Scientific Research Publishing

Advances in Bioscience and Biotechnology, 2026, 17(6), 199-218
https://www.scirp.org/journal/abb
ISSN Online: 2156-8502
ISSN Print: 2156-8456

Exploring the Therapeutic Potential of *Acacia* Species in Texas: A Narrative Review

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How to cite this paper: Gamis, M.C.L. and Ynalvez, R.A. (2026) Exploring the Therapeutic Potential of *Acacia* Species in Texas: A Narrative Review. *Advances in Bioscience and Biotechnology*, **17**, 199-218.
https://doi.org/10.4236/abb.2026.176014

Received: March 26, 2026
Accepted: June 7, 2026
Published: June 10, 2026

Abstract

Acacia sensu lato in Texas comprises 17 native or naturalized species now distributed across the segregate genera *Vachellia*, *Senegalia*, *Acaciella*, and *Acacia* sensu stricto. These taxa are ecologically important and have longstanding ethnomedicinal value among Native American and Mexican American communities. This narrative review synthesizes phytochemical and pharmacological evidence from 1960 to 2025, integrating ethnobotanical reports with experimental studies. Texas *Acacia* species produce diverse secondary metabolites—including flavonoids, tannins, alkaloids, terpenoids, saponins, and phenolic acids—associated with antioxidant, antimicrobial, anti-inflammatory, cytotoxic, and antiparasitic activities. Research has focused primarily on *Vachellia farnesiana*, *Senegalia berlandieri*, *Senegalia greggii*, and *Acaciella angustissima*, which exhibit the strongest phytochemical and bioactivity profiles. However, most investigations remain preliminary, relying on variable extraction methods, limited compound isolation, and minimal *in vivo* validation. Ethnomedicinal uses for fever, inflammation, gastrointestinal ailments, and skin conditions are documented but remain insufficiently verified through contemporary pharmacological testing. Advancing the therapeutic potential of Texas *Acacia* species will require standardized phytochemical workflows, robust pharmacological assays, toxicological evaluation, and integration of ethnobotanical knowledge with metabolomics and translational research approaches.

Keywords

Acacia, Texas Ethnobotany, Phytochemical Profiling, Pharmacological Activity

1. Taxonomic Framework and Biogeographic Patterns of Texas *Acacia sensu lato*

The group historically referred to as *Acacia* is among the most taxonomically

complex lineages within the Fabaceae. Once treated as a single expansive genus, *Acacia sensu lato* has undergone extensive phylogenetic revision, resulting in its division into several segregate genera: *Vachellia*, *Senegalia*, *Acaciella*, and *Acacia* sensu stricto. These changes have generated considerable confusion in the literature, particularly for North American species whose names have shifted over the past several decades [1]-[3]. For clarity, this review uses *Acacia sensu lato* (*s.l.*) to refer collectively to all Texas species formerly placed in *Acacia*.

Texas hosts 17 native or naturalized species across these genera (**Table 1**). Their greatest diversity occurs in the Rio Grande Plains, Edwards Plateau, and Trans-Pecos region, where climatic gradients, soil heterogeneity, and disturbance regimes shape distinct assemblages [4]-[7]. These species occupy ecological niches ranging from semi-arid thornscrub to desert canyons and riparian corridors, reflecting broad adaptive strategies within *Acacia s.l.*

Table 1. Genera and species of *Acacia sensu lato* present in Texas.

Genus	Species	Common Name	Status
Acacia	*dealbata*	Silver Wattle	Naturalized
	schaffneri	Twisted *Acacia*	Native
	stenophylla	Shoestring *Acacia*	Naturalized
Acaciella	*angustissima*	Prairie *Acacia*	Native
	leucothrix	Whitehair *Acacia*	Native
	shrevei	Shreve's *Acacia*	Native
	suffrutescens	Shrubby Acaciella	Native
Senegalia	*berlandieri*	Guajillo/Berlandier *Acacia*	Native
	greggii	Catclaw *Acacia*	Native
	roemeriana	Roemer *Acacia*	Native
	wrightii	Wright *Acacia*	Native
Vachellia	*constricta*	Whitethorn *Acacia*	Native
	farnesiana	Huisache/Sweet *Acacia*	Native
	rigidula	Blackbrush *Acacia*	Native
	schottii	Schott *Acacia*	Native
	texana	Texas Huisache/Chaparro Prieto	Native
	vernicosa	Varnish *Acacia*	Native

