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Phytochemistry and Pharmacology of *Bombax* and *Pseudobombax*: Evidence-Based Insights and Current Limitations

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Abstract

The genera *Bombax* and *Pseudobombax* (Malvaceae) are recognized for their use in traditional medicine. This study provides a systematic review and hierarchical appraisal of their phytochemical and pharmacological profiles. A total of 35 studies were analyzed, revealing 22 distinct biological activities. Our findings uncover a significant "taxonomic bias," with research disproportionately focused on *Bombax ceiba*, while other species and the entire *Pseudobombax* genus remain underexplored. Hierarchical assessment shows that while *Bombax* achieves Level I evidence in metabolic and organ-protective areas through validated *in vivo* models, *Pseudobombax* is largely restricted to preliminary Level II and III screenings. Antioxidant activity is the most frequently reported property across both genera, yet it remains primarily anchored in *in vitro* assays with limited physiological correlation. Furthermore, a "morphological bias" was identified, as investigations favor stem bark and leaves due to methodological convenience and ethnobotanical guidance, often neglecting seeds and roots. This review highlights a persistent translational gap characterized by a lack of pharmacokinetic data and molecular mechanism elucidation. We conclude that future research must shift from repetitive exploratory screenings toward standardized, mechanism-oriented investigations and broader taxonomic exploration to substantiate these genera as viable candidates for modern drug discovery.

Keywords: translational gap; preclinical validation; taxonomic bias

1. Introduction

The use of medicinal plants continues to be a pivotal strategy for the discovery of bioactive compounds and the development of new therapeutic agents. Plant-derived metabolites have demonstrated significant pharmacological relevance, reinforcing the necessity of scientific validation for traditionally used species. Among plant families with recognized medicinal potential, Malvaceae stands out due to its wide distribution in tropical and subtropical regions and its richness in species capable of producing structurally diverse secondary metabolites [1].

Within this family, the genera *Bombax* and *Pseudobombax* (subfamily Bombacoideae) comprise large tropical tree species distributed mainly across Central and South America [2]. Species from these genera have been traditionally employed to treat inflammatory disorders, infections, metabolic diseases, and skin-related conditions. In recent years, experimental studies have reported several biological activities associated with extracts and isolated compounds, including antioxidant, anti-inflammatory, antimicrobial, cytoprotective, and metabolic regulatory effects [3–5]. These properties are frequently attributed to phenolic compounds, flavonoids, and terpenoids.

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Despite the growing number of studies, scientific evidence regarding the phytochemical composition and pharmacological activities of *Bombax* and *Pseudobombax* remains fragmented. Most investigations focus on a limited number of species, particularly *Bombax ceiba*, while most of the genera remains poorly explored. Additionally, existing studies often evaluate different plant parts and employ heterogeneous experimental approaches, hindering direct comparisons and limiting broader conclusions regarding their pharmacological relevance [6]. This gap is particularly evident in high-biodiversity regions, such as Brazil, where native species represent a vast, yet underexplored, reservoir of bioactive molecules [7,8].

Considering these limitations, the present study aims to compile and critically analyze the available literature on the phytochemical constituents and experimentally validated pharmacological activities of *Bombax* and *Pseudobombax*. This narrative review seeks to address the following questions: (i) which pharmacological activities present the strongest experimental evidence; (ii) which species and plant parts remain underexplored; and (iii) what are the main gaps that should guide future phytochemical and pharmacological investigations. Ultimately, this work intends to contribute to a better understanding of the therapeutic potential of these genera and support future efforts in natural product discovery.

2. Materials and Methods

2.1. Study Design

This study was conducted as a narrative literature review aiming to compile and critically analyze available scientific evidence regarding the phytochemical constituents and pharmacological activities of species belonging to the genera *Bombax* and *Pseudobombax*. The narrative review approach was selected due to the heterogeneity of experimental designs, plant parts evaluated, extraction methods, and biological models reported in the literature, which limits the applicability of systematic review methodologies and meta-analysis. Although this approach allows broader conceptual interpretation, it may present limitations related to study selection bias and variability in methodological quality.

2.2. Literature Search Strategy

The literature search was conducted between March and December 2025 using the PubMed and ScienceDirect databases, considering their relevance in pharmacology, phytochemistry, ethnopharmacology, and natural product research.

The following descriptors were used:

- "Bombax"
- "Bombax AND pharmacological activity"
- "Pseudobombax"
- "Pseudobombax AND pharmacological activity"

Search terms were combined using Boolean operators ("AND" and "OR") to expand the retrieval of relevant publications. Only studies published between 2013 and 2025 and written in English were considered.

2.3. Eligibility Criteria

Studies were selected based on the following criteria: (i) presentation of experimental evaluation of biological or pharmacological activities; (ii) investigation of extracts, fractions, or isolated compounds from *Bombax* or *Pseudobombax* species; (iii) availability of full-text access; and (iv) publication as peer-reviewed original research articles.

Studies were excluded if they: (i) mentioned the target genera only superficially; (ii) lacked experimental biological or pharmacological data; or (iii) were conference abstracts, editorials, or duplicated publications. Review articles were excluded to prioritize primary experimental data;

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however, relevant reviews were consulted to support the contextual interpretation and discussion of findings.

2.4. Study Selection Process

The initial search identified 1,702 publications related to *Bombax* and 270 publications related to *Pseudobombax*. After applying the defined temporal filter (2013–2025), 1,173 studies related to *Bombax* and 168 related to *Pseudobombax* remained.

Titles and abstracts were screened to evaluate relevance according to the eligibility criteria. Following this step, 31 articles involving *Bombax* species and 6 articles involving *Pseudobombax* species were selected for full-text analysis and data extraction.

A flow chart summarizing the study selection process is presented in Figure 1.

