

ETHNOMEDICINAL USES, PHYTOCHEMICAL COMPOSITION, PHARMACOLOGICAL ACTIVITIES AND FUTURE PERSPECTIVES OF BOMBAX CEIBA L.

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ABSTRACT

Bombax ceiba L., commonly known as the red silk cotton tree, is a medicinally important plant with a long history of traditional use across South and Southeast Asia. Different parts of the plant, including the roots, bark, leaves, flowers, fruits, seeds, gum, and prickles, have been used in Ayurveda, Unani medicine, and indigenous healthcare systems for the management of gastrointestinal, inflammatory, infectious, metabolic, reproductive, and dermatological conditions. Growing scientific interest in *B. ceiba* has revealed a chemically diverse profile comprising flavonoids, phenolic compounds, tannins, terpenoids, steroids, saponins, glycosides, fatty acids, polysaccharides, and other bioactive constituents. Experimental studies have reported a range of biological activities, particularly antioxidant, anti-inflammatory, antimicrobial, antidiabetic, hepatoprotective, analgesic, gastroprotective, and cytotoxic effects. The seeds and seed oil represent comparatively underexplored components with potential nutritional, pharmaceutical, and industrial value due to their lipid and fatty-acid composition. Despite promising preclinical findings, the current evidence is limited by inadequate extract standardization, incomplete characterization of active constituents, geographical variation, insufficient pharmacokinetic and toxicological studies, and a notable lack of well-designed human clinical trials. This review critically summarizes the ethnomedicinal, phytochemical, and pharmacological evidence concerning *B. ceiba*, with particular emphasis on seed constituents, seed oil, antioxidant activity, safety, and research gaps. Future investigations should prioritize standardized extracts, advanced metabolomic profiling, mechanistic studies, comprehensive toxicological assessment, and clinically relevant trials to establish the evidence-based therapeutic potential of this medicinally valuable species.

Keywords:

Bombax ceiba, phytochemistry, ethnomedicine, medicinal plants, antioxidant activity, pharmacological activities, potential

INTRODUCTION

Medicinal plants have long served as a key source of therapeutic agents and remain central to modern pharmaceutical development and drug discovery, with many active compounds isolated from plant-based natural products. Growing concerns about antimicrobial resistance, chronic diseases, oxidative stress, and the side effects of synthetic drugs have renewed scientific interest in plant-derived bioactive compounds. These plants are rich in secondary metabolites offering diverse pharmacological potential, including antioxidant, anti-inflammatory, antimicrobial, anticancer, and other therapeutic activities. As traditional ethnomedicinal knowledge is increasingly integrated with modern phytochemical and pharmacological research, systematic reviews of medicinal plants are becoming essential. Such reviews help consolidate scattered information and highlight promising bioactive constituents for future drug development [1-3].

Bombax ceiba L. is a large deciduous tropical tree of Malvaceae family, which is now understood to be a part of the family Malvaceae, and is gaining more scientific attention as a medicinal plant.

The medicinal uses of *Bombax ceiba* are closely connected with its various phytochemical constituents. The plant has been previously reported to contain flavonoids, phenolic compounds, tannins, sterols, triterpenoids, glycosides, fatty acids, carbohydrates and other biologically active constituents in various parts of the plant. The various biological activities that are thought to be responsible for their broad spectrum are attributed to these compounds. Through experimental studies it has been proven that the plant possesses various pharmacological properties, such as antioxidant, anti-inflammatory, antimicrobial, anti-diabetic, hepatoprotective, analgesic, wound healing, cytotoxic, and reproductive activities; however, there is significant variation in quality and strength of the evidence for each activity. Its antioxidant activity is significant since oxidative stress is linked to the pathogenesis of various chronic diseases such as cardiovascular disorders, cancer, diabetes, neurodegenerative diseases and inflammatory diseases. Hence, the extraction and elucidation of

natural antioxidant compound from medicinal plants like *Bombax ceiba* can be a great opportunity for development of future treatment and pharmaceutical products [4, 5].

Although *Bombax ceiba* has been widely used in traditional medicine and cultivated for scientific studies, the plant has still not been fully studied in several aspects. Most of the previous studies and reviews have been conducted either on its ethnomedicinal uses or its general phytochemical profile or on the selected pharmacological activities. The literature available, however, tends to be scattered with information found in studies which focused on single plant parts or biological properties. The seeds and seed oil of *Bombax ceiba* L. are of significant nutritional, phytochemical, industrial and therapeutic value but comparatively little attention has been directed towards reviewing them in depth. Important lipid constituents and other bioactive compounds are found in the seeds; they may have an antioxidant and pharmacological effect. Therefore, a detailed knowledge of the composition and biological potential of *Bombax ceiba* seed oil is important to find new opportunities for its pharmaceutical, nutraceutical and functional applications. In addition, differences in phytochemical composition, based on geographical origin, extraction method, part of the plant, and analytical method, make it difficult to interpret the findings reported in the literature.

This review provides an up-to-date, integrated account of *Bombax ceiba*, drawing on ethnomedicinal, phytochemical, pharmacological, and toxicological evidence, with particular emphasis on linking phytochemical constituents to their reported biological effects an aspect underexplored in previous reviews. Special attention is given to the chemical composition of various plant parts, especially the relatively underutilized seeds and seed oil, alongside a critical evaluation of the plant's antioxidant potential and major pharmacological activities, including antimicrobial, anti-inflammatory, antidiabetic, hepatoprotective, and wound-healing effects. The review also addresses safety and toxicological concerns essential for translating phytochemicals into therapeutic applications,

while identifying methodological limitations, data inconsistencies, and the lack of standardization and clinical evidence as key gaps. By integrating traditional knowledge with recent scientific findings, this study offers a comprehensive perspective on the therapeutic potential of *Bombax ceiba* and outlines priority areas for future research.

The review also seeks to highlight significant knowledge gaps and future research directions that could facilitate the development of standardized, safe and evidence base therapeutic applications based on this medicinally valuable plant [6].

Pharmacognostic evaluation

Pharmacognostic evaluation is an essential part of herbal drug research since it is used for establishing the identity, purity, quality and authenticity of the medicinal plant materials. The correct pharmacognostic characterization of *Bombax ceiba* L. is a very significant aspect, due to its traditional use in medicine, with different parts of the plant (bark, roots, flowers, leaves, seeds, gum and thorns). The physical properties and phytochemical content of crude drugs can be greatly affected by the variation in the source, geographical origin, harvesting conditions, processing techniques and storage of the plants. Hence, the systematic pharmacognostic assessment furnishes important parameters for the identification of pure *Bombax ceiba* material from adulterants or substitutes or from other closely allied species. The study by Wahab et al (2012) [7] and Gupta et al (2023) [8] and Kirte & Giri (2026)[9] have shown that morphological, microscopic, physicochemical and phytochemical properties can be used to identify and standardize *B. ceiba* crude drugs and their preparations.

