INFORMATICS JOURNALS

Short Review

Journal of Natural Remedies
DOI: 10.18311/jnr/2026/55088

eISSN: 2320-3358 | Vol 26(6), 2026 | pp. 1593-1608

Unraveling the Pharmacognostic and Mechanistic Landscape of *Bombax ceiba* L.: Exploring its Phytoconstituents and Therapeutic Potentials

Shagun Pathania, Avijit Mazumder* and Saumya Das

Noida Institute of Engineering and Technology (Pharmacy Institute), Knowledge Park-II, Greater Noida - 201306, Uttar Pradesh, India; avijitmazum@gmail.com

Abstract

Background: *Bombax ceiba* (*B. ceiba*) L. is an important plant in the Malvaceae family, widely distributed across tropical and subtropical areas of Africa, Asia and Australia. The medicinal properties of the plant are highly valued under various forms of traditional medicines such as *Ayurveda*, Siddha, Unani, and others. It has been used to treat gastrointestinal, skin, urinary, and wound-healing ailments for a long time. The experimental literature is increasingly becoming popular, but a focused integration linking pharmacognostic identity to mechanistic pharmacology is largely missing. **Aim:** The objective of the mini-review is to combine classical pharmacognosy with molecular pharmacology of *B. ceiba*. As a future orientation in drug development, the morphological authentication, phytochemical characterisation and diversity and the experimentally deciphered bioactivities together with the impact of innovative nano-formulation may be brought into a unified document defined in a "bench-to-biological-pathway". **Methods:** The pharmacognostic characterisation, herbal medicine and ethnopharmacology, phytochemistry, and pharmacology of species belonging to the genus Bombax, specifically *B. ceiba*, were systematically reviewed. This allowed us to assess its medical utility and market potential in the context of a rapidly evolving functional food industry. Relevant information was included in an operational model of pharmacognosy phytochemistry mechanism. **Result:** Stigmasterol, β-amyrin palmitate, lupeol palmitate, and malvalic acid are compounds purified from the parts of *B. ceiba*. The plant is abundantly loaded with lupeol, mangiferin, β-sitosterol, quercetin and its derivatives, shamimin, anthocyanins, naphthoquinones, and others and also possesses a vast scope of applications in cosmetics, pharmacy, and food industry. **Conclusion:** *B. ceiba* emerges as a good multi-target ethnomedicine; it has pharmacognostic identity and good pharmacological preclinical evidence. According to findings, there is a correlation between conventional uses and modulation of the NF-κB, Nrf2, MAPK, and AMPK pathways Consequently, it seems likely a good candidate for phytopharmaceutical preparation. In future perspective, it is important to establish protocols for extracting the plant, study pharmacokinetic, and implement controlled clinical trials to transform this wealth into evidence-based and easily perceptible therapeutic agents.

Major Findings: *B. ceiba* L. covers key bioactives — lupeol, mangiferin, β-sitosterol, and quercetin derivatives — that modulate NF-*κB*, Nrf2, MAPK, and AMPK pathways, granting anti-inflammatory, antioxidant, hepatoprotective, and antidiabetic activities, though the absence of controlled clinical trials and standardised extracts remains a critical translational gap demanding systematic pharmacokinetic and clinical validation.

Keywords: Antioxidant, Anti-inflammatory, *Bombax ceiba* L., Herbal Formulation, Nano Particles, NF-κB pathway, Phytoconstituents

List of Abbreviations: AMPK: Activated Protein Kinase; AST/ALT/ALP: Aspartate Transaminase/Alanine Transaminase/ Alkaline Phosphatase; *B. ceiba*: *Bombax ceiba*; CAT: Catalase; COX-2: Cyclooxygenase-2; EAC: Ehrlich Ascites Carcinoma; GPx: Glutathione Peroxidase; HCHFD: High Carbohydrate High Fat Diet; HO-1: Heme Oxygenase-1; HPTLC: High-Performance Thin Layer Chromatography; IL-6/IL-1β: Interleukin-6/Interleukin-1β; iNOS: Inducible Nitric Oxide Synthase; MAPK: Mitogen Activated Protein Kinase; NFκB: Nuclear Factor kappa-light-chain-enhancer of activated B cells; NQO1: NAD(P)H Quinone Dehydrogenase 1; Nrf2: Nuclear factor erythroid 2-related factor 2; PI3K/Akt: Phosphoinositide-3-kinase/Protein kinase B signaling; PPAR-γ: Peroxisome Proliferator-Activated Receptor gamma; ROS: Reactive Oxygen Species; SAR: Structure-Activity Relationship; SOD: Superoxide Dismutase; TFC: Total Flavonoid Content; TNF-α: Tumor Necrosis Factor-alpha; TPC: Total Phenolic Content.

(Article Chronicle: Article Received on: 25.02.2026; Revised on: 28.04.2026; Accepted on: 12.05.2026)

*Author for correspondence

1. Introduction

Medicinal plants play a significant role in the discovery of bioactive compounds and the identification of novel therapeutic targets across disease spectra. The red silk-cotton or semal tree, *B. ceiba* L. (family *Malvaceae*, formerly *Bombacaceae*), is a versatile ethnomedicinal plant, highly valued for its numerous pharmacognostic and therapeutic properties. *B. ceiba* is widely distributed throughout tropical and subtropical Asia, Africa, and Australia, thriving in deciduous forests and riverine zones up to 1500 m altitude, with its bright crimson flowers and towering habit marking a distinct seasonal landscape[1]. The plant is highly valued for its astringent, cooling, aphrodisiac, demulcent, and tonic properties in traditional systems including *Ayurveda*, *Siddha*, and *Unani*[2]. The classical *Ayurvedic* texts highlight its application in diseases such as dysentery, wounds, skin diseases, diarrhea, and urinary disorders, while tribal pharmacopoeias utilise its gum, roots, flowers, and thorns in a variety of formulation[3,4].

Recent phytochemical researches have unraveled the plant as a source of bioactive metabolites such as lupeol, shamimin, anthocyanins, quercetin derivatives, isohemigossylic acid lactones, mangiferin, and naphthoquinones, exhibiting anti-inflammatory, antioxidant, hepatoprotective, antidiabetic, antihypertensive, and antiangiogenic activities[5]. In the last six years, because of growing global interest in validation through detailed mechanistic pharmacology, *B. ceiba* has emerged as a promising candidate for modern phytopharmaceutical research. Bombax belongs to the subfamily Bombacoideae, which is known for its high diversity of polyphenols, terpenoids, and flavonoids with established bio-functional importance[6]. Despite an increasing number of isolated compounds and experimental pharmacology reports, a consolidated understanding that interlinks its pharmacognostic profile with mechanistic insights into therapeutic translation largely remains fragmented.

Therefore, an integrated review that bridges the gap between classical pharmacognosy and mechanistic biological evidence of *B. ceiba* is timely and pertinent. This synthesis intends to (i) summarise the traditional and morphological features of *B. ceiba* related to pharmacognostic authentication; (ii) explain its phytochemical spectrum and bioactive compounds isolated; (iii) analyse the experimentally established pharmacological mechanisms and molecular signaling pathways; and (iv) discuss available formulations and translational prospects in modern therapeutics.

The novelty of this mini-review lies in an attempt to correlate the pharmacognostic parameters with mechanistic pharmacology, providing a holistic "bench-to-biological-pathway" outlook, different from previous descriptive phytochemical overviews reported. By unraveling the interconnected molecular, cellular, and phytochemical landscape of *B. ceiba*, this article proposes a rational framework for future drug-development strategies, bioguided isolation, and standardised herbal formulations based on traditional wisdom and nano formulations based on modern pharmacological science.

1.1 Conceptual Integration: From Pharmacognostic Identity to Molecular Therapeutics

Although *B. ceiba* L. has been widely documented for its ethnomedicinal uses and phytochemical contents, most reports focus on pharmacognostic characterisation, phytochemical profiling and standardisation and pharmacological activities as separate topics. The present review introduces a unified concept-based framework. including prior pharmacognostic descriptors, phytochemical clustering as well as experimentally validated molecular mechanisms.

Different parts of *B ceiba* exhibit characteristic pharmacognostic markers and correlated main phytochemical classes along with their reported multiple molecular targets of action. Unlike acting through isolated mechanisms, *B. ceiba* operates through multi-target mechanisms and exerts a coordinated modulation of inflammatory, antioxidant and metabolic pathways.

This pharmacognostic-phytochemical-mechanistic correlation provides a systems-level explanation that explains the wide range of ethnomedicinal activity and multi-target relevance in phytopharmacology. By explicitly associating botanical identity to pathway-specific biological effect, this integrative model extends beyond descriptive reviews and provides a mechanistic foundation for bioguided fractionation, formulation development, and therapeutic repositioning strategies in relation to the *B. ceiba*-based phytopharmaceuticals.