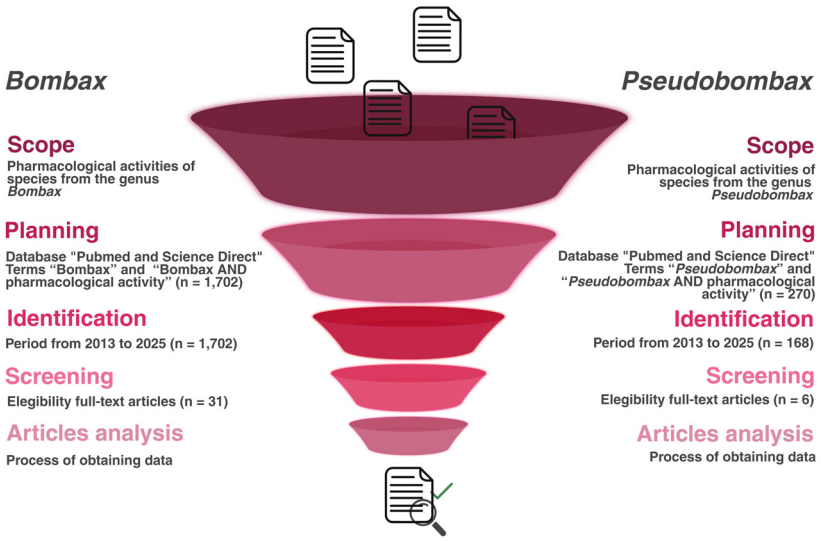

Figure 1. Flowchart summarizing the literature search and study selection process for *Bombax* and *Pseudobombax* species (2013-2025). Numbers represent records identified, screened and included according to predefined eligibility criteria. Created in https://BioRender.com.

2.5. Data Extraction and Synthesis

All selected studies underwent full-text analysis. Data were extracted and systematically organized into a descriptive matrix comprising the following variables:

- Botanical species investigated;
- Plant part(s) utilized;
- Type of extract, fraction, or isolated compound;
- Biological or pharmacological activity evaluated;
- Experimental model employed (*in vitro*, *in vivo*, or *in silico*);
- Identified bioactive compounds (when applicable).

Subsequently, the gathered information was qualitatively categorized and synthesized to identify patterns of pharmacological activity, phytochemical diversity, and potential research gaps within the field.

2.6. Assessment of Evidence Quality

Due to the diversity of experimental approaches, a formal risk-of-bias tool was not applied. Instead, the overall quality of evidence was assessed qualitatively by considering the experimental models used, reproducibility of findings, and level of biological validation.

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Most studies involved *in vitro* assays or animal experimental models, with limited clinical validation. Additionally, considerable variability was observed regarding extraction methods, phytochemical characterization, and pharmacological protocols, which restricts direct comparison between studies and highlights the need for standardized experimental designs in future investigations.

2.7. Hierarchical Classification of Evidence Strength

To contextualize the robustness of the available data and to avoid overstatement of therapeutic potential, the reported biological activities were classified according to experimental depth (Table 1). This hierarchical framework allows a structured interpretation of the evidence beyond mere frequency of reported activities.

Table 1. Hierarchical classification of evidence strength for reported biological activities in *Bombax* and *Pseudobombax* species.

Evidence Level	Definition	Minimum Experimental Criteria	Typical Study Design Observed	Main Limitations Identified
Level I	*In vivo* validation with biochemical and/or molecular mechanistic markers	Established disease model + biomarker quantification + dose–response analysis	Rodent disease models with biochemical endpoints	Limited molecular pathway validation; absence of clinical follow-up
Level II	Functional *in vivo* evidence without detailed mechanistic elucidation	Disease model + functional outcome measurement	Animal models without molecular confirmation	Lack of target-specific validation
Level III	*In vitro* cellular or biochemical assays	Cell viability, enzyme inhibition, or radical-scavenging assays	Cell culture models, DPPH/ABTS assays	No *in vivo* confirmation; limited physiological relevance
Level IV	Exploratory or limited evidence	Qualitative or preliminary assays	Screening assays without replication or controls	Insufficient experimental rigor

3. Results

3.1. Study Identification and Selection

By December 2025, the initial database search identified 1,702 publications related to the genus *Bombax* and 270 related to *Pseudobombax* (Figure 1). Following the application of temporal and eligibility criteria, 1,173 and 168 articles remained, respectively. Subsequent screening of titles and abstracts led to the selection of 31 *Bombax* species articles and 6 *Pseudobombax* species articles for full-text analysis. Ultimately, only 37 studies met the inclusion criteria for qualitative synthesis, representing approximately 2.6% of the initially screened *Bombax* records and approximately 3.5% of the *Pseudobombax* records. This significant reduction (Figure 1) underscores the paucity of studies specifically addressing phytochemical characterization coupled with experimentally validated pharmacological activity within the established scope.

3.2. General Characteristics of the Evidence Base

A structured synthesis of the included studies (encompassing investigated species, plant organs, extraction strategies, phytochemical profiling, and reported biological activities) is detailed in Tables 2 and 3 and visually summarized in Figures 2 and 3. The overall evidence landscape reveals a marked asymmetry between the two analyzed genera.

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Table 2. Reported biological activities of *Bombax* species, including experimental models, plant parts, and associated metabolites.