Macroscopy

The first step of pharmacognostic identification is macroscopic evaluation in which the visible morphological features of the whole plant or individual parts are examined. *Bombax ceiba* is a large, deciduous tree with a spreading canopy, palmately compound leaves, spreading branches and prominent conical type of prickles on young

stems. The large bright red to scarlet flowers, which typically occur at a tree's leafless stage, are a special identifier of the tree. The fruits are elongated capsules with many seeds within a lot of silky cotton-like fibers. Macroscopic features of the various parts of the plant used for medicine can help with preliminary identification. The stem bark is normally irregularly shaped with rough external surface, while the root has characteristic color, texture, fracture and surface characteristics. The seeds are comparatively small with a significant lipid content and are therefore of special interest for phytochemical and pharmacological research. Macroscopic examination of various parameters including size, shape, color, surface features, texture, fracture and general appearance is an inexpensive and quick method of preliminary identification of authentic plant material [10].

Organoleptic Characteristics

Organoleptic or sensory evaluation involves assessment of medicinal plant materials with their characteristics based on the senses such as color, smell, taste, texture and appearance. Such properties give a first indication on the nature and quality of crude plant substances. The organoleptic characteristics can vary from one part of *Bombax ceiba* to another, depending on the botanical origin of the part and the processing conditions. The bark, roots and thorns of *B. ceiba* have been subjected to pharmacognostic analysis, which has yielded characteristic coloration (brown to reddish-brown), texture and odor that can aid in preliminary identification. Coarse or fine particles in powdered material can be caused by the method of processing; changes in color, odor or texture can signal deterioration, improper storage, microbial contamination, and/or adulteration. The organoleptic evaluation, when used in conjunction with microscopic and physicochemical analyses, is an important preliminary assessment method for quality control, although it alone is not sufficient to make a definitive determination of authentication [11].

Microscopy

The microscopic examination gives important anatomical characteristics which help in the identification and authentication of medicinal plants. Studies on the anatomy of the various parts of *Bombax ceiba* have identified several diagnostic features. The stem bark has been investigated and tissues reported are cork, collapsed and non-collapsed phloem, sieve elements, sieve tubes, companion cells, and starch grains. It has been shown in studies of the roots that cork tissue, cambium, xylem vessels, stone cells, calcium oxalate crystals, starch grains, and phloem fibres are present. Such minute features can be used as useful taxonomic as well as pharmacognostic features to differentiate *B. ceiba* from the morphologically similar plant material. Macroscopic features become less recognizable after drying or processing of crude drugs, hence the presence, arrangement and structural characteristics of the vascular tissues, fibers, crystals and storage materials are useful in the authentication of such crude drugs [10].

Powder microscopy

Powder microscopy may be of great value if medicinal plant materials are commercially available already powdered, and the morphologic features of the original plant material will not be seen. Several diagnostic elements have been identified in the powdered *Bombax ceiba* material, such as cork cells, lignified fibers, vessel fragments, stone cells, starch grains, calcium oxalate crystals and phloem fibers, by microscopic examination. In addition, xylem vessels can be thickened in a spiral or reticulate fashion, which may also be helpful for diagnosis. Special histochemical staining techniques can also help in the identification of specific cell components. For instance, phloroglucinol and hydrochloric acid staining can be used to identify lignified tissues, and other chemical stains can be used to identify tannin cells and associated components. The identification of these microscopic structures will help to provide a practical means for detecting adulteration and confirm the authenticity of powdered crude drugs. In recent years, the

pharmacognostic studies of *B. ceiba* thorns [9] and bark [8] also highlighted the utility of powder microscopy as a standard quality control technique for herbal raw material.

Quantitative microscopy

Quantitative microscopy is the assessment of the microscopic features of crude plant materials by measurement and number that can be used to set reproducible standards for crude plant materials. The dimension and frequency of calcium oxalate crystals, the size and shape of fibers and vessels, the size and shape of starch grains, and the proportions of the tissues may be valuable quantitative markers for authentication. Despite the relative abundance of information about the qualitative microscopic description of *Bombax ceiba*, however, relatively limited information on quantitative descriptive microscopic could be found for some plant parts. This is an important research gap as numerical microscopic parameters can enhance the reproducibility and reliability of the pharmacognostic identification. The quantification of the micro data for the different parts of *B. ceiba* (bark, root, leaves, flowers and seeds) would be helpful in the preparation of more detailed monographs and official quality specification. Future studies should thus be directed towards the production of accurate quantitative anatomical values based on standardized sampling and microscopes procedures [12].

Physicochemical evaluation

Physicochemical evaluation offers objective parameters which may be used to assess crude herbal drugs quality, purity and stability. The parameters such as moisture content or loss on drying, total ash, acid-insoluble ash, water-soluble ash, extractive values, foreign matter, swelling index, foaming index and hemolytic index are important physicochemical parameters investigated in *Bombax ceiba*. Loss on drying is important especially when excessive moisture may cause microbial proliferation and/or chemical degradation during storage. Ash values give an indication of the inorganic content of the crude drug and can assist in determining the presence of

soil, sand or extraneous matter. Extractive values measure the number of soluble constituents in specific solvents and can give indirect information about the amounts of bioactive constituents. Some of these parameters have been used in previous pharmacognostic studies of *B. ceiba* roots and bark following the methods used for herbal standardization. Chemical and physical information is crucial to develop based reference standards and batch-to-batch consistency of raw materials used for medicinal purposes [13].

Preliminary phytochemical screening

Preliminary phytochemical screening gives qualitative information about the major classes of secondary metabolites found in medicinal plants. Some significant phytochemical groups identified from various parts of *Bombax ceiba* are flavonoids, phenolic compounds, tannins, alkaloids, glycosides, terpenoids, steroids, saponins and carbohydrates. The phytochemical profile can however vary according to the part of the plant, geographical location, stage of maturity, extraction solvent and analytical method. Bark and root studies have particularly shown the presence of phenolic compounds, flavonoids, tannins, glycosides, terpenoids and other bioactive compounds. The preliminary results will form a chemical basis for many of the traditional experiment report biological activities of the plant. However, it should be taken as a preliminary step as the color reaction and the conventional chemical tests can give the structural identification and accurate quantification of individual compounds only qualitatively [14].