1.1. Habitat and Distribution

The distribution of *Acacia s.l.* across Texas reflects a combination of ecological specialization, soil preferences, and historical biogeographic processes. Species richness is highest in the Rio Grande Plains and South Texas brushlands, where thornscrub communities are dominated by *V. farnesiana*, *S. berlandieri*, and *A.*

schaffneri. These species occupy calcareous soils, rocky slopes, and disturbed rangelands, often forming dense thickets that provide critical forage and wildlife cover [4] [6]-[10]. In West Texas, *S. greggii* and *V. constricta* are characteristic of arroyos, gravel washes, and canyon systems in the Big Bend and Trans-Pecos regions. Their distributions are shaped by episodic water availability, coarse substrates, and extreme temperature fluctuations [10]-[12]. More geographically restricted taxa, such as *V. schottii* and *V. vernicosa*, occur primarily on limestone outcrops and in desert foothills, reflecting adaptations to xeric conditions and shallow, alkaline soils [10] [12] [13].

Several species demonstrate broad ecological tolerance. *V. farnesiana* extends into central counties, thriving in heavy clay soils and highly disturbed environments such as roadsides and pastures [4] [6] [7] [14]. *Acaciella angustissima* occupies sandy loams and upland prairies, providing forage for livestock and wildlife, although mild toxicity has been documented at high intake levels [6] [7] [15] [16]. Naturalized species—including *A. dealbata* and *A. stenophylla*—are confined mainly to horticultural plantings and disturbed urban landscapes in Central Texas, underscoring the role of human-mediated introduction in shaping local floristic composition [6] [10] [17] [18].

Collectively, the Texas *Acacia* flora spans semi-arid thornscrub, desert canyons, riparian corridors, and upland prairies. This ecological breadth underscores their importance in rangeland dynamics, wildlife habitat, and ethnobotanical traditions, while also revealing gaps in systematic ecological and pharmacological research.

1.2. Taxonomic Notes and Diagnostic Characteristics

Synonymy. Several species historically classified under *Acacia* have been reassigned to segregate genera, including *A. farnesiana* → *V. farnesiana* and *A. greggii* → *S. greggii* [19] [20].

Family and Subfamily. All Texas species belong to the subfamily Mimosoideae within the family Fabaceae.

Diagnostic Traits. Shared morphological features include bipinnate leaves, stipular spines (especially prominent in *Vachellia*), glandular nodes at the petiole base, and distinctive inflorescence types—globose heads (e.g., *V. farnesiana*) versus spicate forms (e.g., *S. wrightii*) [19] [21]. These taxonomic distinctions underpin ecological interactions, phytochemical variation, and traditional uses.

2. Botanical Diversity, Cultural Significance, and Phytochemical Richness of Texas *Acacia*

With the taxonomic and biogeographic context established, the botanical and cultural significance of Texas *Acacia s.l.* becomes clearer. For centuries, species such as *Vachellia farnesiana*, *Senegalia berlandieri*, and *Acaciella angustissima* have played integral roles in Native and Hispanic-Mexican traditions. Their bark, pods, and gum exudates have been used to prepare medicinal decoctions for ailments

including diarrhea, sore throat, skin infections, fever, and wounds [4] [8] [22]. Beyond their ethnomedicinal value, these plants provide forage for livestock, serve as sources of fuelwood, and contribute to the production of floral perfume, embedding them deeply in the socio-economic fabric of South-Central North America [4].

Over the past three decades, extensive phytochemical research has revealed a remarkable diversity of specialized metabolites in Texas *Acacia s.l.* Gallotannins, flavonols, and flavan-3-ols contribute to plant defense, pigmentation, and antioxidant activity [22]-[26]. Condensed tannins further support herbivore deterrence and nutrient cycling [4] [27]. Unique diterpenes—including phyllocladane and seco-oxacassane types—underscore the chemical complexity of these taxa and suggest potential pharmacological applications [25] [28]. Additional constituents such as polyisoprenoids, arabinogalactan proteins, and diverse phenethylamine alkaloids—particularly in *V. rigidula* and *S. berlandieri*—highlight the ecological and biochemical significance of these species [29]-[34]. Foundational and contemporary studies collectively emphasize the importance of continuing investigation into these metabolite classes.