2. Botanical and Pharmacognostic Overview

2.1 Botanical Description

Bombax ceiba L. (Family *Malvaceae*, formerly *Bombacaceae*), commonly known as Red Silk Cotton Tree or Semal. It is a very large, deciduous light demander of a fast-growing tree that is distributed throughout the tropical and subtropical regions, including India, Sri Lanka, Bangladesh, Malaysia, Myanmar, Java and Sumatra[7]. The tree grows to a height of 30-40 m and is readily identified by its stout conical woody spines on the thick, straight bole and flowering appearance, as shown in Figures 1 and 2[8]. Taxonomical classification and biological characterisation of *B. ceiba* is summarised in Table 1.

2.2 Macroscopic and Microscopic Pharmacognostic Characters

A number of diagnostic macroscopic features, useful in the botanical identification of *B. ceiba*, may be observed in its aerial parts. The bark is gray-colored, bearing conspicuous prickles on the surface of the trunk, which has been considered a distinguishing feature. Large, showy flowers are borne terminally on leafless branches. The seed pods contain floss-like fibres that are usually collected during the fruiting season. These features are thus important as the basis for initial taxonomic identification and quality control assessments in crude drug evaluation[9,10].

Microscopic examination of the tissues of *B. ceiba* indicates cellular structures characteristic of some plant species[11]. Tests using the mucilage from petals show the presence of typical polysaccharide complexes, consisting of sugar and uronic acid units. The mucilage also shows typical histochemical reactions, such as positive staining with ruthenium red, by which a typical red colouration appears that confirms its identity. Microscopical investigations of tissues show the presence of different cells and tissue arrangements typical of this species. The FT-IR spectrum of isolated mucilage from flower petals presents spectral lines at 1018, 1247, 1455, 1574, 1734, 2923 and 3280 cm^{-1}, indicating the presence of functional groups such as lactone rings, hydroxyl groups (-OH), carboxylic acid groups (-COOH), and carbon-oxygen stretching (-C-O), confirming the polysaccharidic nature of the crude material[11].

Young roots have the following features: a poorly developed xylem, a wide cortex containing starch grains, rosette, and cluster crystals, and prominent mucilage cavities distributed throughout the tissue. However, mature root anatomy presents well-developed secondary xylem with lignified fibres, distinct medullary rays, and reduced cortical thickness[12].

2.3 Phytochemical Screening Overview

Qualitative phytochemical screening of various parts of the *B. ceiba* plant using different extraction solvents showed the presence of various secondary metabolites (Table 2). Thirteen major phytochemical classes, such as steroids, phytosterols, tannins, coumarins,



Figure 1. Tree of *B. ceiba*.



Figure 2. Tree of *B. ceiba* in flowering season.

Table 1. Taxonomical classification and biological characterisation of *B. ceiba*

Kingdom	Plantae
Subkingdom	*Tracheobionta*
Division	*Magnoliophyta*
Class	*Magnoliopsida*
Order	*Malvales*
Family	*Malvaceae* (*Bombacaceae*)
Genus	*Bombax*
Species	*Bombax ceiba* L
Chromosome number	n = 48, 2n = 96
Genome assembly	783.55 Mb
Distribution	Tropical and subtropical Asia, Africa and Australia
Habit	Large, deciduous tree, up to 30-40 m tall, trunk diameter up to 3 m
Leaves	Palmate, compound, deciduous
Flower	Large, showy, red/orange/yellow, pentamerous, high ornamental value
Fruit/ Fibre	Capsule with silky fibres (kapok), used in textiles (Figure 3)
Bark external morphology and anatomy	Grey-coloured with prominent prickles (Figure 4). Contains cork cells, lignified fibres, calcium oxalate crystals, xylem vessels
Physiology	High resistance to drought, heat, pollution; efficient antioxidant enzyme system
Physiochemistry	Rich in phenolics, flavonoids, tannins, alkaloids, glycosides, sesquiterpenoids, steroids, naphthoquinones
Ecological role	Pioneer species, improves soil nutrients, supports agroforestry
Medicinal uses	Traditional medicine for fever, inflammation, ulcers, hepatotoxicity, anthelmintic, *etc.*

phlobatannins, flavonoids, carbohydrates, reducing sugars, amino acids, proteins, glycosides, terpenoids, and phenolic compounds, were identified using acetone-water and chloroform extracts. The flower parts exclusively contain ten flavonoids, including quercetin, rutin, vitexin, and isovitexin; three xanthones, represented by mangiferin and its derivatives; and four coumarins, namely esculetin, scopoletin, and fraxetin, besides several other

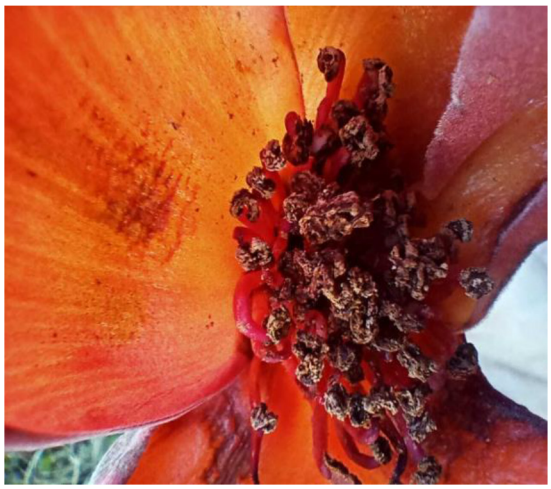


Figure 3. Flower of *B. ceiba*.



Figure 4. Stem bark of *B. ceiba*.

bioactive principles such as phenolic and aromatic acids[10,13]. Surprisingly, these bioactive constituents are absent in the ethyl acetate and chloroform extracts; this reveals that the chosen extraction solvent may substantially affect the yield of the phytochemicals[14,15]. Quantitative analyses reveal higher concentrations of these compounds in polar solvents, especially water and ethanol, with the majority contained in leaves and flowers. The TPC and TFC in flower and leaf extracts from the plants were determined to be as high as 120.33 mg/g and 60.77 mg/g, respectively, in water extracts[14,16]. These elaborated results highlight the rich phytochemical profile the plant possesses, which forms the basis for its applications in traditional medicine and other pharmaceutical uses.

2.4 Crude Drug Standards

Pharmacognostical standardisation of the crude material of *B. ceiba* requires certain physicochemical parameters. Ash value, extractive values and morphological features are accurate parameters that help in reliable identification and standardisation[17]. The mucilage isolated from its flower petals exhibited a Loss on Drying value of 1.34%, pH of 7.13 in an aqueous solution, and a swelling ratio of 30 in distilled water. Its micromeritic properties were determined to show Carr's Index at 13.79±0.031, Hausner's ratio at 1.12±0.022, and angle of repose at 24.8±0.121, indicating its good flow property, thus suitable for pharmaceutical purposes. These standards, apart from ash values and determination of moisture content, set the quality control benchmarks so important in terms of ensuring consistency and authenticity in herbal preparations and support the safe and effective use of *B. ceiba* in both traditional and modern medicine[10,11].

3. Phytochemical and Phytoconstituent Profile

3.1 Major Classes of Phytochemicals

The phytochemical constituents identified from various parts of *B. ceiba* mainly include flavonoids, tannins, triterpenoids, polysaccharides and aromatic phenolic constituents crucial for diverse pharmacological applications (Figure 5).

3.1.1 Flavonoids

These are polyphenolic compounds possessing medicinal properties including anti-inflammatory, antioxidant, antidiabetic and cardioprotective activities. Shamimin, quercetin, kaempferol and some flavonoid glycosides are specific flavonoids that have been detected within *B. ceiba* parts like flowers and leaves, contributing significantly to hydrogen scavenging and regulation of inflammatory cytokines[24,25].

3.1.2 Alkaloids

They are reported as a predominant class of phytoconstituents in leaves, bark, root, flowers and fruit of *B. ceiba*. The alkaloid content has been reported to occur for up to 1.52% (stem bark), and this is also indicative of the presence of moderate levels in leaves and roots as well. Alkaloids of *B. ceiba* have analgesic, antimicrobial and neuroprotective properties[20,26].

3.1.3 Sterols

A major class of phytoconstituents in different parts of *B. ceiba* are sterols, and also, they are partly responsible for much of the pharmacological effects. Detailed phytochemical work has revealed the existence of sterols, including β-sitosterol linoleate, β-amyrin, lupeol and stigmasterol acetate, with higher amounts of β-amyrin and lupeol in leaves and other parts. Phytosterols are commonly found in its leaves and flowers, with β-sitosterol known for the hypolipidemic, anti-inflammatory and hormone-like activities[27–29].

3.1.4 Triterpenes

These are a group of phytochemicals, isolated from different parts of *B. ceiba,* including leaves, bark and stem. Major triterpenes identified are β-amyrin, lupeol, β- amyrin acetate, β-amyrin palmitate and β-amyrone, with β-amyrin being most often the dominant compound and accounting for up to 45% in leaf extract's triterpenoid content. For example, lupeol shows significant activity against inflammatory mediators like COX-2, and its structural characterisation has been well established by sophisticated methodologies[26,28,30].