Quantitative Phytochemistry

Data obtained from quantitative phytochemical analysis is necessary to quantify the concentrations of the major groups of bioactive compounds and compare extracts from various parts of a plant or extraction methods. Some of the most widely assessed parameters include total phenolic content, total flavonoid content, total tannin content and total saponin content. The extracts of *Bombax ceiba* have been subjected to spectrophotometric analysis for total phenolic content (Folin-Ciocalteu method) and flavonoids

(Aluminum chloride method). Comparative studies of leaf and bark extracts have shown that there are measurable differences between the total phenolic and total flavonoids content of aqueous and ethanolic extracts, and thus the extraction solvent is significant in the recovery of phytochemicals. Quantitative estimation is of particular importance because phenolic and flavonoid compounds are often correlated with antioxidant activity and can be involved in other biological activities. But total-content assays will only give rough estimates, and they should be supplemented with advanced analytical methods that will allow for the identification and quantification of individual marker compounds [15].

Identification by chromatography and spectroscopy

Chromatographic Fingerprinting is one of the significant methods used in herbal drug authentication as it allows the separation and comparison of several chemical constituents of complex botanical extracts. To investigate the pharmacognostic investigations of *Bombax ceiba*, Thin Layer Chromatography (TLC) and High-Performance Thin Layer Chromatography (HPTLC) have been used. The root extracts have been analyzed by HPTLC, which has established characteristic chromatographic profile and helped in the detection of the phytochemical groups such as steroidal components. These fingerprint patterns can be used as reference patterns to compare raw materials and recognize differences between samples. HPLC, UHPLC, GC-MS, LC-MS, NMR and Fourier-transform infrared spectroscopy (FTIR) are more advanced analytical methods that have increased potential for detailed chemical authentication. The methods may aid in identification of single marker compounds, in the analysis of the composition of seed oil and in the detection of geographical and/or processing-related chemical variation. However, the standardization of advanced chromatographic and spectroscopic authentication procedures for all the medicinal parts of *B. ceiba* is still limited and is one of the areas that need further research [16].

Adulteration and authentication

A big problem in herbal medicine is adulteration which can be intentional or accidental by substitution, contamination, incorrect identification, mixing with inferior materials or the use of closely related species. The high level of uses for *Bombax ceiba*, such as dried, whole, powdered and processed matter, may make the use of macroscopic characters not enough to guarantee authenticity. Therefore, morphological, micro, physicochemical, phytochemical and chromatographic parameters are required to ensure reliable authentication. Cellular diagnostic features like cork cells, phloem fibers, calcium oxalate crystals, stone cells, starch grains, and characteristic vessel fragments can help identify substitution in powdered materials. Chemical evidence for authenticity and deviations from reference profiles is also obtained by chromatographic fingerprints. The creation of authenticated samples and voucher specimens validated chemical fingerprints and DNA-based identification systems could further bolster the quality assurance of *B. ceiba* raw materials. An integrated authentication approach is of special significance as the therapeutic efficacy and safety may vary due to variations in plant part and source [17].

Standardization

There is a need for standardization of *Bombax ceiba* as it would enable the consistent identification, purity, quality, safety and therapeutic reliability of crude drug and plant derived preparations. It is recommended that a detailed standardization program should start with accurate botanical identification and authenticated plant collection, followed by the evaluation of the organoleptic and macroscopic features, the microscopy, the powder microscopy, the physicochemical parameters and the phytochemical composition. An important bioactive constituent should then be quantified and a chromatographic fingerprint included to set up reproducible quality specifications. Other safety related tests such as microbial count, pesticide residues, heavy metals, mycotoxins and other contaminants should also be taken into consideration, especially for pharmaceutical or nutraceutical uses. It is important to note that

recent pharmacognostic research has continued to highlight the need to develop set quality parameters for various parts of *B. ceiba* especially for its bark, roots and thorns. However, a universally accepted and comprehensive monograph which covers all parts of the species used for medicinal purposes is still missing. Conventional methods of pharmacognostic analysis need to be combined with the new chromatographic, spectroscopic, metabolomic and molecular authentication methods to incorporate these into future standardization. Such a comprehensive framework will provide robust scientific support for *Bombax ceiba* and support its progression into standardized, safe and reproducible herbal medicines [18].

Traditional and ethnomedicinal uses

Bombax ceiba L. or red silk cotton tree (Semal) is an old plant medicinal tree with long use in traditional healing systems of South and Southeast Asia. The plant has been identified in Ayurveda, Unani medicine, Siddha medicine and various local indigenous ethnomedicinal system. Traditional knowledge attributes therapeutic value to almost all the major parts of the plant such as roots, root bark, stem bark, leaves, flowers, fruits, seeds, seed oil, gum/exudate, prickles and heartwood. Traditionally used as astringents, tonics, demulcents, diuretics, cooling agents, gastrointestinal, reproductive, urinary, dermatological, inflammatory and febrile remedies. Historically recorded ethnomedicinal use and demonstrated pharmacological activities, however, should be distinguished. Traditional use is important ethnobotanical information and could serve as a justification for scientific research but should not be regarded as proof of clinical efficacy. The scientific data regarding *B. ceiba* is largely derived from phytochemical analysis, in vitro assay and animal experiments, with little solid human clinical evidence available [19].

Roots

Roots of *Bombax ceiba* have been used in various South Asian communities for metabolic, gastrointestinal, reproductive and genitourinary conditions. In ethnomedicines root preparations

are often used as a decoction, powder or a fresh preparation taken orally. Root decoction is used traditionally for the removal of abdominal worms. Likewise, the roots are used in traditional medicine for diabetes in tribal people of India. The roots are also utilized in ethnomedicinal preparations for treatment of gonorrhea in Bangladesh, some combined with other medicinal plants. The root has also been used in Ayurvedic medicine for its tonic and restorative effects, and it has been associated with reproductive health and overall debility [20].

Root Bark

Root bark of *Bombax ceiba* has traditionally been recognized as an important medicinal component of this plant, especially in Ayurvedic and indigenous medicine. Preparations of the root bark, generally in powdered or decocted form, have been associated with astringent and tonic properties. Classical uses are in diarrhea, dysentery, copious discharges, reproductive troubles and general lassitude. The astringent properties of *B. ceiba* bark preparations have led to its application in gastrointestinal and gynecological disorders in traditional South Asian medicine. Pharmacognostic and phytochemical studies confirmed the presence of biologically active constituents in the root tissues, but clinical validation of many of the traditional uses of the rootbark has not been found [21].