Biological activity	Experimental model	Plant part / Extract	Main associated metabolites	Reference
***Bombax ceiba* L.**				
Antioxidant	*In vitro* (DPPH, ABTS, FRAP); in vivo (MDA reduction)	Leaves (methanolic), flowers, calyces, stamens, bark	β-Sitosterol; gallic acid; rutin; scopoletin; mangiferin; flavonoids; tannins	[4,9–18]
Antiviral	*In vitro* (RSV cytopathic effect and plaque reduction assays)	Flowers	Mangiferin	[18]
Hypoglycemic / Antidiabetic	*In vivo* (diabetic rodent models; α-glucosidase/α-amylase inhibition)	Leaves, calyces, roots, flowers	Mangiferin; protocatechuic acid; quercetin; isovitexin	[10,19]
Anti-obesity	*In vivo* (high-fat diet model)	Stem bark	Lupeol; flavonoids	[20]
Antibacterial	*In vitro* (MIC assays against Gram-positive and Gram-negative bacteria)	Flowers, roots, seeds	Not chemically characterized	[14,21,22]
Anti-inflammatory	*In vivo* (carrageenan-induced edema); in vitro (NO inhibition)	Leaves	Not chemically characterized	[23]
Anti-arthritic	*In vivo* (adjuvant-induced arthritis; IL-6, TNF-α reduction)	Aerial parts	Not chemically characterized	[3]
Nephroprotective	*In vivo* (STZ-induced nephropathy)	Leaves	Mangiferin	[24]
Hepatoprotective	*In vivo* (ethanol-induced liver injury; ALT/AST reduction)	Leaves, flowers	Polyphenols; flavonoids; saponins	[25]
Cytotoxic / Anticancer	*In vitro* (MCF-7, HepG2, A549, HIO180, Huh7 cell lines)	Flowers, bark	β-Sitosterol; gallic acid; flavonoids; phenolics	[4,26–28]
Anthelmintic	*Ex vivo* helminth model	Flowers	Not chemically characterized	[29]
Antihyperglycemic	*In vivo* (T2DM rodent model)	Leaves	Mangiferin; isoorientin; vitexin; isomangiferin; isovitexin; quercetin hexoside; 2′-trans-O-coumaroyl mangiferin; nigricanoside	[13]
Antihyperlipidemic	*In vivo* (lipid profile modulation)	Leaves	Same as above	[13]
Antiglycation	*In vitro* (AGE formation inhibition; BSA–methylglyoxal model)	Flower calyx	Myo-inositol; scopoletin; D-sedoheptulose; succinic acid; xylitol	[30]
Gastrointestinal (laxative effect)	*In vivo* (intestinal motility assays)	Flowers (aqueous extract)	Chlorogenic acid; rutin	[31]
Anti-hemorrhagic	*In vitro* (human endometrial stromal cells; ESR1, CD56, SDF-1 expression)	Dried resin	Not chemically characterized	[32]
Osteogenic / Anti-osteoporotic	*In vivo* (bone mineral density in Wistar rats)	Bark	Lupeol; β-sitosterol; gallic acid	[33]
Gastroprotective / Antiulcerogenic activity	*In vivo* study in rats with experimentally induced gastric ulcers	Gum (plant exudate)	Alkaloids, flavonoids, glycosides; interaction with targets such as EGFR, SRC, COX2, MMPs	[34]
***Bombax costatum* Pellegr. & Vuillet**				
Anti-inflammatory / Anti-arthritic	*In vivo* (prostaglandin E_2-induced edema; Freund's adjuvant arthritis model)	Stem bark	Not chemically characterized	[35]

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Antihistaminic	*In vivo* (clonidine-induced catalepsy)	Stem bark	Not chemically characterized	[35]
Antidepressant	*In vivo* (sucrose preference, forced swim test; corticosterone, serotonin, dopamine levels)	Stem bark	Not chemically characterized	[36]
Antiamnesic	*In vivo* (Morris water maze; object recognition test)	Stem bark	Not chemically characterized	[36]
***Bombax buonopozense* P. Beauv.**				
Antiplasmodial	*In vivo* (*Plasmodium berghei*-infected mice)	Root bark	Not chemically characterized	[37]

Only experimentally validated studies meeting inclusion criteria were considered. When available, structurally characterized metabolites are listed.

Of the 37 included studies, 83.7% focused on *Bombax*, while only 16.2% investigated *Pseudobombax*, demonstrating a pronounced taxonomic imbalance. Within *Bombax*, *B. ceiba* predominated with 28 publications, representing 90.3% of the genus-specific research and 75.7% of the total selected articles. Conversely, other species such as *B. costatum* and *B. buonopozense* were minimally represented. In the six studies involving *Pseudobombax*, the distribution was more equitable among *P. ellipticum* (33.3%), *P. marginatum* (33.3%), *P. simplicifolium* (16.7%) and *P. parvifolium* (16.7%), with no single species showing research dominance comparable to *B. ceiba*.

This concentration pattern suggests that research efforts have been driven primarily by historical usage, geographic accessibility, and legacy phytochemical data rather than by systematic taxonomic or comparative strategies. Consequently, pharmacological generalizations at the genus level remain constrained, particularly for *Pseudobombax*, where the evidence base is sparse.

The organ-specific distribution of biological activities for the genera *Bombax* and *Pseudobombax* are visually synthesized in Figures 2 and 3, respectively. While these mappings underscore a multifaceted pharmacological profile, the broader evidence landscape reveals a significant taxonomic disparity. Regarding plant morphology, leaves, flowers, and stem bark were the most frequently investigated organs overall. However, this distribution varies strictly by taxa: *Bombax* species were evaluated across a wide range of plant parts (Figure 2), whereas *Pseudobombax* investigations remain largely restricted to stem bark and flowers (Figure 3). Such preference appears to reflect research convenience and geographic accessibility rather than demonstrated phytochemical superiority. Consequently, the scarcity of systematic organ-to-organ comparisons limits robust conclusions regarding tissue-specific bioactive potential, particularly for the less-studied *Pseudobombax*.

Methodological heterogeneity was also pervasive across literature. Experimental designs varied significantly in extraction procedures, the depth of chemical characterization, and the selection of biological validation models. Several studies relied on crude extracts lacking standardized profiling, and inter-study comparability was often hindered by inconsistent reporting of experimental parameters. Such variability constrains reproducibility and complicates the integrative interpretation of pharmacological evidence.