Table 2. Comparison of phytochemical content and biological activity across *B. ceiba* plant parts

Plant Part	Major phytochemicals (Qualitative)	Highest Quantitative content (mg/g or %)	Biological activity	References
Flower	Flavonoids, phenolics, tannins	TPC: 120.33, TFC: 60.77 (water extract)	Antioxidant, antidiabetic	16,18,19
Leaf	Flavonoids, saponins, tannins	TPC: 7.38, TFC: 3.20 (ethanol extract)	Antioxidant, antimicrobial	14,20,21
Bark	Phenols, flavonoids, tannins	TPC: 6.27, TFC: 2.60 (ethanol extract)	Antioxidant, anti-inflammatory	18,20
Root	Saponins, reducing sugars	Saponins: 1.37%	Antibacterial	18,22
Thorn	Flavonoids, sterols, tannins	-	Antioxidant, antifungal	14,23

3.1.5 Phenols

Bombax ceiba is well known to be rich in phenolic compounds like phenolic acids and tannins present in different parts of the plant (including flowers, leaves, bark, roots, and thorns). There are reviewed the oxidative stress inhibition and the increasing or decreasing expression of the cellular antioxidant defence system, as well as anti-inflammatory, antidiabetic and antimicrobial activities[21,29].

Other than the commonly reported compounds like haematoxylan, flavonoids, tannins, triterpenoids, polysaccharides and aromatic phenolic components, it bears a variety of other compounds too. They contain shamimicin, lupeol, quercetin, hentriacontane, rutin, anthocyanin, vicenin, fraxetin; and many glycosides, of which arequereitn-3-O -β-D-glucurono pyranoside and kaempferol-3-O-β-D-glucuronopyranoside. Other important constituents are scopolin, iso-mangiferin, and mangiferin itself, as well as esculetin; scopoletin and a series of other complex organic acids and derivatives. These substances exist in different plant parts such as root, bark, stem and flower[20].

3.2 Isolation of Compounds

There are several bioactive constituents screened from various parts of *B. ceiba*, possessing pharmacological activities:

3.2.1 Bombaxquinone

Bombaxquinone, a naphthoquinone from *B. ceiba*. It is a member of a family of bioactive compounds with antibacterial and anticancer activity. Its isolation consists of plant parts extraction and purification methods, including chromatographic methods (*e.g.*, quinones like bombaxquinone can be separated, and the compound purified from different part of the like roots, seeds or bark). Its isolation reveals that the phytochemical diversity of *B. ceiba* could be an attractive source for exploring therapeutic leads[31,32].

3.2.2 Lupeol

About 0.359% of lupeol (a pentacyclic triterpene) is present in the *B. ceiba* stem bark[33]. It is found in a gum (polysaccharide) of the plant along with other compounds like tannic acid, beta-sitosterol, and

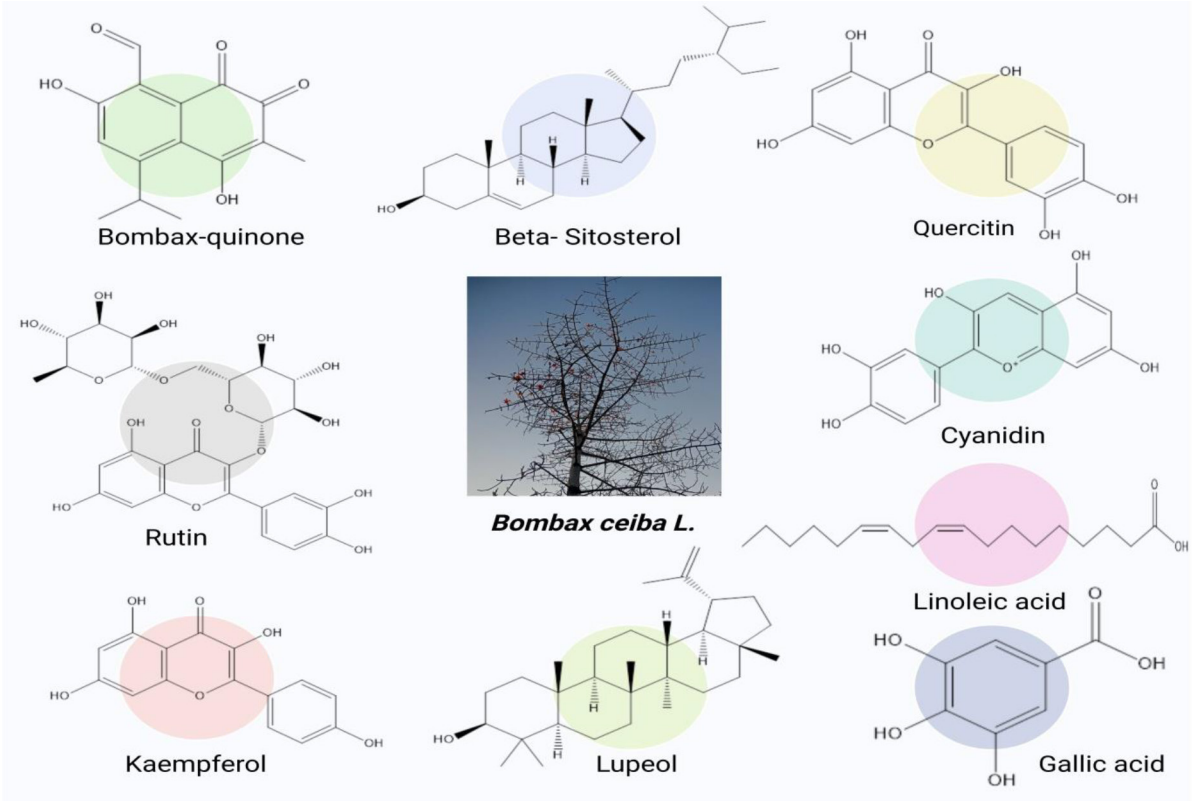


Figure 5. Major Phytoconstituents present in root, stem, bark and flower of *B. ceiba* L.

catechutannic acid[34]. The dried powder of stem bark was extracted with methanol by using a process of isolation. This methanol extract is passed through silica gel chromatography, eluted with petroleum ether and ethyl acetate gradient. Fractions that contain lupeol are detected and purified by recrystallisation from methanol to obtain pure lupeol[35]. Pharmacologically, by providing bone remodelling and oestrogenic modulation properties like gallic acid and beta-sitosterol, lupeol may have the therapeutic affinity of treating osteoporosis[36].

3.2.3 β-sitosterol

Beta-sitosterol is present in *B. ceiba*, in the flowers and the petroleum ether extract of stem bark, and in the gum exudate from the stem bark[37]. To perform the isolation, beta-sitosterol was estimated in the petroleum ether extract of *B. ceiba* stem bark by HPTLC and was found to contain 3.806% w/w[38]. Therapeutically, beta-sitosterol, along with lupeol and gallic acid, is reported to be responsible for anti-osteoporotic activity in *B. ceiba* stem bark[39].

4. Pharmacological and Mechanistic Landscape

Bombax ceiba L. is known to exhibit a vast range of pharmacological activities , which may be attributed to the presence of diverse phytoconstituents (alkaloids, saponins, tannins, phenols and flavonoids), as evidenced by experimental and preclinical studies[40]. Effects of its bioactive phytoconstituents are moderated by several molecular pathways like NF-κB, Nrf2, AMPK, COX and MAPK that collectively support its therapeutic potential against antiulcer, anti-inflammatory, antioxidant, hepatoprotective, wound healing, antidiabetic and antimicrobial spectrums (Figure 6)[41].

4.1 Anti-inflammatory Activity

Bombax ceiba L. exerts significant anti-inflammatory activities that are mediated by bioactive chemical entities such as mangiferin, quercetin and β-sitosterol, mainly through the mediation of NF-κB and MAPK signalling pathways[42–44]. *In vivo* or *in silico* models have been applied to assess the anti-inflammatory activity, such as the carrageenan-induced paw oedema model; however, lack of pharmacokinetic data is a significant restriction[45]. Activation of these transduction pathways triggers the release of inflammatory cytokines (including TNF-α, IL-6 and IL-1 β) and enzymes including COX-2 as well as iNOS. Inhibition of TLR4/NF-κB signalling decreases the nuclear transfer of NF-κB, resulting in the reduction of the production of inflammatory mediators[44].

NF-κB Pathway: Inhibition of the TLR4/NF-κB signalling pathway inhibits IκBα degradation, thus preventing NF-κB from entering into the nucleus and inhibiting the secretion of pro-inflammatory cytokines such as tumour necrosis factor-alpha (TNF-α), interleukin-6 (IL-6) and IL-1β[46,47]. Natural products, such as *B. ceiba*, act on this pathway to produce a broad spectrum of anti-inflammatory effects that may allow better safety and effectiveness than synthetic drugs.