Stem Bark

Aqueous decoctions, juice, powders and sometimes topical uses of stem bark are traditional preparations. In other Indian ethnomedicinal communities, stem bark is used for diarrhea, dysentery, skin disorders, wounds, acne, boils, and some reproductive disorders. The juice of the stem has traditionally been used for diarrhea and ethnobotanical reports are available for its use in the treatment of herpes and skin diseases. The Ayurvedic and Unani preparations of bark are also mentioned as astringent, tonic, cooling and of good effect in gastrointestinal disturbances and weakness. Another traditional claim about stem bark is its use for sexually transmitted diseases,

such as gonorrhea, which need to be scientifically validated [22].

Leaves

According to ethnomedicinal reports, the leaves are used to treat inflammatory, painful, respiratory and dermatological ailments in the form of leaf decoctions, infusions, extracts and fresh leaf paste. Leaves soaked in water have been used traditionally as bath preparation for body pain. The leaves of this plant have been used in India for topical application to treat snake bites on the skin. Other ethnomedicinal reports indicate that leaves are used for fever, cough, flu, sore throat, menstrual discomfort and inflammatory conditions. Leaves and flowers are infused or powdered for cough, fever, flu, sore throat, menstrual pain and tumors [23].

Flowers

The flowers can be used either fresh or dried, as powders, pastes, infusions, or decoctions. Traditional systems have classified the flowers under the following categories: cooling, astringent and beneficial for inflammation, diarrhea, dysentery, fever, weakness and reproductive disorders. Ethnobotanical uses of Rose in preparations for cough, fever, flu, sore throat, menstrual pain and others were also documented in Pakistan. The flowers in ayurvedic literature are often attributed as astringent and cooling. The antioxidant and other biological activities that have been reported in flower extracts have mostly been found in scientific studies and are experimental [22].

Fruits

The fruits of *Bombax ceiba* are also utilized in traditional medicine, but not as much as the bark and flowers, and have not been studied as extensively. The traditional preparations involved were from fruits extracts, powders and other orally administered preparations. Documentation of the ethnomedicines use of fruits for urinary diseases has been reported in India. Kidney and urinary bladder, and digestive and reproductive systems were also linked to fruits, in general traditional medicine texts. Although the fruit has been

reported to be used traditionally, current pharmacological evidence is still limited and specific for the therapeutic use of the fruit is less extensive than those of other parts of plant [24].

Seeds

The seeds of *B. ceiba* have been gaining focus due to their nutritional profile, lipid content, and suggested bioactive properties. In some tribal groups seeds have traditionally been used for metabolic and reproductive reasons. The ethnobotanical studies conducted in India indicated the use of the seeds as traditional medicine for diabetes management. The ethnobotanical surveys carried out in India showed that the utilization of seeds as traditional medicine for diabetes management. Another traditional medicinal use of seeds is tonic and aphrodisiac. These can be given by mouth as powder or in compound herbal medicines.

Gum/Exudate

The gum has been traditionally used as an astringent, demulcent and restorative. In classical medicinal systems Mochras correlated diarrhea, dysentery, excessive bleeding, leucorrhea, wounds, fractures and reproductive disorders. It is also used in compound medicine for gynecological complaints and excessive discharge from the body. The gum is described with reference to wound healing and tissue repair in Ayurvedic classifications while the exudate has been described as having a uterine tonic, astringent and semen related restorative properties in Unani medicine [26].

Other parts that are used traditionally in the local area are listed below

Apart from the main medicinal parts, various other parts of *Bombax ceiba* such as prickles or

Experimental studies on constituents and biological activity of the seeds are encouraging, further research is needed to standardize preparation, effective dosage, mechanism of action and safety profile [25].

Seed oil

Oil has potential nutritional, pharmaceutical and industrial applications due to the presence of appreciable amounts of oil and fatty acids in seeds. The ethnomedicinal information related to seed preparations is generally brief and focuses mostly on tonic and restorative benefits, while the information about the oil is far sparser than that of bark, flowers, roots and gum. The oil extracted from the seeds is currently of interest in the scientific field mainly due to its fatty acid content, physicochemical characteristics, and potential antioxidant and biological applications, but not for its traditional therapeutic uses [25]

thorns, heartwoods and young plant tissues have been utilized as traditional medicines. Prickles have been mentioned in some traditional medicine systems for topical and internal medicines, and the heartwood has been linked to tonic medicines and medicinal preparations. Ethnomedicinal reviews show that parts such as the young roots, prickles and other parts have been traditionally applied to various ailments like inflammatory disorders, skin ailments and general debility. Specific details about preparation, dosage, the way the medicine is administered, and ethnic specificity are not always consistent in the literature, however. The non-standardized ethnobotanical documentation makes it difficult to use comparative analysis of traditional practices among different geographical areas [27].

Table: Traditional and Ethnomedicinal uses of different parts of *Bombax ceiba*

Plant part	Traditional use	Preparation	Region/community	Reported source
Root	Abdominal worms; diabetes; reproductive and genitourinary complaints	Decoction, oral preparation	Khushab, Punjab, Pakistan; Pradesh, India	[28] [19]

Root	Gonorrhea and related genitourinary conditions	Oral combination with other medicinal plants	Garro communities, Bangladesh	[28]
Root bark	Diarrhea, dysentery, weakness, reproductive complaints	Powder, decoction	Ayurveda and South Asian traditional medicine	[19]
Stem bark	Diarrhea and dysentery	Bark juice, decoction	Gond community, Andhra Pradesh, India	[28]
Stem bark	Skin conditions, boils, acne, wounds	Paste, topical preparation, decoction	India	[19] [8]
Stem bark	Traditional treatment of herpes-related skin conditions	Local preparation	Coastal Karnataka, India	[28]
Leaves	Body pain and inflammatory discomfort	Leaves soaked in water and used for bathing	Orang Asli, Kampung Bawong, Malaysia	[28]
Leaves	Snakebite	Fresh leaf paste, topical application	Mullu Kuruma tribe, Kerala, India	[28]
Leaves	Cough, fever, flu, sore throat and menstrual pain	Infusion and powder	Samahni Valley, Azad Jammu and Kashmir, Pakistan	[23]
Flowers	Boils and skin lesions	Flower paste, topical application	Chakma community, Chittagong Hill Tracts, Bangladesh	[28]
Flowers	Fever, cough, flu and sore throat	Infusion, powder	Samahni Valley, Azad Jammu and Kashmir, Pakistan	[23]
Flowers	Diarrhea, dysentery, weakness and inflammatory conditions	Powder, infusion, decoction	Ayurveda and traditional South Asian medicine	[19], [8]
Fruits	Urinary problems	Traditional oral preparation	Gond tribe, Adilabad District, India	[28]
Fruits	Gastrointestinal and general medicinal applications	Powder or extract	South Asian traditional medicine	[26]
Seeds	Diabetes	Oral administration; traditional seed preparation	Tribal communities of Chitteri Hills, India	[28]
Seeds	Tonic and aphrodisiac purposes	Powder or compound formulations	Traditional South Asian medicine	[19]
Seed oil	Traditionally associated with restorative applications; detailed medicinal	Oil or seed-derived preparation	South Asian traditional knowledge	[26] [8]