Collectively, the current body of literature reveals a research landscape characterized by taxonomic concentration, organ-level selectivity, and methodological disparity. While both genera exhibit significant biological activity and phytochemical richness, the uneven distribution of investigative efforts highlights the urgent need for broader species coverage, standardized analytical profiling, and systematic comparative approaches.

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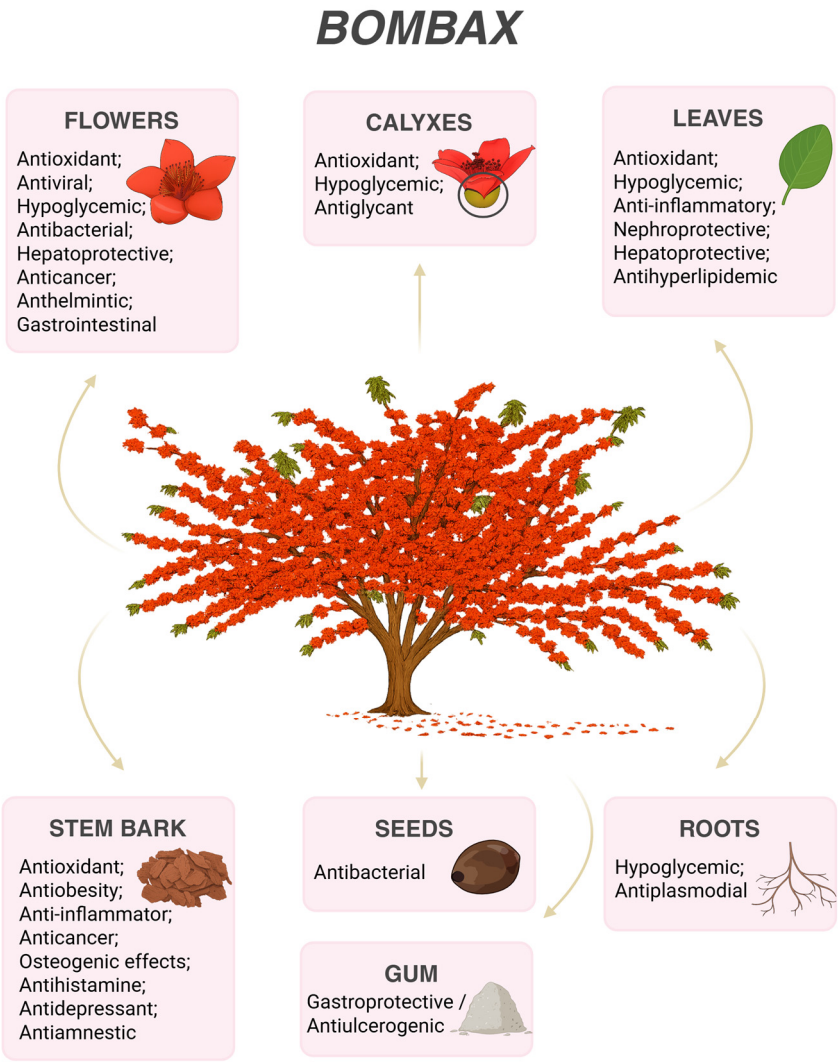

Figure 2. Organ-specific pharmacological landscape of the genus *Bombax*. The infographic illustrates the diversity of biological activities identified in literature for specific plant parts, including flowers, calyxes, leaves, stem bark, seeds, and roots. Note the high concentration of reported activities for flowers and stem bark, reflecting their prominence in pharmacological research. Created in https://BioRender.com.

Table 3. Reported biological activities of *Pseudobombax* species, including experimental models, plant parts, and associated metabolites.

***Pseudobombax parvifolium* A.DC.**				
Activity	**Model**	**Plant part**	**Key metabolites**	**Ref.**
Antioxidant	*In vivo* (lipid peroxidation reduction; SOD and GPx increase in rodents)	Stem bark	Loliolide	[5]
***Pseudobombax ellipticum* (Kunth) Dugand**				
Activity	**Model**	**Plant part**	**Key metabolites**	**Ref.**
Antioxidant	*In vitro* (DPPH, FRAP, iron chelation assays)	Stem bark; fresh flowers	Phenolic acids; flavonoids; pelargonidin-3-O-glucoside; cyanidin-3-O-rutinoside; rutin; kaempferol-3-O-glucoside	[38,39]

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Antibacterial	*In vitro* (biofilm inhibition against *Pseudomonas aeruginosa*)	Stem bark	Phenolic acids; flavonoids	[38]
Antisickling	*In vitro* (reduction of sickled erythrocytes)	Fresh flowers	Pelargonidin-3-O-glucoside; cyanidin-3-O-rutinoside; rutin; kaempferol-3-O-glucoside	[39]
***Pseudobombax simplicifolium* A. Robyns**				
Antioxidant	*In vitro* (DPPH, ABTS, TAC)	Stem bark	Phenolic compounds, flavonoids, tannins	[40]

***Pseudobombax ellipticum* cultivar alba Hort.**

Activity	Model	Plant part	Key metabolites	Ref.
Antisickling	*In vitro* (erythrocyte sickling assay)	Fresh flowers	Pelargonidin-3-O-glucoside; cyanidin-3-O-rutinoside; rutin; kaempferol-3-O-glucoside	[39]
Antioxidant	*In vitro* (DPPH, iron chelation assays)	Stem bark; fresh flowers	Pelargonidin-3-O-glucoside; cyanidin-3-O-rutinoside; rutin; kaempferol-3-O-glucoside	[39]

***Pseudobombax marginatum* (A. St.-Hil.) A. Robyns**

Activity	Model	Plant part	Key metabolites	Ref.
Anti-inflammatory	*In vivo* (carrageenan-induced paw edema in Wistar rats)	Stem bark	Not chemically characterized	[41]
Antinociceptive	*In vivo* (acetic acid-induced writhing test)	Stem bark	Not chemically characterized	[41]
Cytoprotective / Genoprotective	*In vitro* (comet assay; DNA damage reduction)	Stem bark	Flavonoids; tannins; coumarins	[42]

Only experimentally validated studies meeting inclusion criteria were considered. When available, structurally characterized metabolites are listed.