MAPK Pathway: Suppression of MAPK pathways such as JNK and p38, which limit the cellular reactions to oxidative stress and inflammation-inducing agents or activators, e.g. LPS (lipopolysaccharides)[48].

4.2 Antioxidant Activity

Bombax ceiba extracts contain polyphenolic compounds, anthocyanins and flavonoids, which mediate its antioxidant properties, alleviating oxidative stress through scavenging of ROS and restoring cellular equilibrium of redox homeostasis[49]. The antioxidant activity may have been studied *in vitro*, *in vivo*, or *in silico*, with the evaluation of antiproliferative activity against EAC cells in mice, using target validation as the primary limitation[50].

4.2.1 Nrf2 Pathway

It is a redox sensor and stress-responsive transcription factor that has emerged as an important regulator of the redox system, cellular homeostasis and an adaptive response to oxidative stress. Imbalance in the redox system is one of the triggering factors for disease development and progression.[51]. The bioactive molecules that dissociate Nrf2 from Keap1 translocate to the nucleus, negative modulates NF-κB pathway and decreasing pro-inflammatory cytokines TNF-α and IL-6 and improve the antioxidant state by increasing nuclear translocation of Nrf2 and upregulation of antioxidative enzymes including GPx, HO-1, NQO1, CAT and SOD.[52,53].

4.3 Wound Healing

The wound healing potential of *B. ceiba* is reinforced by astringent and antimicrobial activity of its polyphenolic content along with activation of collagen synthesis pathways[54]. Studies have demonstrated wound healing effects of methanolic extract from *B. ceiba* leaves and flowers in experimental settings. 2% and 5% (w/w) of the extract in ointment bases promoted wound contraction, decreased epithelialisation period, and accelerated tensile strength in both excisional and incision wound models in rats[55,56]. The underlying mechanisms partly include the modulation of several signalling pathways, such as AMPK, Nrf2, MAPK, PI3K/Akt and NF-κB. Activation of AMPK promotes autophagy and ferritinophagy to eliminate senescent cells and facilitate tissue repair[57].

4.4 Hepatoprotective Activity

The methanolic extract of *B. ceiba* has hepatoprotective activity by virtue of its antioxidant activity especially at carbon tetrachloride (CCl4) induced into rats and is ideal admixed with the mitigated effect on liver enzymes such as GOT, GPT, ALP, Bilirubin and TG, along with heart glutathione concentration were significantly restored to near normal level in the BCE (*B. ceiba* extract) treated group compared to those that received CCl4 alone. It also reduced histological lesions like hepatocellular degeneration and collagen deposition[58]. Furthermore, BCE treatment can significantly decrease body and liver weights, normalise the levels of liver enzymes (AST, ALT and ALP) activities in serum, increase hepatic antioxidant parameters such as GSH, GST, SOD and CAT; meanwhile, decrease levels of MDA (malinodialdehyde)[59]. In the ethanol plus moderate-fat diet and high-carbohydrate high-fat diet models, flower and leaf extracts (200-400 mg/kg) downregulated hepatic enzymes, improved the lipid profile, enhanced antioxidant status, improving steatosis and inflammation[60,61]. Young-root ethanolic extract (400 mg/kg) in alloxan-diabetic mice also diminished SGOT/SGPT and promoted lipids, suggesting hepatoprotection against diabetes induced liver toxicity[62].

Despite the strength of these preclinical data, the translational gap is large: there are no human clinical trials; optimal dose and standardised preparations are unknown; long-term safety is untested; yet all evidence rests in controlled animal experiments, which may not entirely predict efficacy or toxicity in patients.

4.5 Anti-diabetic Activity

Bombax ceiba has great potential as an antidiabetic, mainly due to its inhibitory action on α-glucosidase (AG) and α-amylase (AMY), essential enzymes in carbohydrate digestion[43]. The antidiabetic activity of *B. ceiba* is mediated by its phytoconstituents such as mangiferin and saponins, mainly through regulation of glucose metabolism and insulin signalling pathways. *B. ceiba* lowers fasting blood glucose, improves lipid profile, and protects pancreatic β-cells probably by antioxidant action and insulin secretion modulation. Activation of AMPK increases the uptake of glucose into peripheral tissues and sensitises them to insulin by affecting the trafficking of GLUT4[63]. Reduction of oxidative stress is also achieved by the regulation of Nox4 and mitochondrial function in the case of diabetic neuropathy[64].

Bombax ceiba has been pharmacologically confirmed for antidiabetic activity mostly in preclinical models. The methanolic leaf extract of *B. ceiba* elicited a marked reduction in blood glucose caused by glucose-induced hyperglycemia in a mouse model. After glucose loading, there were statistically significant hypoglycemic activities at 1st, 2nd and 3rd hours, where both doses of the methanolic crude extract of *B. ceiba* were administered (200 mg/kg bw and 400 mg/kg bw). Therefore, the observed hypoglycaemic effect in *B. ceiba* leaf extract could be related to the presence of potential antidiabetic phytoconstituents[65].

4.6 Antimicrobial Activity

Bombax ceiba leaves are rich in phytochemicals like alkaloids, phenols, tannins, saponins and carbohydrates that may be responsible for the antimicrobial activity, specifically with solvents influencing this property to a greater or lesser degree. The disc-diffusion method was used to examine this activity. The maximum antimicrobial inhibition zone of 25.33 mm was observed with *B. ceiba* leaf ethanol extracts against *Pseudomonas aeruginosa*[66].

Because of the diversified pharmacological properties shown by *B. ceiba*, it is important to identify which aspect of treatment is prioritised for beneficial translational research. The combination of

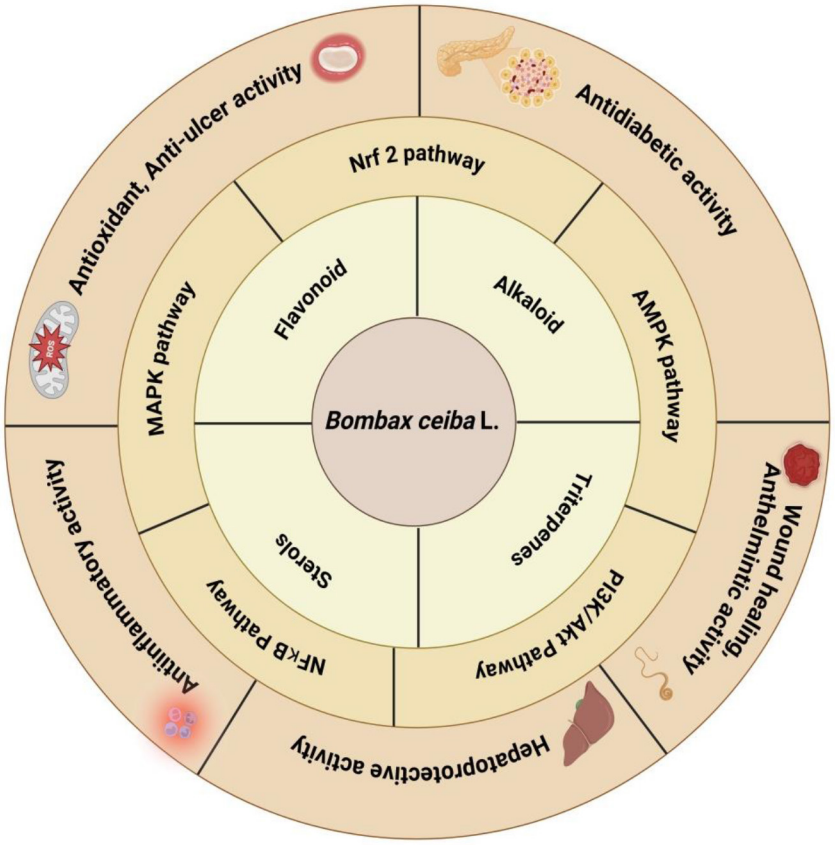


Figure 6. Mechanistic and Therapeutic Profile of *B. ceiba* L.

ethnopharmacological relevance with mechanistic and experimental evidence indicates that diseases induced by inflammation, oxidative stress, and metabolic disarray may be the best candidates. The simultaneous optimisation of Nf-κB, Nrf2, and AMPK as major signalling cross-networks represents a molecular rationale for subsequent studies on chronic inflammatory diseases, metabolic dysregulation-involved disorders, and retarded wound healing.

4.7 Strength of Evidence and Translational Limitations

Despite extensive experimental evidence about the pharmacological efficacy of *B. ceiba*, confidence in general is moderate in therapeutic indications. Most of the activity is predicated on *in vitro* screens or short-term *in vivo* animal models, predominantly using acute or chemically induced disease paradigms. While these models are useful for understanding mechanism, they have limited ability to predict chronic human diseases.