	documentation remains limited				
Gum/exudate (Mochras)	Diarrhea, dysentery, leucorrhea and excessive discharges	Powder and compound formulations	Ayurveda and Unani medicine	[26] [19]	
Gum/exudate (Mochras)	Wound healing, fractures and gynecological conditions	Paste, powder, traditional formulations	Indian traditional medicine	[19]	
Prickles/thorns	Traditional medicinal and topical applications	Powder or local formulations	Ayurveda and indigenous South Asian practices	[26] [8]	
Heartwood	Tonic and general medicinal applications	Decoction or traditional formulations	Traditional South Asian medicine	[26]	
Multiple plant parts	Diabetes, urinogenital disorders, gastrointestinal diseases, skin diseases and general debility	Various preparations	South India and broader tropical Asia	[26] [19]	

Phytochemical composition

Phytoconstituents of *Bombax ceiba* L. are chemically diverse and the therapeutic potential is linked to these constituents. The flowers, leaves, bark, roots, stem, gum, fruits, seeds and seed oil of the plant have been investigated by phytochemical methods, and many primary and secondary metabolites have been recorded in the plant. *B. ceiba* is composed of various phytochemicals that vary significantly, depending on plant part, geographical source, developmental stage, extraction solvent and analytical methods used. Traditional phytochemical tests have been based primarily on colorimetric reactions and precipitation tests, but modern analytical investigations have adopted modern chromatographic techniques. A wide range of chemical classes is present, which gives a plausible biochemical explanation for the various pharmacological activities reported for the plant [29].

Flavonoids

The flavonoids are one of the most biologically significant class of secondary metabolites reported in *Bombax ceiba*. Preliminary phytochemical screening and quantitative assays of different extracts of flowers, leaves, bark and other aerial parts of the plant have shown the presence of

flavonoids. The plant has been reported for phytochemical studies of compounds of flavanol and flavone subclasses, which include quercetin and kaempferol related compounds. Polar and moderate polar solvents like methanol, ethanol, hydroethanolic mixture and aqueous alcohol are generally used for effective extraction of flavonoids. They have been traditionally measured by the aluminium chloride colorimetric method for total flavonoids content and chromatographic methods like TLC, HPTLC, HPLC and LC-MS are more specific for identifying the compounds [30] [31].

Phenolic compounds

Another large class of phyto-constituents found in *Bombax ceiba* are the phenols. The extracts from the leaves, bark and flowers of this plant have been reported to contain total phenomenon, as well as other plant tissues. Phenolic constituents are typically extracted with polar solvents, such as methanol, ethanol, aqueous ethanol, and water. The Folin-Ciocalteu method is a common technique for spectrophotometric estimation of total phenolics and HPLC, LC-MS and like chromatographic procedures are more accurate methods for the identification of individual phenolic compounds. The phenolic acid and

polyphenolic constituents are thought to make significant contributions to plant chemistry [32].

Tannins

Tannins, polyphenolic compounds, are high molecular weight compounds that have been reported in various parts of *Bombax ceiba*, including the bark, roots and other plant materials that are traditionally used as astringents. Ferric chloride, gelatin or lead acetate and similar tests are commonly used for qualitative determination of tannins and spectrophotometric methods can be used to quantitate tannins. The presence of tannins may offer a chemical basis for the traditional application of *B. ceiba* for diarrhea, dysentery, wounds, excess secretions and inflammatory diseases [33].

Terpenoids

The terpenoids are a structurally diverse group of natural products reported in *Bombax ceiba*. Phytochemical analysis has shown the presence of different parts of the plant such as triterpenoid and related terpenoid constituents in various plant parts, especially in bark and roots. Ethanol, methanol, chloroform, petroleum ether, ethyl acetate, or other solvents, depending on the polarity of the compounds to be extracted, are often used in traditional extraction processes. Conventional phytochemical tests can be used for preliminary identification including Salkowski reaction and Liebermann-Burchard reaction, while chromatographic and spectroscopic methods give more information about the structure [34].

Steroids and Phytosterols

Studies on the species and related members of the Bombacoideae subfamily have reported the presence of a group of phytosterols including β -sitosterol and related sterols in the species. The extraction method used determines whether these relatively non-polar compounds are extracted with petroleum ether, hexane, chloroform or ethyl acetate. They are initially identified by Liebermann-Burchard and Salkowski reactions, and then confirmed by chromatography like GC-MS, HPLC, LC-MS, or NMR spectroscopy [35].

Saponins

Phytochemical screening of some extracts of *Bombax ceiba* has revealed the presence of saponins. The compounds have amphiphilic structures composed of one or more sugar units and a lipophilic aglycone. They are usually extracted with polar solvents, such as aqueous ethanol and methanol. The foam test is used for preliminary identification, and advanced chromatographic methods will be necessary for the characterization of individual molecules of saponin [36].

Alkaloids

In the preliminary phytochemical screening, extracts of selected *Bombax ceiba* have been reported to contain alkaloids, but in-depth characterization of its individual alkaloid constituents is still limited. Dragendorff's reagent, Mayer's reagent, Wagner's reagent and Hager's reagent are common traditional reagents for the detection of alkaloids. Alkaloids can be extracted from plant material with an aqueous solution containing an acid, then an organic solvent. Qualitative detection must, however, be treated with caution as it may give false positive or non-specific results as result of color reactions [37].

Glycosides

Glycosidic compounds have been reported in a couple of phytochemical studies of *Bombax ceiba*. Glycosides are composed of a sugar portion (the glycosidic group) and an aglycone portion, which can be sugars, peptides, or lipids, that contribute significantly to the biological activity of the glycosides. Polar extracts of the plant may contain flavonoids glycosides, phenolic glycosides, etc. The plant may contain flavonoids glycosides, phenolic glycosides, etc. in polar extracts. Aqueous alcohols, methanol and ethanol, are often used to extract rich glycoside fractions. Specific color reactions can be used for preliminary identification, while HPLC and LC-MS are better suited to the identification of individual glycosidic structures [38].

Anthocyanins

The red to scarlet color of *Bombax ceiba* flowers creates interest in the possibility of the existence of anthocyanin pigments and related phenolic colorants. Anthocyanins are water-soluble flavonoid pigments that are found in flowers and fruits and are the most common pigments for giving red, purple and blue coloration. They are usually recovered from the plant material with acidified methanol, ethanol or alcoholic water, and can be quantified using UV-visible spectrophotometry, HPLC and LC-MS methods [39].