3.3. Phytochemical Characterization: Analytical Scope and Depth

As summarized in Tables 2 and 3, the phytochemical characterization of *Bombax* and *Pseudobombax* species revealed a predominance of phenolic compounds, flavonoids, tannins, alkaloids, terpenoids, and polysaccharides. Analytical characterization primarily relied on HPLC, LC–MS, and GC–MS platforms to identify secondary metabolites. While *B. ceiba* presented a more extensive profile, with repeated identification of mangiferin, beta-sitosterol, gallic acid, and lupeol, reporting for other species was considerably more limited. The analytical focus was largely qualitative, with most studies identifying major chemical classes without performing precise quantification of individual constituents.

Despite these technological advances, phytochemical reporting consistently exhibited critical methodological gaps, including:

- Lack of comprehensive quantitative profiling: Studies often focused on qualitative identification without determining compound concentrations.
- Non-standardized extraction protocols: High variability in solvent systems and extraction parameters limits inter-study comparability.
- Absence of batch reproducibility assessments: Minimal data exists regarding the chemical consistency of plant materials across different harvests or geographic locations.
- Underutilization of bioassay-guided fractionation: Systematic isolation strategies to identify active principles remain scarce.

In many instances, biological activities were attributed to broad chemical classes rather than structurally confirmed isolated compounds. Although compounds such as mangiferin, beta-sitosterol, gallic acid, lupeol, and various flavonoid derivatives were frequently identified in *B. ceiba*, a direct causal linkage between specific molecules and their pharmacological effects remain insufficiently demonstrated.

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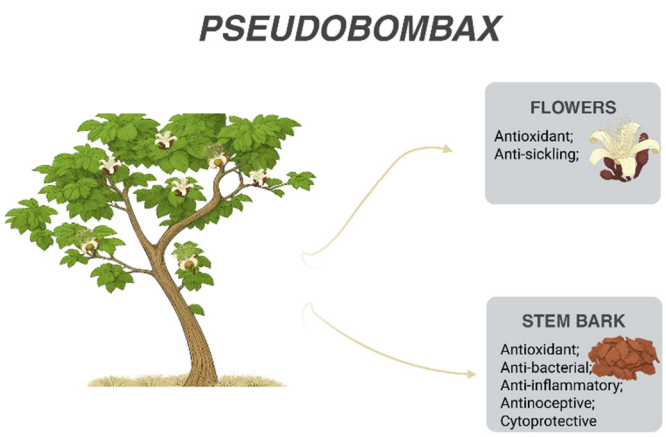

Figure 3. Organ-specific pharmacological landscape of the genus *Pseudobombax*. The diagram summarizes the biological activities associated with plant organs investigated in the included studies. In contrast to *Bombax*, research on *Pseudobombax* is markedly concentrated on stem bark and flowers, with reported activities such as anti-sickling, antinociceptive, and cytoprotective effects. This comparatively restricted mapping highlights the existing gaps in the pharmacological exploration of other plant parts within this genus. Created in https://BioRender.com.

3.3. Genus Bombax

3.3.1. Biological Activities: Critical Appraisal of Experimental Evidence

The range of reported pharmacological activities is extensive (Table 2); however, the depth of experimental validation varies substantially across the literature.

3.3.2. Antioxidant Activity

Antioxidant capacity represents the most frequently evaluated biological property (Figure 2). Nevertheless, most studies relied on chemical-based assays, such as DPPH, ABTS, and FRAP, which measure radical-scavenging capacity *in vitro* but do not necessarily translate to physiological redox modulation. Only a limited number of investigations evaluated in vivo oxidative stress biomarkers, and mechanistic insights into endogenous antioxidant signaling pathways (e.g., Nrf2/ARE) were rarely explored. Consequently, while antioxidant potential is consistently reported, its translational relevance remains largely unverified.

3.3.3. Antimicrobial and Antiviral Activities

Antimicrobial activity has been predominantly assessed via in vitro growth inhibition assays (Table 2). While inhibitory effects were observed against multiple pathogenic strains, there is a lack of data regarding pharmacokinetics, systemic toxicity, or efficacy in in vivo infection models. Similarly, antiviral activity (against respiratory syncytial virus - RSV) was demonstrated exclusively in cell-based systems. The absence of mechanistic elucidation and in vivo validation limits the extrapolation of these findings toward therapeutic applications.

3.3.4. Cytotoxic and Anticancer Effects

Cytotoxic effects against various tumor cell lines have been reported (Table 2). However, the evidence is frequently constrained by significant methodological limitations, including:

- Lack of selectivity indices: Failure to evaluate toxicity in non-tumoral (healthy) cell lines.

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- Absence of mechanistic confirmation: Lack of data regarding apoptosis induction or cell cycle arrest pathways.
- Inadequate validation: Absence of *in vivo* tumor xenograft models.
- Pharmacological gaps: No assessment of pharmacodynamic or pharmacokinetic profiles.

As illustrated in Figure 2, cytotoxicity represents a secondary research focus compared to antioxidant screening. Therefore, current findings should be interpreted as preliminary cytotoxic screening rather than substantiated anticancer efficacy.

3.3.5. Metabolic and Organ-Protective Effects

Metabolic and organ-protective activities, including antidiabetic, antihyperlipidemic, nephroprotective, hepatoprotective, and antiosteoporotic effects, were primarily evaluated in rodent models (Table 2). Although improvements in biochemical surrogate markers were commonly observed, molecular pathway validation and target-specific analyses were frequently omitted. While specific secondary metabolites were hypothesized to drive these effects, the definitive molecular mechanisms and their direct targets remain insufficiently established.