A major limitation across studies is the lack of standardised extracts, low dose normalisation, and no link between pharmacokinetic and pharmacodynamic effects. Moreover, only a limited number of investigations isolate and validate single bioactive components responsible for these *in vivo* activities making it difficult to describe a well-defined activity to some compounds or chemical families. The chronic toxicity, potential herb- drug interaction and the long-term safety profile are commonly uninvestigated.

However, despite substantial ethnomedicinal evidence and potential preclinical efficacy no controlled clinical trials have demonstrated the therapeutic effectiveness of *B. ceiba* in human populations. These deficiencies identify the importance of well-designed translational studies involving standardised phytochemical profiling, mechanistic biomarkers and clinical outcomes.

5. Ethnopharmacological Relevance

Bombax ceiba L., also known as Mochrus and has been of considerable ethnopharmacological importance in *Unani*, *Ayurvedic* and other indigenous systems

of medicine worldwide (Asia, Africa and Australia). Various parts of the plant as well as its exudates, are used for different types of medicinal treatments[67,68]. The traditional medicinal values of *B. ceiba*, were denoted as ethnopharmacological importance (EP) and is due to usage pattern by local individuals itself that mainly belong to region Panchmahal. In the light of above traditional knowledge and available literature, the plant represented an important medicinal value. Root, flower, gum, leaf, prickles, stem bark of fruit seed and heartwood on *B. ceiba* are used in food among indigenous community/forest dwellers to address diverse diseases. Its anti-diarrheal, anti-boil, wound healing, anti-leprosy and acne activities have been documented through ethnobotanical studies. It has traditionally been used as an anthelmintic[17,31]. Ethnobotanical studies reveal its medicinal value for asthma, impotency, leprosy, pimples and other skin diseases. Modern pharmacological studies on this plant are in line with its uses, with an array of activities such as hypotensive, antioxidant, analgesic and anti-inflammatory, antipyretic, antibacterial, cytotoxic, hepatoprotective, diuretic, anthelmintic, anticancer, spermatogenic and anti-helicobacter pylori. These results support its traditional uses in classical medicine[1,67]

6. Herbal Formulations and Experimental Developments

Bombax ceiba is widely applied in traditional medicine and has been incorporated into different commercial or experimental formulations such as herbal tonics, wound ointments and advanced delivery systems[81]. Various parts of *B. ceiba,* including leaf, flower, bark and gum, have been formulated into decoctions, pastes, powder and topical preparations possessing different therapeutic properties[69]. The detailed phytoconstituents, mechanism of action, therapeutic applications and herbal formulations of *B. ceiba* are summarised in Table 3.

7. Nano Formulations

7.1 Rationale and Challenges of Nano-formulation Strategies

In the recent past, efforts have been concentrated on validation of pharmacological actions and bioavailability enhancement by employing novel formulations like nanoparticles. Specifically, *B. ceiba*-based nanoparticles (BcNPs) have demonstrated therapeutic potential against various diseases[77] as summarised in Table 4. The extract of *B. ceiba* possesses a wide range of phytochemicals including flavonoids, tannins, phenols, terpenoids, steroids, carbohydrates and other secondary metabolites that are essential in the synthesis of these nanoparticles[78]. Nano-formulation techniques have recently been a promising strategy to overcome the crucial drawbacks of *B. ceiba* phytoconstituents like low aqueous solubility, chemical instability and poor oral aqueous bioavailability. Despite the high bioactivity, triterpenoids and polyphenols often exhibit rapid metabolism and poor systemic exposure, which suggests that nanoparticle-drug delivery systems should be studied further. This nano formulation approach holds immense potential in improving bioavailability, targeting efficiency and overall therapeutic efficacy[79].

However, the current nano-formulation research mainly concentrates on antimicrobial or antioxidant endpoints with little emphasis on *in vivo* pharmacokinetics and biodistribution of nanoparticles or their eventual safety[80,81]. In addition, nanotoxicological assessment, batch-to-batch reproducibility, and scalable production are the bottlenecks for clinical translation. Regulatory aspects around plant-mediated nanoparticles also need to be systematically assessed before medicinal application[82]. Therefore, although nano-formulations are a promising advancement, their translational potential will rely on thorough safety profiling, disease-specific targeting approaches and compatibility with regulatory guidelines.

8. Future Perspectives

The emerging field of phytopharmacology emphasises the potential of *B. ceiba* as translational therapeutics. Hence, future research areas need a focus on (1) bioguided fractionation of extracts and establishment of structure activity relationship for highly potent bioactive compounds with therapeutic potential; (2) preclinical toxicology and safety for various promising molecules in the pathophysiological relevant disease model; (3)

Table 3. Tabulated Overview of phytoconstituents, mechanisms, therapeutic applications and herbal formulations of *B. ceiba*

Plant Part	Major Phyto constituents	Isolated Principal Constituents	Mechanism of Action	Signalling Pathway Involved	Pharmacological / Therapeutic Effects	Marketed Herbal Formulations	References
Roots	Lupeol, β-Sitosterol, Gallic acid, Tannins, Flavonoids	Lupeol, Beta-Sitosterol, Gallic acid	Inhibits COX, LOX, cytokines, Modulates lipid metabolism and ROS, Antioxidant and NF-κB suppression	NF-κB, MAPK, Nrf2/HO-1, PPAR-γ	Anti-inflammatory, anti-ulcer, hepatoprotective	Raw gum ("Mochras") decoction used for diarrhea and leucorrhea	18,45,49,70,71
Stem Bark	Phenolics, Flavonoids, Glycosides, Saponins, Steroids	Protocatechuic acid methyl ester, Lupeol, **β-Sitosterol**	Apoptosis induction and cytokine suppression	NF-κB, PI3K/Akt, Caspase-3, Nrf2/HO-1	Anti-inflammatory, antitumor, hepatoprotective	Bark extract studied for anti-diabetic effect	18,31,45,49,74
Leaves	Quercetin, Kaempferol, Rutin, Phenolic acids	Quercetin, Kaempferol	iNOS and ROS inhibition Enhances antioxidant enzymes, ↓ cytokines	Nrf2/ Keap1, PI3K/Akt	Anti-ulcer, immunomodulatory, anticancer, antidiabetic, anthelmintic	Methanolic leaf extract *in silico*-validated as NF-κB modulator	70,72,73
Flowers	Flavonoids (Quercetin, Cyanidin), Phenols, Tannins, Alkaloids, Polysaccharides	Cyanidin, Quercetin	Inhibits lipid peroxidation, enhances antioxidant defences, Nitric oxide inhibition, mitochondrial protection	PI3K/Akt, Nrf2/HO-1	Antioxidant, anti-inflammatory, anti-bacterial, aphrodisiac, menorrhagia	Simbal Flower Extract (market product), Shalmali *ghrita* (menstrual disorders)	18,31,45,49,71,74
Fruits / Seeds	Fatty acids (Linoleic, Oleic), β-Sitosterol	Linoleic acid, **β-Sitosterol**	Improves lipid profile, reduces oxidative damage, PPAR-γ activation	PPAR-γ, AMPK	Antihyperlipidemic, hepatoprotectiv, Boil treatment due to smallpox	Fruit extract effective against urolithiasis in rats Seed paste prepared in water	18,49,75,76
Thorns	Alkaloids, Flavonoids, Phenolics	Ethanolic thorn extract	Inhibits bacterial growth (*S. aureus*, *P. acnes*)	—	Antimicrobial, wound healing	Antibacterial gel and polyherbal mouth ulcer gel	75
Gum/ Exudate	Polysaccharides (Arabinose, Galactose, Rhamnose)	Mucilaginous polysaccharides	Physical protection of mucosa; demulcent	—	Anti-ulcer, soothing agent	Mochras raw gum used in *Ayurvedic* cough and GI formulations	75

pharmacokinetic and systemic delivery studies to offer optimal dosage regimen; (4) formulation development using quality by design approach for standardising preparation technology assuring consistent biological responses from plant extract/extracts derived biomolecule(s); (5) clinical validation of efficacy in inflammation, metabolism and microbial diseases. The combined network pharmacology and systems

Table 4. Characterisation and pharmacological activity of nanoparticle formulation of *B. ceiba*

Nano-formulation	Nanocarrier	Plant Part	Characterisation	Pharmacological effects	References
SeNPs	Selenium	Flower	Spherical nanoparticles, size ranges between 30-150 nm	Antibacterial, urea detection	[77]
Bc-AgNPs	Silver	Bark	Crystalline size of 26 nm with an average grain size of 59.8 nm	Antihaemolytic, antioxidant, anti-inflammatory	[83]
ZnO NPs	Zinc oxide	Stem	hexagonal crystalline structure with an average crystallite size of 14.086 nm (XRD), particle sizes of 16.08 nm (FESEM) and 17.89 nm (HRTEM)	Antibacterial, dye degradation	[84]
AuNPs	Gold	Flower	Spherical nanoparticles with a size range of 1nm	Antibacterial	[45]
NiO NPs	Nickle oxide	Leaf	Spherical nanoparticles with particle size range in between 14 and 35 nm	Antioxidant, antidiabetic, antibacterial	[85]
AgNPs	Silver	Thorn	Cylindrical-shaped nanoparticles with an average size of 20-30 nm	Antibacterial (anti-*Staphylococcus aureus*) activity	[86]

biology method will provide a polypharmacological system view. Furthermore, sustainable harvesting and ethnopharmacological validation in endemic regions will reinforce evidence-based incorporation into contemporary medicinal practices.