Together, these botanical, cultural, and chemical perspectives illustrate the multifaceted importance of Texas *Acacia s.l.* Yet understanding their full value requires examining how these phytochemical constituents translate into measurable biological effects. The following section, therefore, shifts from botanical and chemical diversity to pharmacological activities, toxicological considerations, and research gaps that shape their therapeutic potential.

3. Pharmacological Potential, Toxicological Considerations, and Research Gaps in Texas *Acacia*

3.1. Antimicrobial, Antioxidant, and Anti-Inflammatory Activities

Evidence for antimicrobial, antioxidant, and anti-inflammatory activity in Texas *Acacia s.l.* is derived predominantly from *in vitro* assays and animal-based models, with no corresponding human clinical data to date. A subset of Texas *Acacia s.l.* has demonstrated compelling pharmacological properties, producing secondary metabolites with antimicrobial, antioxidant, anti-inflammatory, and enzyme-modulatory activities. Extracts from *V. farnesiana* pods exhibit strong vibriocidal activity against *Vibrio cholerae*, attributed to methyl gallate, and show anti-inflammatory effects *in vivo* [34]. Leaves of *V. rigidula* exhibit potent antioxidant activity and are effective against resistant bacterial strains [24] [29]. Additional studies on *V. farnesiana* bark further support its antioxidant and anti-inflammatory potential [35]. Together, these findings indicate promising bioactivity but remain confined to preclinical experimental systems.

3.2. Metabolic, Enzyme Modulatory, and Neuroprotective Effects

Evidence supporting metabolic and neurological effects is based largely on *in vitro* enzyme inhibition studies and controlled rodent models, with no validation in

human subjects. Several species have been investigated for potential roles in metabolic and neurological disorders. *Acaciella angustissima* pod extracts reduce hyperglycemia and oxidative stress in diabetic rats, partially through modulation of *α*-amylase, *α*-glucosidase, and angiotensin converting enzyme activity [36]. Phenolic compounds from *Acacia dealbata* inhibit enzymes associated with cognitive decline and glucose metabolism, with effects demonstrated *in vitro* and supported by mechanistic animal studies [26] [37]. These results are comparable to the hypoglycemic, anti-inflammatory, and neuroprotective properties of the non-Texas-native *V. nilotica* [37]. Diterpenoids from *Acacia schaffneri* roots exhibit selective cytotoxicity against cancer cell lines *in vitro*, underscoring their pharmacological promise, though this remains preliminary [28]. Collectively, these results suggest therapeutic relevance but warrant cautious interpretation in the absence of translational or clinical validation.

3.3. Toxicological Considerations and Ethnoveterinary Context

Current toxicological understanding is derived from phytochemical isolation studies, livestock observations, and ethnoveterinary reports, rather than standardized toxicology trials. In particular, phenethylamine alkaloids identified in *Senegalia berlandieri* and *Vachellia rigidula* are consistently associated with adverse neurological effects in grazing animals, including locomotor ataxia and the "limber leg" syndrome documented in livestock systems [28] [32] [38]. These effects are supported by both alkaloid characterization studies and field observations, thereby establishing a clear toxicological risk under conditions of uncontrolled exposure.

Importantly, these documented livestock toxicities are not indicators of therapeutic potential but rather reflect dose-, route-, and species-specific sensitivities in real-world grazing contexts. From a pharmacological perspective, phenethylamine alkaloids remain of interest because they interact with central nervous system pathways and monoaminergic signaling, mechanisms relevant to the stimulant, neuroactive, and enzyme-modulating effects observed in related compound classes. Consequently, their presence signals bioactivity rather than inherent therapeutic suitability.

Ethnoveterinary reports further highlight this duality, describing traditional medicinal or functional uses of these taxa alongside explicit recognition of toxicity risks, particularly in animal husbandry contexts [39]. However, the absence of standardized dose-response data, controlled toxicological studies, and long-term safety assessments prevents meaningful separation of pharmacologically relevant activity from hazardous exposure. Resolving this distinction remains a critical research gap, particularly for taxa containing phenethylamine alkaloids, where therapeutic exploration must proceed in parallel with rigorous safety evaluation.