Carotenoids

The lipophilic pigments, such as carotenoids, might also be involved in the coloration and chemical diversity of *Bombax ceiba*, especially in flowers and in other pigmented tissues. The usual solvents used for extraction of carotenoids are non-polar or moderately non-polar solvents such as hexane, acetone, petroleum ether, and solvent mixtures. They can be characterized by UV – visible spectroscopy, HPLC and photodiode-array detection, or mass spectrometry [40].

Fatty acids

Bombax ceiba seeds are a rich source of lipids and fatty acids which make them a great potential for further phytochemical research. Seed oil is usually extracted mechanically or by Soxhlet extraction with non-polar solvents like hexane, or petroleum ether. The oil removed from the plants can then be transformed to fatty-acid methyl esters and identified using either GC-MS or gas chromatography with flame-ionization detection. Seed oil reported constituents include major fatty acids (saturated and unsaturated) which may include palmitic acid, stearic acid, oleic acid, and linoleic acid (proportions may vary depending on geographical origin and seed processing method) [41].

Proteins and amino acids

Apart from secondary metabolites, *Bombax ceiba* seeds are also rich in primary nutritional metabolites such as proteins and amino acids. The seed proteins also have significance as they could play a role in the nutrition of the plant and offer

possibilities for functional food and nutraceutical uses. Protein extraction is usually performed by aqueous buffers, alkaline solutions or any other suitable solvent followed by analytical characterization by electrophoretic, chromatographic or mass-spectrometric methods. The amino acid composition of a protein can be determined by hydrolysis and chromatography [37].

Poly sugars and plant gum

Polysaccharides are especially significant components of the gum or exudate of *Bombax ceiba*. Mucilaginous and demulcent, the gum is traditionally used and valued for its medicinal properties. Generally, plant gums are complex polysaccharide molecules that are formed from several monosaccharide units, and can be extracted by aqueous methods, then precipitated and purified. Monosaccharide composition analysis, FTIR spectroscopy, chromatographic techniques, molecular-weight determination and NMR spectroscopy are all forms of analytical characterization [42].

Pharmacological/ biological activities

The different parts of *Bombax ceiba* L. (flowers, bark, root, leaves, gum and seeds) have been explored for their pharmacological significance through extracts and isolated constituents. According to the available evidence, they have antioxidant, anti-inflammatory, antimicrobial, antidiabetic, hepatoprotective, analgesic, antipyretic, cytotoxic and other biological activities. .

Antioxidant activity

The biological property of *Bombax ceiba*, which has been the most studied, is its antioxidant activity. Flower, leaf, bark, root and seed extracts have been shown to possess free-radical scavenging activity in various experimental systems. Several oxidative stress assays are commonly used, such as the DPPH assay, ABTS assay, ferric-reducing antioxidant power assay, nitric oxide scavenging assay, and others. The presence of phenolic compounds, flavonoids, tannins, mangiferin, catechins and other polyphenolic compounds are

generally reported as antioxidant potential. The *B. ceiba* seed oil has also been studied recently, and the GC-MS analysis showed the presence of various chemical constituents and antioxidant activity [25].

Anti-inflammatory activity

Based on experimental evidence, *Bombax ceiba* shows anti-inflammatory activity. In vitro and in vivo models have been used to investigate crude extracts and isolated constituents such as the membrane stabilization, protein denaturation, and carrageenan induced paw edema. Anti-inflammatory activity of protocatechuic acid methyl ester (PCE) isolated from *B. ceiba* has recently been reported, including experimental inflammation models. The compound was later studied computationally, and this represents a recent trend of moving away from screening crude extracts and towards the characterization of individual bioactive compounds.

Potential anti-inflammatory compounds include flavonoids, phenolic compounds, mangiferin, triterpenoids, and phytosterols. These compounds could potentially affect inflammatory mediators and signaling pathways, such as oxidative stress pathways and cytokine regulation [43, 44].

Antimicrobial activity

The antimicrobial activity of various extracts of *Bombax ceiba* is studied in relation to selected microorganisms of the bacterial and fungal group. The activity of the activity seems to have been dependent on the plant part, the solvent system, the concentration of the extract, and the test organism. Antimicrobial activity could be attributed to the phenolic compounds, flavonoids, tannins, terpenoids and other secondary metabolites which may help in the disruption of microbial membrane, inhibition of microbial enzymes, nucleic acid synthesis and metabolic pathways [45].

Antibacterial activity

Extracts from *Bombax ceiba* have been reported to have inhibitory effects on selected Gram-positive and Gram-negative bacteria during antibacterial investigations. Laboratory studies have shown that

extracts from seeds have activities against microorganisms like *Escherichia coli* and *Staphylococcus aureus* using an aqueous-based, methanolic, ethanolic, and acetone-based extraction system. The antibacterial activities of other parts of the plant have also been studied.

These effects observed may be due to the combination of several phytochemicals. Polyphenols and tannins can interact with the protein and membranes of microorganisms, while terpenoids (and other lipophilic compounds) can disrupt membrane integrity [44].

Antifungal activity

Antifungal activity has been reported less so than antibacterial activity. Some extracts have shown anti-fungal activity against various fungi in preliminary studies, although there is not as much evidence for this. There are multiple strains of fungi, multiple extraction methods, concentrations, and experimental endpoints, which makes it difficult to draw conclusive statements about the effectiveness of the different antifungals.

Standardized susceptibility testing procedures, minimum inhibitory and fungicidal concentrations, possible mechanisms of action and toxicity to mammalian cells should be explored in future studies. In the absence of such evidence, antifungal activity cannot yet be considered a definitive pharmacologic activity of *B. ceiba* [46].

Anti diabetic and Anti-hyperglycemic activity

Antidiabetic and antihyperglycemic properties are an important experimental research field since metabolic disorders are a traditional use of *B. ceiba* in several communities. In vitro enzyme inhibition assays and animal models of hyperglycemia have been taken into consideration to research extracts from various plant parts, especially the flowers and leaves. The proposed biological basis is attributed to the presence of Mangiferin, flavonoids, phenolic compounds and other secondary metabolites with potential importance to modulate oxidative stress, carbohydrate metabolism and glucose homeostasis.

The possible mechanisms are inhibition of carbohydrate-digesting enzymes, antioxidant defense improvement, modulation of insulin-related pathways, and prevention of hyperglycemia-associated with oxidative damage. But there are significant shortcomings. In many studies, no comparison of the activity of standardized extracts or isolated compounds in chemically induced diabetic animal models are provided. Long-term effects, insulin sensitivity, pancreatic histology (histomorphology), pharmacokinetics, and clinical relevance are also not frequently studied. The present study thus suggests *B. ceiba* as a good source for extracting anti-hyperglycemic compounds and warrants further research on the use of the plant for diabetes treatment in humans [47].