9. Conclusion

Bombax ceiba benefits from a remarkable alignment of ancient ethnomedicinal knowledge with modern molecular pharmacology and is among the most intriguing multi-target candidates within the Bombacoideae. This mini-review indicates that the breadth of therapeutic activities anti-inflammatory, antioxidant, hepatoprotective, antidiabetic, antimicrobial, and wound healing results from the coherent and coordinated modulation of key disease-relevant signalling networks of bioactives (e.g. lupeol, mangiferin, quercetin, shamimin, and β-sitosterol). These bioactives reduce chronic inflammation, re-establish redox homeostasis, improve insulin resistance, and enhance hepatic and tissue repair via their concerted action on the signalling networks involving NF-*κB*, Nrf2/Keap1, MAPK (JNK/p38), AMPK, and PI3K/Akt. Nanoparticles including silver, gold, zinc oxide, selenium and nickel oxide were synthesised by using *B. ceiba* extracts may be promising technologies to overcome the inherent limitations in bioavailability of its polyphenolic and triterpenoid components; however, there are several key translational hurdles which remain, including an overwhelming preclinial evidence base, a total lack of randomised controlled clinical trials, undefined standardised extract preparations, uncharacterised herb-drug interaction potential, and uninvestigated nanotoxicological safety profiles of nanoparticle biodistribution *in vivo*. To unlock the complete therapeutic potential of this plant, further research must consist of an integrated research pipeline. This study should include bioguided fractionation based on SAR. In addition, it has to involve Quality by Design. Furthermore, network pharmacology and multi-omics approaches for polypharmacological target validation will be essential. It will also include well-powered phase I/II clinical trials with defined efficacy endpoints in inflammatory disease, metabolic disease, and hepatic disease settings. Lastly, it must be anchored by sustainable wildcrafting and ethnopharmacological validation in endemic regions. The evidence collected here together proves *B. ceiba* tree as a novel phytopharmaceutical scaffold that combines mechanistic validation with pharmacognostic authentication and holds clinical promise, and warrants an urgent investment in robust translational research to fulfil demand from modern therapeutic practice.

10. Acknowledgement

Authors express their sincere gratitude to the management of Noida Institute of Engineering and

Technology, Pharmacy Institute, for their continuous support, motivation, enthusiasm, and immense knowledge.

11. References

1. Raigar R. *Bombax ceiba* plant. IP Int J Compr Adv Pharmacol. 2022; 7(1):1-4. https://doi.org/10.18231/j.ijcaap.2022.001
2. Chaudhary PH, Tawar MG. Pharmacognostic and phytopharmacological overview on *Bombax ceiba*. Syst Rev Pharm. 2018; 10(1):20-25. https://doi.org/10.5530/srp.2019.1.4
3. Gupta N, Sharma D, Rani R. *Bombax ceiba* Linn: a critical review on phytochemistry, traditional uses, pharmacology, and toxicity. Int J Pharm Pharm Sci. 2023; 15:8-15. https://doi.org/10.22159/ijpps.2023v15i1.46533
4. Jaffar HM, Rizwan B, Sukhera S, *et al*. Therapeutic properties of *Bombax ceiba*. Pak Biomed J. 2023; 6:8-15. https://doi.org/10.54393/pbmj.v6i04.865
5. Hassan M, Rasul A, Jabeen F, *et al*. *Bombax ceiba* extract as α-glucosidase inhibitor. J King Saud Univ Sci. 2024; 36(8):103267. https://doi.org/10.1016/j.jksus.2024.103267
6. Das G, Shin HS, Ningthoujam SS, *et al*. Plants of Bombacoideae: systematics and pharmacology. Plants. 2021; 10(4):651. https://doi.org/10.3390/plants10040651 PMid:33805546 PMCid:PMC8067233
7. Panwar A, Singh Y, Naik B. Nutritional and pharmacological benefits of *Bombax ceiba*. Pharma Innov J. 2020; 9(6):392-396
8. Wang Y, Zhang Y, Mao K, *et al*. Morphological responses of *Bombax ceiba*. Front Ecol Evol. 2023;10. https://doi.org/10.3389/fevo.2022.1118045
9. Refaat J, Desoky SY, Ramadan MA, *et al*. Bombacaceae: Phytochemical review. Pharm Biol. 2013; 51(1):100-130. https://doi.org/10.3109/13880209.2012.698286 PMid:22974340
10. Joshi KR, Devkota HP, Yahara S. Chemical analysis of *Bombax ceiba* flowers. Nat Prod Commun. 2013; 8(5). https://doi.org/10.1177/1934578X1300800508
11. Bhadkariya S, Patley C. Isolation and characterization of mucilage from *Bombax ceiba*. J Pharmacogn Phytochem. 2024; 13(2):215-219. https://doi.org/10.22271/phyto.2024.v13.i2c.14881
12. Parkhi VV, Dabhi SP, Acharya R, *et al*. Root evaluation of *Bombax ceiba*. J Drug Res *Ayurvedic* Sci. 2025; 10(5):360-374. https://doi.org/10.4103/jdras.jdras_18_24 PMid:35021273
13. Gupta P, Goyal R, Chauhan Y, *et al*. *Bombax ceiba* in obesity signaling. BMC Complement Altern Med. 2013; 13:281. https://doi.org/10.1186/1472-6882-13-281 PMid:24160453 PMCid:PMC4016212
14. Aguoru C. Phytochemical analysis of *Bombax ceiba*. Int J Sci. 2015; 1(5):37-41. https://doi.org/10.18483/ijSci.713
15. Kumar A. Phytochemical screening of *Bombax ceiba* fruit. Int J Res Appl Sci Eng Technol. 2019; 7(9):431-435. https://doi.org/10.22214/ijraset.2019.9059
16. Kamble MA, Mahapatra DK, Dhabarde DM, *et al*. Pharmacological studies of *Bombax ceiba* thorn extract. J Pharm Pharmacogn Res. 2017; 5(1):40-54
17. Depani P, Gadhvi K, Vyas S. Ethnobotany of *Bombax ceiba*. Eur J Med Plants. 2019; 29:1-8. https://doi.org/10.9734/ejmp/2019/v29i430163
18. Yin K, Yang J, Wang F, *et al*. Chemical composition and bioactivity of *Bombax ceiba* flower and its mechanism in type 2 diabetes. Front Nutr. 2022; 9. https://doi.org/10.3389/fnut.2022.1018733 PMid:36313078 PMCid:PMC9608341
19. Huang SKH, Hsieh CY, Fu PW, *et al*. Anti-inflammatory activity of *Bombax ceiba*. Biointerface Res Appl Chem. 2023; 13(5):408. https://doi.org/10.33263/BRIAC135.408
20. Karole S, Gautam G, Gupta S. Phytochemical analysis of *Bombax ceiba* leaf. J Drug Deliv Ther. 2018; 8(6):105-110. https://doi.org/10.22270/jddt.v8i6-s.2094
21. Kumari S, Kumari A, Ambastha S, *et al*. Pharmacological attributes of *Bombax ceiba* L. Paripex Indian J Res. 2022: 69-71. https://doi.org/10.36106/paripex/9005417
22. Alrabie A, AlSaeedy M, Al-Adhreai A, *et al*. Unraveling the therapeutic potential of *Bombax ceiba* roots: Chemical composition, heavy metal content, antibacterial activity, and *in silico* analysis. Open Chem. 2023; 21(1). https://doi.org/10.1515/chem-2023-0179
23. Vadalia J, Bavishi N. Comparative phytochemical, antioxidant and antifungal evaluation of successive extracts of *Bombax ceiba* L. thorns. Discov Plants. 2024; 1(1):27. https://doi.org/10.1007/s44372-024-00027-w
24. Chaudhary P, Khadabadi S. *Bombax ceiba* Linn.: Pharmacognosy, ethnobotany and phytopharmacology. Pharmacogn Commun. 2012; 2(3):2-9. https://doi.org/10.5530/pc.2012.3.2
25. Carvalho-Sobrinho JG, Alverson WS, Alcantara S, *et al*. Revisiting the phylogeny of Bombacoideae (Malvaceae): Novel relationships and new tribal classification. Mol Phylogenet Evol. 2016; 101:56-74. https://doi.org/10.1016/j.ympev.2016.05.006 PMid:27154210
26. Taher MA, Hossain MJ, Zahan MS, *et al*. Phytopharmacological and computational profiling of *Bombax ceiba* Linn. leaves. Heliyon. 2024; 10(15):e35422. https://doi.org/10.1016/j.heliyon.2024.e35422 PMid:39170236 PMCid:PMC11336592
27. Yadav H, Kumar M, Nivsarkar M, *et al*. Multiple marker-based evaluation of *Kalanchoe pinnata*, *Bombax ceiba*, and *Morus alba* leaves using HPTLC. J Planar Chromatogr. 2014; 27(6):438-443. https://doi.org/10.1556/JPC.27.2014.6.6
28. Mostafa NM. β-amyrin-rich *Bombax ceiba* leaf extract with neuroprotective activity. Rec Nat Prod. 2018; 12(5):480-492. https://doi.org/10.25135/rnp.47.17.10.062