3.4. Research Gaps and Limitations

The broader pharmacological literature on Texas *Acacia s.l.* remains largely preclinical and exploratory, with uneven species coverage and limited methodologi-

cal standardization. Despite promising early findings, only *V. farnesiana* and *V. rigidula* have been evaluated across multiple biological endpoints [24] [30] [34]. Many Texas species—including *V. texana*, *V. constricta*, *V. shrevei*, *V. schottii*, *S. wrightii*, *Acaciella leucothrix*, *Acaciella suffrutescens*, and *Acaciella roemeriana*—lack modern bioactivity studies beyond preliminary chemical screening [19]. No clinical trials exist, and few investigations employ dose-standardized extracts, limiting reproducibility and cross-study comparison [21]. Toxicological assessments of phenethylamine alkaloids remain particularly underdeveloped, leaving critical gaps in safety evaluation and risk-benefit interpretation [28] [32] [38].

This review, therefore, synthesizes and critically evaluates experimental studies on the pharmacological properties of the 17 *Acacia s.l.* in Texas. By integrating ethnobotanical knowledge with phytochemical and bioassay evidence, it aims to: 1) Summarize current findings across antioxidant, antimicrobial, anti-inflammatory, metabolic, cytotoxic, and other biological activities; 2) Identify underexplored species and metabolite classes; 3) Propose strategic research priorities, including compound isolation, HPLC-based phytochemical standardization, advanced *in vivo* models, and sustainability considerations. These efforts seek to advance Texas *Acacia* species toward safe, evidence-based therapeutic development while balancing ecological and toxicological concerns.

While pharmacological findings highlight promising avenues for therapeutic development, they represent only one dimension of *Acacia s.l.*'s broader significance in Texas. Understanding the full therapeutic landscape of these species requires situating modern bioactivity research within the long-standing cultural and medicinal traditions that guided their use. The following section, therefore, examines the ethnobotanical knowledge and traditional practices associated with Texas *Acacia s.l.*, providing essential context for interpreting their contemporary pharmacological relevance.

4. Ethnobotanical Knowledge and Traditional Uses of Texas *Acacia* Species

Ethnobotanical records across Texas and northern Mexico highlight the longstanding medicinal, cultural, and utilitarian importance of *Acacia s.l.* species. Traditional uses draw on readily accessible plant parts—bark, leaves, pods, flowers, and gum exudates—prepared as decoctions, infusions, poultices, or topical applications. These practices reflect deep ecological familiarity and cultural continuity among Native communities and Mexican-American populations [8] [31] [40].

Historical sources document several widely used species. *Vachellia farnesiana* pods and gum have been used to treat skin infections and sore throats, while its fragrant flowers are valued in perfumery and flavoring [31] [40]. The bark and leaves of *Senegalia berlandieri* are traditionally used for gastrointestinal discomfort and fever, although their stimulant alkaloids are also reported in ethnoveterinary contexts [32] [41]. Decoctions of *Acacia schaffneri* are used for colds, fevers, and dermatological conditions [8], and infusions of *Senegalia wrightii* are admin-

istered for respiratory relief and inflammation [31] [40]. Beyond human medicine, *Acaciella angustissima* is incorporated into forage systems, offering nutritional value despite reports of mild toxicity at high intake [14] [15].

These uses underscore the ethnobotanical relevance of Texas *Acacia s.l.*, bridging medicinal, cultural, and ecological domains. Despite extensive traditional knowledge, few species have undergone systematic pharmacological validation, underscoring the need for evidence-based research to assess bioactivity, toxicology, and therapeutic potential [8] [32].

4.1. Traditional Medicinal Practices across Texas and Northern Mexico

Ethnomedical practices involving Texas *Acacia s.l.* are closely tied to ecological distribution and cultural accessibility (**Table 2**). Remedies prepared from bark, leaves, pods, flowers, and gum are used to address a broad spectrum of ailments, including gastrointestinal disorders, respiratory infections, skin conditions, inflammation, and fever [8] [31] [40].