3.3.6. Hierarchical Assessment of Evidence Strength

The hierarchical classification framework was applied to all included studies, resulting in the categorization of 23 distinct pharmacological activities (Table 4). Level II evidence predominated (34.8%) with Level I (34.8%), followed by Level III (21.7%), and Level IV (8.7%) (Table 4).

Although 69.6% of the reported activities (Levels I–II) involved *in vivo* experimental models, only 34.8% fulfilled the criteria for robust validation supported by established disease models and quantifiable biochemical or molecular biomarkers (Level I). Besides, no clinical-level evidence was identified among the included studies.

Activities classified as Level I were primarily associated with metabolic and organ-protective effects, including hypoglycemic, antihyperlipidemic, hepatoprotective, nephroprotective, anti-inflammatory, gastroprotective and osteogenic properties, generally employing validated *in vivo* models and objective biochemical endpoints. Level II activities comprised functional *in vivo* evidence lacking detailed mechanistic elucidation (e.g., antiobesity, antiarthritic, and antidepressant effects). Conversely, Level III evidence was largely restricted to *in vitro* systems, particularly antioxidant and antibacterial assays, which represent a substantial proportion of the exploratory investigations (Figures 2 and 3). Level IV corresponded to preliminary validation, such as *ex vivo* or isolated cellular systems without systemic confirmation.

Table 4. Hierarchical classification and critical appraisal of pharmacological activities reported for *Bombax* species.

Species	Biological Activity	Evidence Level	Critical Appraisal	Major Methodological Gaps
Bombax ceiba	Antioxidant	III	Activity consistently demonstrated *in chemical* and cellular assays; physiological relevance remains to be fully established	Limited *in vivo* confirmation; insufficient redox pathway characterization; extract standardization inconsistently reported
Bombax ceiba	Antiviral	III	Promising *in vitro* antiviral effect	Absence of *in vivo* validation; limited host–virus interaction analysis
Bombax ceiba	Hypoglycemic / Antidiabetic	I	Supported by established metabolic models with biochemical endpoints	Molecular target identification and pharmacokinetic profiling remain limited
Bombax ceiba	Antiobesity	II	Functional efficacy demonstrated in diet-induced models	Lack of mechanistic investigation of metabolic signaling pathways
Bombax ceiba	Antibacterial	III	Reproducible *in vitro* inhibition observed	*In vivo* infection models and toxicity evaluation not reported

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Bombax ceiba	Anti-inflammatory	I	Demonstrated activity in validated inflammatory models	Deeper cytokine profiling and pathway-level analyses are warranted
Bombax ceiba	Antiarthritic	II	Functional improvement reported in induced arthritis models	Limited molecular mediator assessment
Bombax ceiba	Nephroprotective	I	Biochemical and functional renal protection observed	Mechanistic renal signaling pathways remain underexplored
Bombax ceiba	Hepatoprotective	I	Activity supported by biochemical and histological parameters	Further molecular-level validation desirable
Bombax ceiba	Anticancer / Cytotoxic	III	Cytotoxic potential demonstrated in tumor cell lines	Selectivity in normal cells and *in vivo* tumor validation lacking
Bombax ceiba	Anti-helminthic	IV	Preliminary biological activity observed	Requires in vivo confirmation and pharmacodynamic assessment
Bombax ceiba	Antihyperglycemic	I	Consistent metabolic improvements reported	Direct causative linkage with identified metabolites requires clarification
Bombax ceiba	Antihyperlipidemic	I	Classical lipid biomarkers modulated	Gene-level pathway investigation limited
Bombax ceiba	Antiglycation	III	*In vitro* AGE inhibition demonstrated	Physiological validation absent
Bombax ceiba	Gastrointestinal	II	Functional improvement observed *in vivo*	Mechanistic basis remains insufficiently explored
Bombax ceiba	Anti-hemorrhagic	IV	Activity suggested in cellular systems	Systemic hemostatic validation required
Bombax ceiba	Osteogenic / Antiosteoporotic	I	Bone density improvements suggest translational relevance	Molecular osteogenic signaling requires further investigation
Bombax ceiba	Gastroprotective / Antiulcerogenic activity	I	Robust dual-model preclinical design; integrated metabolomics + network pharmacology	No clinical data; small sample (n=6); mechanism not experimentally validated; no PK or biomarker analysis
Bombax costatum	Anti-inflammatory / Antiarthritic	II	Functional *in vivo* evidence reported	Mediator-level confirmation limited
Bombax costatum	Antihistaminic	II	Activity supported in pharmacological models	Receptor-level validation not reported
Bombax costatum	Antidepressant	II	Behavioral improvements observed	Neurochemical biomarker evaluation limited
Bombax costatum	Antiamnesic	II	Cognitive benefits demonstrated	Synaptic and neuroplasticity markers not investigated
Bombax buonopozense	Antiplasmodial	II	Activity demonstrated in relevant infectious model	Expanded replication and molecular target characterization desirable

3.4. Genus Pseudobombax

3.4.1. Biological Activities: Critical Appraisal of Experimental Evidence

The range of reported pharmacological activities for *Pseudobombax* is markedly more restricted compared to *Bombax* (Table 3), with research efforts concentrated on a limited number of species and plant organs.

3.4.2. Antioxidant Activity

As illustrated in Figure 3, antioxidant capacity is one of the few properties investigated for this genus. Like the trends observed in *Bombax*, these evaluations relied almost exclusively on *in vitro* radical-scavenging assays (e.g., DPPH and ABTS). There is an absence of *in vivo* redox modulation studies or mechanistic investigations into cellular antioxidant pathways. Consequently, the antioxidant potential of *Pseudobombax* remains at a preliminary screening stage, lacking physiological validation.