29. Panja SK, Patra S, Bag BG. Self-assembly of lupeol for nano-structures and drug delivery applications. RSC Adv. 2021; 11(53):33500-33510. https://doi.org/10.1039/D1RA06137B PMid:35497535 PMCid:PMC9042272
30. Arya I, Nautiyal N, Uniyal K, *et al*. Antibacterial and antioxidant activity of *Bombax ceiba* floral extracts. Environ Ecol. 2024; 42(2):405-412. https://doi.org/10.60151/envec/BFRU1901
31. Jain V, Verma SK. Pharmacology of *Bombax ceiba* Linn. Berlin: Springer; 2012.
32. Rathore D, Geetanjali, Singh R. Phytochemistry and pharmacology of genus *Bombax*. Nat Prod J. 2019; 9(3):184-196. https://doi.org/10.2174/2210315508666180831095836
33. Meena AK, Ilavarasan R, Ojha V, *et al*. Conservative sourcing of *Bombax ceiba*: LC-MS, GC-MS, and HPLC profiling. ChemistrySelect. 2023; 8(5). https://doi.org/10.1002/slct.202203623
34. Alrabie A, Alrabie NA, AlSaeedy M, *et al*. Metabolomic profiling and bioactivity of *Bombax ceiba* root. Nat Prod Res. 2023; 37(13):2263-2268. https://doi.org/10.1080/14786419.2022.2149519 PMid:36441059
35. Zizka A, Carvalho-Sobrinho JG, Pennington RT, *et al*. Biome transitions in *Bombacoideae* (*Malvaceae*). J Biogeogr. 2020; 47(6):1310-1321. https://doi.org/10.1111/jbi.13815
36. Zhang YB, Wu P, Zhang XL, *et al*. Phenolic compounds from *Bombax malabaricum* flowers and their activities. Molecules. 2015; 20(11):19947-19957. https://doi.org/10.3390/molecules201119660 PMid:26556329 PMCid:PMC6331941
37. Yasien S, Iqbal MM, Javed M, *et al*. Extraction techniques and antidiabetic activity of *Bombax ceiba* flower metabolites. Bioengineering. 2022; 9(10):486. https://doi.org/10.3390/bioengineering9100486 PMid:36290454 PMCid:PMC9598353
38. Volli V, Varma R, Pradhan D, *et al*. Thermal degradation and kinetics of *Bombax malabarica* seeds. Sustain Energy Technol Assess. 2023; 57:103150. https://doi.org/10.1016/j.seta.2023.103150
39. Lam SH, Chen JM, Tsai SF, *et al*. Chemical investigation of *Bombax malabarica* root bark. Fitoterapia. 2019; 139:104376. https://doi.org/10.1016/j.fitote.2019.104376 PMid:31629048
40. Pithalekar SR, Gavade AE, Matele SN. Medicinal importance of *Bombax ceiba*: A review. Int J Sci Res Arch. 2025; 17(1):791-800. https://doi.org/10.30574/ijsra.2025.17.1.2875
41. Upadhyay SS, Parate SS, D'Souza UP, *et al*. An integrative omics and network pharmacology approach to evaluate the antiulcer activity of *Bombax ceiba* L. gum in rats. ACS Omega. 2025. https://doi.org/10.1021/acsomega.5c07822 PMid:41502739 PMCid:PMC12771444
42. Chauhan S, Sharma A, Upadhyay NK, *et al*. *In vitro* osteoblast proliferation and *in vivo* anti-osteoporotic activity of *Bombax ceiba* with quantification of lupeol, gallic acid and β-sitosterol by HPTLC and HPLC. BMC Complement Altern Med. 2018; 18(1):233. https://doi.org/10.1186/s12906-018-2299-1 PMid:30086745 PMCid:PMC6081808
43. Xu GK, Qin XY, Wang GK, *et al*. Antihyperglycemic, antihyperlipidemic and antioxidant effects of ethanol extract of *Bombax ceiba* leaves in type 2 diabetic rats. Chin J Nat Med. 2017; 15(3):168-177. https://doi.org/10.1016/S1875-5364(17)30033-X PMid:28411685
44. Haftcheshmeh SM, Abedi M, Mashayekhi K, *et al*. Berberine as a natural modulator of inflammatory signaling pathways in the immune system: Focus on NF-κB, JAK/STAT and MAPK signaling pathways. Phytother Res. 2022; 36(3):1216-1230. https://doi.org/10.1002/ptr.7407 PMid:35142403
45. Haque MdU, Alam AHMK, Rahman MdAA, *et al*. Pharmacological evaluation of protocatechuic acid methyl ester from *Bombax ceiba* Results Chem. 2025; 18:102694. https://doi.org/10.1016/j.rechem.2025.102694
46. Zhao Y, Wu J, Liu X, *et al*. Multi-target anti-inflammatory mechanisms of natural products in the TLR4/NF-κB pathway. Front Pharmacol. 2025; 15. https://doi.org/10.3389/fphar.2024.1467193 PMid:39877388 PMCid:PMC11772364
47. Jang WY, Hwang JY, Cho JY. Ginsenosides from *Panax ginseng* as key modulators of NF-κB signaling are anti-inflammatory and anticancer agents. Int J Mol Sci. 2023; 24(7):6119. https://doi.org/10.3390/ijms24076119 PMid:37047092 PMCid:PMC10093821
48. Maroufi NF, Vahedian V, Akbarzadeh M, *et al*. Apatinib inhibits breast cancer cell line MDA-MB-231 by inducing apoptosis, cell cycle arrest and regulating NF-κB and MAPK pathways. Breast Cancer. 2020; 27(4):613-620. https://doi.org/10.1007/s12282-020-01055-6 PMid:32026267
49. Diab K, El-Shenawy R, Helmy N, *et al*. Polyphenol content, antioxidant, cytotoxic and genotoxic activities of *Bombax ceiba* flowers in liver cancer cells Huh7. Asian Pac J Cancer Prev. 2022; 23(4):1345-1350. https://doi.org/10.31557/APJCP.2022.23.4.1345 PMid:35485695 PMCid:PMC9375612
50. Haque MU, Alam AK, Islam Shovon MT, *et al*. Apoptotic potential of antioxidant-rich medicinal plant extracts and computational modeling of antitumor compounds. Heliyon. 2024; 10(20):e38885. https://doi.org/10.1016/j.heliyon.2024.e38885 PMid:39492885 PMCid:PMC11531630
51. Peng Y, Wei J, Yang Y. NRF2-targeted therapy in cardiovascular disease: from systemic activation to precision redox medicine. Antioxidants (Basel). 2026; 15(2):219. https://doi.org/10.3390/antiox15020219 PMid:41750600 PMCid:PMC12937701
52. Di Stasi LC. Natural coumarin derivatives activating Nrf2 signaling pathway for intestinal anti-inflammatory drug design. Pharmaceuticals (Basel). 2023; 16(4):511. https://doi.org/10.3390/ph16040511 PMid:37111267 PMCid:PMC10142712