Hepatoprotective activity

Extracts and preparations of *Bombax ceiba* have been reported to have hepatoprotective activity, especially the roots and exudates. Protective effects have been studied in chemically induced models of liver injury. Commonly believed mechanisms involved in the proposed antioxidant activity, reduction of lipid peroxidation and the preservation of endogenous antioxidant enzymes. Antioxidants such as polyphenols, flavonoids and other antioxidants compounds might also play a protective role against oxidative liver damage [48].

Anti-ulcer activity

A few traditional and experimental studies indicate the gastroprotective and antiulcer activity of *Bombax ceiba*, especially those involving the flowers and polyphenol antioxidants. The mechanisms suggested are antioxidant activity, reduction of oxidative mucosal damage, modulation of gastric secretion and mucosal protection.

Though there have been some early encouraging results, this zone is not very well developed. There is minimal evidence from limited experimental models, and a lack of information on active constituents, dose standardization, mechanism of mucosal protection and comparative efficacy. Before antiulcer activity can be deemed well established, further studies with well-established

ulcer models and proven biochemical and histological endpoints are needed [49].

Analgesic activity

Experimental studies have reported *Bombax ceiba*'s analgesic properties. The activity can be related to phenolic acids, flavonoids, terpenoids, and anti-inflammatory substances that can act on peripheral inflammatory mediators or pain-related signaling pathways.

But there are relatively few studies of analgesia, and they are mostly conducted in animal models. Another drawback is that it is not straightforward to see if the reduction of pain occurs at the target site through a direct analgesic effect or if it is secondary to the anti-inflammatory activity that is also seen. Central and peripheral analgesic mechanisms should be distinguished, receptor-level interactions should be studied and bioactive constituents responsible should be identified in future studies. So, existing data suggests a preliminary analgesic effect, which needs to be further validated with a mechanism [50].

Antipyretic activity

The antipyretic activity has been mentioned in various traditional pharmacological reviews of *B. ceiba*. Some extracts have been shown in experiments to lower raised temperature in animal models. The mechanisms that have been proposed include modulation of pathways related to inflammatory mediators and prostaglandins.

However, this activity is not as well-studied as antioxidant or antihyperglycemic properties. There are still only a few independent studies and detailed molecular mechanisms that are not well examined. Therefore, the antipyretic effect of the plant should be considered as preliminary experimental evidence, which needs to be replicated and standardized [51].

Antidiarrheal activity

The traditional utilization of *Bombax ceiba* in diarrhea and dysentery might be related partly to its constituents that contain tannin and astringent. Tannins have a potential to interact with proteins and may also decrease digestive secretions in the gastrointestinal tract, which may

give a biochemical basis for the traditional uses of gastrointestinal tract.

The evidence for antidiarrheal activity is somewhat less complete than those for antioxidant activity, however, there is direct evidence for this activity. Standardized experimental models of secretory and motility-related diarrhea should be used in future studies to study the accumulation of fluid in the intestine, electrolyte balance, gastrointestinal transit and molecular mechanisms. The use of antidiarrhea should be regarded as an ethnomedicinal formulation or a limited experimental basis with a low level of evidence, and not as a valid therapeutic use, until further proof is available [52].

Anti-cancer activity

Multiple experimental studies indicate the extracts or purified compounds from *Bombax ceiba* exhibits cytotoxic or antiproliferative properties. The extracts of the flowers have exhibited activity against human renal adenocarcinoma cells in laboratory assays, and the root extracts have exhibited cytotoxicity in brine shrimp lethality assays. It is noteworthy that protocatechuic acid methyl ester has been recently isolated from *B. ceiba* and its anti-tumor activity has been explored in a model of Ehrlich ascites carcinoma. The study revealed inhibition of tumor growth and molecular modifications related to apoptosis and tumor proliferation such as changes in the expression of p53 and BCL2.

The findings are scientifically meaningful, as they go beyond crude extract screening to the process of compound isolation and mechanism evaluation. However, cytotoxicity against cancer does not necessarily imply anticancer activity. Most studies are still basic laboratory research, and selectivity to malignant over normal cells needs to be carefully examined. There is also a lack of pharmacokinetics and bioavailability, toxicity, tumor-specific models, and human clinical trials. Thus, *B. ceiba* is not an anticancer medicine, but rather a novel source of compounds for anticancer research studies [53].

Neuroprotective activity

In wider phytopharmacological literature, some phytochemicals found in *B. ceiba* e.g., mangiferin and polyphenolic compounds have been shown with neuroprotective potential. Cholinesterase-related activity has also been mentioned in reviews of *B. ceiba*. But direct evidence for neuroprotection using well-designed disease-specific models is still scarce.

Moving forward, the mechanisms of neuronal oxidative stress, neuroinflammation, cholinergic signaling, mitochondrial dysfunction, and behavioral outcomes in valid neurodegenerative disease models should be explored [54].

Wound healing activity

Bombax ceiba is prominently used in traditional medicine for wound healing with a strong emphasis on bark, gum, and other parts. The healing property may be attributed to tannins, polysaccharides, flavonoids and antioxidant elements, giving a sound rationale for the investigation of the wound healing property. These constituents can affect inflammation, oxidative stress, microbial growth, collagen deposition and tissue regeneration.

However, experimental wound-healing studies are still relatively few and are generally controlled. Wound contraction, epithelialization time, collagen content, hydroxyproline level, angiogenesis, histopathological, and microbial burden should be investigated in the future. Standardized formulations of the topical treatments should also be explored. Thus, wound healing activity is a very promising research field which is not completely validated [55].

Antiarthritic activity

Anti-inflammatory properties of *B. ceiba* offer a rationale to investigate the antiarthritic potential of this plant. Direct data from validated arthritis models, however, are still limited. Because arthritis is a complex disease of immune, inflammatory, cartilage and bone pathways, inflammation related assays must not be used alone to determine antiarthritic efficacy.

Further research using validated models of inflammatory arthritis, and assessment of

cytokines, oxidative stress markers, joint histology, cartilage degradation and bone markers is encouraged. Currently, antiarthritic activity is insufficiently characterized [56].

Anthelmintic activity

It is reportedly used in traditional medicine for parasitic and worm infestations. But the evidence obtained from experimental studies on its anthelmintic activity is not as well documented as some other activities.

Standardized testing with appropriate helminth species is necessary, concentration-response relationships need to be established, and comparisons with known anthelmintic drugs are needed to ensure reliable evaluation. Active compounds isolation and the investigation of their action-mechanisms are also required. This activity is thus an initial zone that needs to be systematically validated [57].