3.4.3. Antimicrobial Activity

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Antimicrobial investigations in *Pseudobombax* are largely confined to *in vitro* assessments of stem bark extracts (Table 3). Although inhibitory effects against specific bacterial strains have been identified, the evidence base lacks diversity in tested pathogens and is devoid of *in vivo* efficacy trials, toxicity profiles, or pharmacokinetic data. No antiviral activities were identified for this genus within the evaluated timeframe.

3.4.4. Anti-Inflammatory and Antinociceptive Effects

A significant portion of the research on *Pseudobombax* (mainly *P. marginatum*) focuses on anti-inflammatory and antinociceptive properties. While these studies often employ *in vivo* functional models, such as paw edema or writhing tests, they frequently lack molecular depth. The specific mediators involved and the potential modulation of signaling pathways (e.g., COX-2 or cytokine cascades) remain insufficiently characterized.

3.4.5. Other Biological Properties

Other reported effects, such as anti-sickling and cytoprotective activities, represent isolated investigative efforts (Figure 3). These findings, while promising, are predominantly based on *in vitro* or *ex vivo* models without systemic confirmation. The lack of broader pharmacological screening across different plant parts, such as leaves or roots, limits the understanding of the genus's full therapeutic potential.

3.4.6. Hierarchical Assessment of Evidence Strength

The hierarchical classification of *Pseudobombax* research highlights a fragmented evidence landscape. In contrast to *Bombax*, where Level I evidence is more prevalent, *Pseudobombax* studies are largely situated at Levels II and III (Table 5).

- Level II: Predominates in studies concerning anti-inflammatory and antinociceptive effects, where *in vivo* functional efficacy is demonstrated but mechanistic details are sparse.
- Level III: Comprises the bulk of antioxidant and antimicrobial research, restricted to *in vitro* systems with low translational predictability.
- Level IV: Includes preliminary reports on anti-sickling and specific cellular protective effects lacking systemic validation.

Collectively, this distribution (Figure 3) reveals that the evidence base for *Pseudobombax* is not only smaller in volume but also lower in hierarchical strength. The reliance on a few species and the focus on stem bark research emphasize a significant taxonomic and morphological bias, precluding robust generalizations at the genus level.

Table 5. Critical appraisal of biological activities reported for *Pseudobombax* species.

Species	Biological Activity	Evidence Level	Critical Appraisal	Major Methodological Gaps
Pseudobombax parvifolium	Antioxidant	I	*In vivo* antioxidant modulation supported by reduced lipid peroxidation and increased SOD and GPx activity	Absence of pathway-level redox signaling analysis; lack of standardized extract characterization
Pseudobombax ellipticum	Antioxidant	III	Consistent radical scavenging and metal chelation activity in chemical assays	No *in vivo* confirmation; limited mechanistic elucidation of cellular antioxidant pathways
Pseudobombax ellipticum	Antibacterial	III	Demonstrated inhibition of biofilm formation against *Pseudomonas aeruginosa*	Lack of *in vivo* infection models; absence of toxicity and pharmacokinetic evaluation
Pseudobombax ellipticum	Antisickling	III	Reduction of erythrocyte sickling observed *in vitro*, suggesting hematological relevance	No *in vivo* validation; mechanism of hemoglobin stabilization not investigated

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Pseudobombax ellipticum (cv. alba)	Antioxidant	III	Reproducible antioxidant activity in chemical assays	Limited comparative phytochemical profiling; no biological validation beyond *in vitro* assays
Pseudobombax ellipticum (cv. alba)	Antisickling	III	*In vitro* erythrocyte stabilization demonstrated	Translational hematological assessment and systemic validation lacking
Pseudobombax simplicifolium	Antioxidant	IV	Multiple complementary antioxidant assays; phytochemical screening and phenolic/flavonoid quantification; exclusively *in vitro*	No *in vivo*/clinical validation; no cytotoxicity or dermatological safety tests; no photostability/formulation studies; no compound isolation or mechanistic assays
Pseudobombax marginatum	Anti-inflammatory	II	Functional reduction of carrageenan-induced edema *in vivo*	Limited cytokine profiling; absence of molecular inflammatory pathway analysis
Pseudobombax marginatum	Antinociceptive	II	Significant reduction in nociceptive responses in validated rodent models	Mechanistic differentiation between central and peripheral pathways not performed
Pseudobombax marginatum	Cytoprotective / Genoprotective	III	DNA damage reduction demonstrated in comet assay	No systemic confirmation; responsible bioactive compounds not fully isolated

4. Discussion

The present systematic review reveals not merely a disparity in research volume between *Bombax* and *Pseudobombax*, but a structural imbalance in scientific maturity, mechanistic depth, and translational progression. Although both genera display a wide array of reported biological activities, the evidence landscape is unevenly distributed, with research efforts disproportionately concentrated on a limited number of species and plant organs. This dual taxonomic and morphological bias restricts a comprehensive pharmacological interpretation of these taxa and may obscure chemically distinct and therapeutically relevant species that remain underexplored.

Within *Bombax*, the overwhelming predominance of *B. ceiba* likely reflects its broad geographical distribution and long-standing incorporation into traditional Asian medical systems [6]. However, this concentration has shaped the pharmacological identity of the genus in a way that may not accurately represent its internal chemical diversity. While B. ceiba demonstrates relatively advanced experimental validation in metabolic, organ-protective, and osteogenic contexts, other species such as *B. costatum* and *B. buonopozense* remain largely confined to functional screening stages. This imbalance narrows phytochemical discovery pipelines and limits opportunities to identify structurally novel metabolites potentially restricted to less-investigated taxa. From a drug discovery perspective, this concentration represents a clear constraint on chemical diversification and translational innovation.

