabolic stability, and safety remains essential before clinical translation.

7. TOXICOLOGY & SAFETY

Acute toxicity studies on *Caesalpinia pulcherrima* consistently report a wide safety margin in commonly used experimental models. Early work following OECD-guided acute-toxicity protocols found no mortality or gross behavioural toxicity at doses up to 2000 mg/kg orally in rodents[3] Subsequent investigations of different extracts and seed mucilage have reported even higher LD_{50} thresholds (mucilage and some crude extracts >5 g/kg by oral route) and at least one recent study reported an LD_{50} in excess of 8000 mg/kg, indicating low acute lethality under tested conditions[4, 53–54] Sub-chronic evaluations are fewer but available reports indicate no major alterations in routine haematological or biochemical parameters at therapeutic dose ranges used in efficacy studies; nonetheless, full GLP-standard 28- or 90-day toxicology datasets are lacking[4] Reported adverse events from human/poisoning case reports are limited but notable: ingestion of seeds from Caesalpinia species has been associated with gastrointestinal symptoms (nausea, vomiting, abdominal pain, dehydration) in paediatric poisoning cases, indicating that seeds can be a hazard if consumed[55] Importantly, preclinical reproductive studies demonstrate anti-fertility/uterotonic effects (anti-implantation, increased uterine weight, resorption) for bark and other extracts, supporting traditional abortifacient use and signalling clear contraindication in pregnancy until safety is established[56] Herb–drug interaction data are essentially predictive at present: *in silico* ADME/Tox screens and docking-based ADME assessments flag potential CYP and P-glycoprotein liabilities for several lipophilic cassane diterpenoids and suggest possible reductions in oral bioavailability or metabolic interactions; empirical CYP inhibition/induction and transporter studies are required to confirm clinical relevance[51] Overall, acute safety data are reassuring, but gaps remain—systematic sub-chronic/long-term toxicology, reproductive-toxicity panels, standardized dose–response safety margins, and controlled herb–drug interaction studies are necessary before clinical applications can be recommended.

8. LIMITATIONS OF EXISTING RESEARCH

Despite an expanding literature on *Caesalpinia pulcherrima*, several clear limitations constrain translation of preclinical findings. First, there is a pervasive lack of standardized extracts: studies use heterogeneous plant parts, solvents, concentrations and extraction procedures, which prevents direct comparison and meta-analysis of bioactivity data[1] Second, mechanistic depth is often insufficient; many reports document phenotypic effects (antioxidant, antimicrobial, cytotoxic) without rigorous target validation, pathway analysis, or orthogonal confirmation (e.g., knockdown/overexpression, enzyme assays) to substantiate proposed modes of action[57] Third, clinical evidence is effectively absent—searches and recent comprehensive reviews report few if any controlled human trials for *C. pulcherrima*, leaving a translational gap between *in vitro/in vivo* promise and clinical applicability. Fourth, experimental models and reporting standards vary widely (differing animal species, doses, assay conditions, and outcome measures), producing inconsistent datasets and limiting reproducibility[1, 58] Finally, quality control and chemo profiling are emergent rather than routine: few studies provide validated HPLC or LC–MS quantitative markers and seasonal/geographical chemo variation data are sparse, complicating efforts to define safe, efficacious, and reproducible preparations for further development[2, 59] Addressing these limitations is essential to move from exploratory studies to mechanistic pharmacology and clinical evaluation.

9. FUTURE PERSPECTIVES

To advance *C. pulcherrima* toward translational applications, a prioritized, methodical research agenda is needed. First, modern metabolomics (LC–MS/MS, UHPLC-QTOF, NMR) should be applied systematically across seasons, geographies and plant parts to generate reproducible chemical fingerprints that underpin standardised HPLC/DAD marker assays for quality control[57,59] Second, adoption of HPLC-based metabolomic fingerprinting and validated marker quantification will enable batch-to-batch standardization and facilitate regulatory-grade dossier development[58] Third, bioactivity-guided fractionation should be integrated with target-based mechanistic studies (enzyme assays, target engagement, pathway perturbation) and orthogonal validation (siRNA/CRISPR, biochemical assays) to convert phenotypic hits into tractable lead molecules[2] Fourth, nano-formulation and delivery strategies (e.g., polymeric nanoparticles, lipid carriers, phytosome systems), already explored in related plant systems and for green-synthesised metal nanoparticles using *C. pulcherrima* extracts, offer routes to improve solubility, bioavailability and targeted delivery of lipophilic diterpenoids and flavonoids[60,61] Finally, early-phase clinical translational work—beginning with well-designed Phase I safety and pharmacokinetic studies using standardized extracts or characterized lead compounds—must follow robust preclinical ADME/Tox profiling to bridge laboratory promise with human therapeutic evaluation[62] Collectively, these steps will create the reproducible evidence base necessary for

responsible development of *C. pulcherrima*-derived therapeutics.

10. CONCLUSION

Caesalpinia pulcherrima demonstrates a rich and diverse phytochemical profile, including cassane-type diterpenoids, flavonoids, phenolics, and alkaloids, many of which exhibit significant pharmacological promise. Experimental evidence supports antimicrobial, anti-inflammatory, antioxidant, anticancer, antidiabetic, cardioprotective, and neuroprotective activities, alongside emerging insights from *in silico* analyses. Despite these strengths, the plant remains under-translated due to limited mechanistic validation, non-standardized extracts, and absence of clinical trials. Advancing this lead medicinal plant will require rigorous metabolomic profiling, standardized phytochemical markers, mechanistic assays, safety evaluation, and early-phase human studies. Collectively, these steps may position *C. pulcherrima* as a promising natural source for future therapeutic development.

ETHICAL APPROVAL

This study is based entirely on previously published data and does not involve any human or animal experimentation.

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