Antiviral activity

In reviews of *Bombax ceiba* and its phytochemical studies, anti-HIV and antiviral properties have been referred. In contrast, there is limited direct antiviral evidence as opposed to antioxidant, antimicrobial, or metabolic evidence.

Extensive replication, the presence of standardized viral models, and mechanistic investigation are lacking, and thus strong conclusions cannot be drawn. Antiviral research in the future should utilize validated cell culture systems, viral replication assays, cytotoxicity analysis, and identification of molecular targets. As of today, antiviral activity is considered as an emerging research field instead of demonstrated biological activity [58].

Activity related to reproduction and fertility

Bombax ceiba has a significant traditional history of use for reproductive health, such as an aphrodisiac, uterine tonic and treatment for reproductive disorders. It is noteworthy that gum and Mochras are of special historical importance in the field of Unani and Ayurvedic medicine. In the past, it was used for leucorrhea, excessive discharge and reproductive weakness.

The traditional use/validation distinction is more pertinent in this area, however. Evidence of

fertility, reproductive hormones, sperm parameters, sexual behavior or reproductive safety is limited and variable. Additionally, reproductive toxicity has not been sufficiently studied. Further research should employ standardized extracts and validated reproductive models and include an assessment of potential benefits and risks. Claims for reproduction should thus not be described as clinically proven effects, as in traditional reproduction [59].

Current research gaps

There are several key research gaps that hinder the potential of *Bombax ceiba* as a traditional medicinal plant moving into an evidence-based pharmaceutical or nutraceutical application. Firstly, there is a significant lack of standardized extracts. The detailed information about botanical authentication, extraction yield, solvent composition, chemical fingerprints and concentrations of marker compounds is frequently not detailed in many published studies. It makes it difficult to reproduce and makes it difficult to compare results between studies.

Secondly, there is very limited human clinical evidence. Most of the reported pharmacological effects have been carried out in vitro or in animals and there is a lack of well-designed randomized controlled trials. Thirdly, there is a lack of pharmacokinetic information. Absorption, distribution, metabolism, bioavailability and elimination of major constituents like mangiferin or other phytochemicals in *B. ceiba* preparations specifically need to be investigated.

Fourth, there is still a lot of work to be done in terms of toxicological assessment. Acute toxicity test is not enough to determine safety. Long term studies, genotoxicity, reproductive toxicity, herb-drug interactions, and chronic toxicity are required. Comprehensive chemical characterization and safety assessment is very important for this to be recommended for pharmaceutical or nutritional use, especially when considering seed oil.

Fifth, there has been little attention given to geographical and environment variation. Phytochemical composition can significantly vary due to climate, soil composition, season, plant age

and harvesting conditions. Therefore, it is necessary to have comparative studies of authenticated samples from various geographical regions. Likewise, comparative studies of flowers, bark, roots, leaves, seeds, gum and seed oil are inadequate.

Another is the lack of use of validated biomarkers and mechanisms. Most studies provide only general biological results and fail to study molecular targets, signaling pathways, changes in gene expression, protein regulation, or metabolite changes. A more extensive correlation between chemical composition and pharmacological effect may be achieved by means of advanced metabolomics, proteomics and transcriptomics.

Future perspectives

Moving forward, further studies on *Bombax ceiba* should be based on systematic and evidence-based approaches instead of the number of preliminary activity reports. Isolation and structural characterization of novel compounds should be coupled with bioactivity guided fractionation of extracts and fractions to determine compounds which are truly responsible for specific biological effects. The metabolomic approaches, both untargeted and targeted, involving LC-MS/MS, UHPLC-MS, GC-MS, and NMR can be applied to generate full-featured chemical fingerprints and to compare various plant parts and geographical populations.

Molecular docking and computational methods can be used to support the generation of mechanistic hypotheses and identification of potential molecular targets. Computational predictions, however, should not be viewed as evidence of therapeutic activity without the proper in-vitro, cellular, and in-vivo experimental validation. Computational chemistry could be coupled to mechanistic pharmacology to speed up prioritization of potential compounds.

Pharmacokinetic studies need to be conducted to examine the bioavailability and metabolism of major constituents and to establish whether the in-vivo concentrations of the pharmacologically active constituents can be reached that have been shown in-vitro. Standardized extracts should be prepared by means of validated chemical markers,

reproducible extraction method and batch to batch quality control. Acute, subchronic, chronic, genotoxic, reproductive and interaction studies should be used in a comprehensive toxicological evaluation.

The two most important areas of future research are seed and seed oil. Studies of oxidative stability, nutritional quality, possible bioactivity and toxicological safety should be complemented by comprehensive GC-MS and lipidomic profiling. Comparative evaluation of the extraction methods may also lead to the discovery of methods which maximize the desired constituents and minimize potentially undesirable constituents.

Sustainable cultivation and harvesting, which may be jeopardized by increased commercialization interest in medicinal plants, should also be considered. Long-term utilization may be supported by good agricultural and collection practices, botanical authentication, controlled cultivation and the conservation of genetically diverse populations.

Last, formulation of pharmaceutical and nutraceutical products should only be attempted after proper standardization, pharmacokinetic studies, safety testing, and efficacy studies have been completed. Possible formulations include standardized extracts, topical formulations, functional foods, and products from seeds. Formulation development must be based on reproducible scientific data and not just traditional claims.

Conclusion

Bombax ceiba medicinally important tree, chemically diverse with long ethnomedicinal history. Experimental investigations show that this plant has several biological activities like antioxidant, anti-inflammatory, antimicrobial, anti-hyperglycemic, hepatoprotective and cytotoxic properties. However, the evidence for each activity is variable and many findings are at the in-vitro or preclinical level. Chemically characterized constituents and mechanistic pathways have been a recent thrust, with significant gaps still in the areas of standardization, identification of active compounds,

pharmacokinetics, long-term safety, and efficacy in the clinical arena.

There is a need to get to stage 2, which is mechanism-specific and clinically relevant research, from preliminary screening. The advanced analytical methods, such as LC-MS/MS, GC-MS, metabolomics, proteomics, and bioactivity-guided fractionation can enhance the understanding of the chemical composition-biological effects correlation. Likewise, computer predictions must be tested in the lab, and any successful standard preparations must be thoroughly tested for toxicity and clinical effects. Seed oil and other relatively under-explored components of plants are significant research opportunities. In conclusion, *B. ceiba* can be considered as a valuable source of bioactive compounds and potential pharmaceutical or nutraceutical ingredients, although most of its reported therapeutic effects warrant more robust experimental and clinical studies to support their translation into clinical practice.

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