A similar bias is evident at the morphological level. Leaves, flowers, and stem bark dominate the experimental landscape across both genera. Although ethnobotanical guidance partially explains this preference, methodological convenience appears equally influential. As discussed by Penido et al. [43], these organs are readily accessible and, in the case of bark and leaves, often available year-round, facilitating repeated experimental use. Nevertheless, the scarcity of systematic organ-to-organ comparative studies precludes definitive conclusions regarding tissue-specific bioactive superiority. Importantly, flowers are metabolically specialized structures enriched in flavonoids and anthocyanins [44], and the antisickling activity reported in *Pseudobombax* flowers underscores how underexplored organs may harbor clinically relevant bioactivities. Conversely, the predominant use of stem bark, particularly in *Pseudobombax*, raises sustainability concerns, as excessive harvesting can compromise plant viability and ecological balance [45]. These findings reinforce the necessity of aligning pharmacological exploration with conservation-aware research strategies.

Perhaps the most consequential finding of this review is the persistence of a pronounced translational gap. Antioxidant activity represents the most frequently reported biological property across both genera; however, its predominance is largely driven by chemical assays such as DPPH

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and ABTS, which provide limited physiological relevance. The reliance on rapid screening methodologies reflects a broader research paradigm oriented toward exploratory bioactivity detection rather than mechanistically grounded pharmacological development. In *Bombax*, several biological properties have progressed beyond this stage into validated *in vivo* models supported by biochemical and histological endpoints, suggesting a more advanced position along the preclinical validation continuum. In contrast, *Pseudobombax* remains predominantly positioned in early investigative phases, with activities frequently lacking systemic confirmation, molecular target identification, or pharmacokinetic characterization. Although both genera exhibit methodological limitations in extract standardization and pathway-level analysis, these constraints are more structurally limiting for *Pseudobombax*, where foundational translational infrastructure remains insufficiently developed.

Collectively, this asymmetry delineates two distinct developmental trajectories. *Bombax* represents a genus with consolidating pharmacological credibility that now requires deeper mechanistic refinement and chemical standardization to sustain translational progression. *Pseudobombax*, in contrast, emerges as a largely untapped phytochemical reservoir situated at the threshold of systematic exploration. Advancing the field will require a deliberate transition from repetitive exploratory screenings toward integrated, mechanism-oriented investigations combining phytochemical fingerprinting, target-based validation, and pharmacokinetic assessment. Expanding taxonomic coverage beyond *B. ceiba*, implementing comparative organ profiling, and strengthening molecular-level confirmation are essential to transform descriptive evidence into clinically meaningful insight.

Ultimately, the current body of literature reflects not the full pharmacological potential of *Bombax* and *Pseudobombax*, but rather the limitations of prevailing investigative paradigms. Bridging this gap demands a strategic reorientation from exploratory abundance to mechanistic precision. Only through such a shift can these genera transition from ethnopharmacological relevance to evidence-driven candidates within the modern drug discovery framework.

5. Conclusions

This systematic review provides a comprehensive and hierarchically structured appraisal of the pharmacological evidence available for the genera *Bombax* and *Pseudobombax*, revealing a pronounced asymmetry in research depth, taxonomic coverage, and translational maturity. While *Bombax*, particularly *B. ceiba*, exhibits a relatively advanced preclinical evidence profile supported by validated *in vivo* models and biochemical endpoints, the genus remains heavily centralized around a single species, limiting broader phytochemical and pharmacological generalization. In contrast, *Pseudobombax* is positioned at an earlier stage of scientific development, with most activities confined to exploratory or functionally descriptive investigations that lack mechanistic and pharmacokinetic refinement.

Across both genera, antioxidant activity predominates; however, it is largely anchored in chemical assays with limited physiological correlation, highlighting a persistent translational gap between *in vitro* screening and clinically relevant validation. Additionally, the preferential investigation of specific plant organs, particularly stem bark and flowers, reflects methodological and ethnobotanical influences rather than systematic phytochemical comparisons, raising both scientific and sustainability concerns regarding plant survival.

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Abbreviations

The following abbreviations are used in this manuscript:

A549	Human alveolar basal epithelial cell line
ABTS	2,2@azino-bis(3-ethylbenzothiazoline-6-sulfonic acid
AGE	Advanced Glycation End-products
ALT	Alanine Aminotransferase
ARE	Antioxidant Response Element pathway
AST	Aspartate Aminotransferase
BSA	Bovine Serum Albumin
CD56	Cluster of Differentiation 56
COX-2	Cyclooxygenase-2
DNA	Deoxyribonucleic Acid
DPPH	2,2-diphenyl-1-picrylhydrazyl
EGFR	Epidermal Growth Factor Receptor
ESR1	Estrogen Receptor 1
FRAP	Ferric Reducing Antioxidant Power
GC-MS	Gas Chromatography–Mass Spectrometry
GPx	Glutathione Peroxidase
HepG2	Human hepatocellular carcinoma cell line
HIO180	Human intestinal organoid 180
HPLC	High-Performance Liquid Chromatography
Huh7	Human hepatocellular carcinoma cell line
LC-MS	Liquid Chromatography–Mass Spectrometry
MCF-7	Human breast adenocarcinoma cell line
MDA	Malondialdehyde
MIC	Minimum Inhibitory Concentration
MMPs	Matrix Metalloproteinases
Nrf2	Nuclear factor erythroid 2–related factor 2 pathway
PK	Pharmacokinetics
RSV	Respiratory syncytial virus
SDF-1	Stromal cell–Derived Factor 1
SOD	Superoxide Dismutase
SRC	Proto-oncogene tyrosine-protein kinase Src
STZ	Streptozotocin
T2DM	Type 2 Diabetes Mellitus
TAC	Total Antioxidant Capacity

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