53. Iranshahy M, Iranshahi M, Abtahi SR, *et al*. Role of Nrf2 in hepatoprotective activity of natural products: A review. Food Chem Toxicol. 2018; 120:261-276. https://doi.org/10.1016/j.fct.2018.07.024 PMid:30009889
54. Faizi S, Zikr-ur-Rehman S, Naz A, *et al*. Bioassay-guided study of *Bombax ceiba* leaf extract: isolation of shamimoside, a new antioxidant xanthone C-glucoside. Chem Nat Compd. 2012; 48(5):774-779. https://doi.org/10.1007/s10600-012-0379-x
55. Kumar DA. Evaluation of wound healing activity of *Bombax ceiba* leaves. J Med Sci Clin Res. 2018; 6(12). https://doi.org/10.18535/jmscr/v6i12.18
56. Paradee N, Saengratwatchara P, Srichairatanakool S, *et al*. *Bombax ceiba* flower extract enhances antioxidant defense and wound healing in human keratinocytes and fibroblasts. Pharm Biol. 2026; 64(1):599-614. https://doi.org/10.1080/13880209.2026.2655481 PMid:41995694 PMCid:PMC13094256
57. Liu M, Wei X, Zheng Z, *et al*. AMPK activation eliminates senescent cells in diabetic wounds via NCOA4-mediated ferritinophagy. Mol Med. 2024; 30(1):63. https://doi.org/10.1186/s10020-024-00825-8 PMid:38760678 PMCid:PMC11100200
58. Wanjari MM, Gangoria R, Dey YN, *et al*. Hepatoprotective and antioxidant activity of *Bombax ceiba* flowers in carbon tetrachloride-induced hepatotoxicity. Hepatoma Res. 2016; 2(6):144. https://doi.org/10.20517/2394-5079.2015.55
59. Arafa AF, Foda DS, Mahmoud AH, *et al*. *Bombax ceiba* flower extract ameliorates ethanol-induced hepatosteatosis in rats. Toxicol Rep. 2019; 6:401-408. https://doi.org/10.1016/j.toxrep.2019.04.008 PMid:31080748 PMCid:PMC6507047
60. Aly O, Elias TR, Ashour MH, Agaibyi M, *et al*. Antidiabetic and hepatoprotective activities of *Bombax ceiba* extract in obese rats with metabolic syndrome. Plant Arch. 2021; 21(Suppl 1):748-756. https://doi.org/10.51470/PLANTARCHIVES.2021.v21.S1.113
61. El-Bana MA, Ashour MN, Rasheed WI, *et al*. *Bombax ceiba* Linn. leaf extract rich in phenolic compounds mitigates non-alcoholic fatty liver-related complications. J Complement Integr Med. 2023; 20(2):343-352. https://doi.org/10.1515/jcim-2021-0479 PMid:36935561
62. Khurshid Alam AHM, Sharmin R, Islam M, *et al*. Antidiabetic and hepatoprotective activities of *Bombax ceiba* young roots in alloxan-induced diabetic mice. J Nutr Health Food Sci. 2018; 6(5):1-7. https://doi.org/10.15226/jnhfs.2018.001140
63. Marín-Aguilar F, Pavillard L, Giampieri F, *et al*. AMP-activated protein kinase: a new target for nutraceutical compounds. Int J Mol Sci. 2017; 18(2):288. https://doi.org/10.3390/ijms18020288 PMid:28146060 PMCid:PMC5343824
64. Wang D, Li J, Luo G, *et al*. Nox4 as a therapeutic target for diabetic vascular complications. Redox Biol. 2023; 64:102781. https://doi.org/10.1016/j.redox.2023.102781 PMid:37321060 PMCid:PMC10363438
65. Komati A, Anand A, Nagendla NK, *et al*. *Bombax ceiba* calyx displays antihyperglycemic activity via improving insulin secretion and sensitivity: Identification of phytometabolites by UPLC-QTof-MS/MS. J Food Sci. 2022; 87(4):1865-1881. https://doi.org/10.1111/1750-3841.16093 PMid:35279832
66. Kumari S, Ambastha S, Kumari A, *et al*. Phytochemical screening and antimicrobial activities of *Bombax ceiba* leaves. South Asian J Exp Biol. 2023; 13(5):381-385. https://doi.org/10.38150/sajeb.13(5).p381-385
67. Rajput RT. Ethnomedicine and pharmacology of semal (*Bombax ceiba* L.): A review. Agric Rev. 2021. https://doi.org/10.18805/ag.R-1942
68. Fatima, Siddiqui S, Khan A, Afshan. Mochrus (*Bombax ceiba* Linn.): Pharmacology, phytochemistry and ethnomedicinal uses. CellMed. 2019; 9:4.1-4.5
69. Iyengar P, Godoy-Brewer G, Maniyar I, *et al*. Herbal medicines for treatment of ulcerative colitis: A systematic review and meta-analysis. Nutrients. 2024; 16(7):934. https://doi.org/10.3390/nu16070934 PMid:38612967 PMCid:PMC11013716
70. Bhavsar C, Talele GS. Antidiabetic activity of *Bombax ceiba*. Bangladesh J Pharmacol. 2013; 8(2). https://doi.org/10.3329/bjp.v8i2.13701
71. Kumari N, Radha, Puri S, *et al*. Therapeutic potential of *Bombax ceiba* flowers for functional food development: A review. Chem Biodivers. 2025; 22(11). https://doi.org/10.1002/cbdv.202500247 PMid:40825150
72. Sharma N, Kispotta S, Mazumder P. Immunomodulatory and anticancer activity of *Bombax ceiba* leaf extract. Asian Pac J Trop Biomed. 2020; 10(9):426. https://doi.org/10.4103/2221-1691.290134
73. Ullah N, Khan A, Mehwish S, *et al*. Mechanism of action of *Bombax ceiba* extracts against *Leishmania tropica*. Int J Infect Dis. 2020; 101:309. https://doi.org/10.1016/j.ijid.2020.09.808
74. Aziz N, Alhajouj SA, Basit A, *et al*. Green synthesis and antibacterial activity of nanoparticles using *Bombax ceiba* flavonoids. Cell Mol Biol. 2025; 71(2):127-135. https://doi.org/10.14715/cmb/2025.71.2.18 PMid:39976903
75. Rani S, Rahman K, Sultana A. Ethnomedicinal and pharmacological activities of mochrus (*Bombax ceiba* Linn.): An overview. TANG (Humanitas Medicine). 2016; 6(1):2.1-2.9. https://doi.org/10.5667/tang.2015.0025
76. Gadge NB, Jalalpure SS. Treatment with *Bombax ceiba* fruit extract reduces calcium oxalate urolithiasis risk in rats. Pharm Biol. 2012;50(3):310-317. https://doi.org/10.3109/13880209.2011.604332 PMid:22321032
77. Kakkar S, Jha RK, Hattila D, *et al*. Plant-derived natural product-based nanoformulations for healthcare application. Nanotheranostics. 2025; 9(3):262-279. https://doi.org/10.7150/ntno.113606 PMid:40959483 PMCid:PMC12435207

78. Safdar M, Aslam S, Akram M, *et al*. *Bombax ceiba* flower extract-mediated synthesis of selenium nanoparticles for antibacterial activity and urea detection. World J Microbiol Biotechnol. 2023; 39(3):80. https://doi.org/10.1007/s11274-022-03513-z PMid:36646906
79. Wickramasinghe ASD, Kalansuriya P, Attanayake AP. Nanoformulation of plant-based natural products for type 2 diabetes mellitus: From formulation design to therapeutic applications. Curr Ther Res Clin Exp. 2022; 96:100672. https://doi.org/10.1016/j.curtheres.2022.100672 PMid:35586563 PMCid:PMC9108891
80. Pandey RP, Vidic J, Mukherjee R, *et al*. Experimental methods for biological evaluation of nanoparticle-based drug delivery risks. Pharmaceutics. 2023; 15(2):612. https://doi.org/10.3390/pharmaceutics15020612 PMid:36839932 PMCid:PMC9959606
81. Tirumala MG, Anchi P, Raja S, *et al*. Safety evaluation of nanoparticle formulations: *In vitro* models and adverse outcome pathways. Front Pharmacol. 2021; 12. https://doi.org/10.3389/fphar.2021.612659 PMid:34566630 PMCid:PMC8458898
82. Đorđević S, Gonzalez MM, Conejos-Sánchez I, *et al*. Current hurdles to translation of nanomedicines from bench to clinic. Drug Deliv Transl Res. 2022; 12(3):500-525. https://doi.org/10.1007/s13346-021-01024-2 PMid:34302274 PMCid:PMC8300981
83. Dharavath N, Porika M, Tippani R, *et al*. Characterization and therapeutic assessment of phytomediated silver nanoparticles from *Bombax ceiba*. Drug Res (Stuttg). 2025; 75(9):362-366. https://doi.org/10.1055/a-2695-0339 PMid:40992410
84. Jalasutram JK, Nowduri A, Samudrala PK, *et al*. Biofabrication of zinc oxide nanoparticles using *Bombax ceiba* and evaluation of antibacterial and dye degradation efficacy. Mor J Chem. 2025; 13(2):903-921.
85. Roshid MH, Alam MS, Ibn Amin KA, *et al*. Green synthesis of nickel oxide nanoparticles using plant extracts including *Bombax ceiba* and evaluation of antioxidant, antidiabetic and antibacterial properties. Heliyon. 2025; 11(6):e42953. https://doi.org/10.1016/j.heliyon.2025.e42953
86. Telrandhe R, Mahapatra DK, Kamble MA. *Bombax ceiba* thorn extract-mediated synthesis of silver nanoparticles and evaluation of anti-*Staphylococcus aureus* activity. Int J Pharm Drug Anal. 2017; 5(9):376-379

Author Contribution

SP: Conceptualization, Investigation, Writing-Original Draft AM: Formal analysis, Supervision SD: Data Curation, Supervision. All authors have read and agreed to the published version of the manuscript.