Table 2. Notable ethnomedicinal reports by species.

Species	Traditional Use	Parts Used	Region/Community	Reference
A. dealbata	Used to investigate bioactivities with potential for dementia, diabetes, and antimicrobial treatments (related to enzyme inhibition of acetylcholinesterase, alpha-glucosidase, and lipase).	Flowers	Central region of Portugal (as an invasive species). Although not native to Texas, *A. dealbata* is included in regional phytochemical studies due to its relevance in medicinal innovation.	[26]
A. schaffneri	Traditionally used to treat symptoms associated with cancer and inflammation. The bark decoction is used to treat gastric ulcers and skin conditions.	Bark for decoction Roots for compound isolation	South-central valleys of Mexico.	[28]
Acaciella angustissima	Traditionally used to relieve toothache, arthritis, gastritis, rheumatic disorders, and skin lesions. Used to treat digestive problems and diarrhea. Used for firewood, wood, and fodder.	Roots and bark for medicinal purposes Pods as fodder	Distribution from the Southern United States to Costa Rica.	[25] [35]
S. berlandieri	Ingestion by livestock (sheep and goats) during drought causes a locomotor ataxia known as "guajillo wobbles" or "limberleg". Used for wood and construction.	Leaves (primary toxic component). Fruit (alkaloids detected) Wood	Edwards Plateau of Texas and Northern Mexico. Rio Grande plains of Texas. Rayones, Nuevo León, México (wood use).	[8] [22] [28] [31] [32] [33]
S. greggii	Pods are used to prepare eyewashes for the treatment of conjunctivitis. Ground leaves and pods into powder to prevent bleeding and soothe sore skin. Tea may treat diarrhea and dysentery. Adding flowers to tea may treat nausea and vomiting.	Pods, Leaves, Flowers	Southwest United States and northwestern Mexico.	[42]

Continued

V. farnesiana	Used in traditional medicine to treat diarrhea, dysentery, tuberculosis, and indigestion. Pods are traditionally used to treat dyspepsia and diarrhea and are also used topically for dermal inflammation. Wood is valued for posts and woodwork. Bark and fruit are used for ink making, dyeing, and tanning.	Pods. Bark and fruit. Wood Flowers for perfume	Mexico and Central America. Pantropical. Rayones, Nuevo León, México (used for wood, fuel, construction, fences).	[4] [8] [27] [43]
V. rigidula	Extracts used in popular weight-loss supplements. Roots used in cosmetic preparations for hair care.	Leaves for extracts Root for cosmetics	The southern part of Texas and the northern states of Mexico. Rayones, Nuevo León, México.	[8]

4.2. Synthesis and Research Gaps

Collectively, the ethnobotanical record of Texas *Acacia s.l.* reflects a profound interplay between cultural heritage, ecological familiarity, and medicinal innovation. Traditional uses—from respiratory relief with *S. wrightii* to antimicrobial applications of *V. farnesiana*—offer valuable leads for pharmacological exploration. Yet systematic validation remains limited. Few species have been rigorously evaluated in controlled bioassays or toxicological studies, and many reported uses lack corroborating experimental evidence [8] [31] [32] [40]. This gap underscores the need for targeted research to determine whether traditional practices align with measurable biological activities.

Although ethnobotanical records provide valuable insight into traditional applications, validating these uses requires a detailed understanding of the chemical constituents responsible for biological activity. The following section, therefore, examines the phytochemistry of Texas *Acacia* species, highlighting the metabolite classes and analytical methods that underpin modern pharmacological investigations.

5. Phytochemistry of Texas *Acacia* Species

Texas *Acacia s.l.* species exhibit extensive chemical diversity, producing a broad spectrum of secondary metabolites that underpin their ecological functions and therapeutic potential. Major phytochemical classes reported *Vachellia*, *Senegalia*, *Acaciella*, and *Acacia* include flavonoids, tannins, phenolic acids, alkaloids, terpenoids, saponins, and polysaccharides [19] [20] [30] [32]. Recent global reviews reinforce the chemical richness of the genus, highlighting the structural diversity of flavonoids, diterpenoids, and gum polysaccharides across multiple *Acacia* species [22] [44] [45].

The abundance and composition of these metabolites vary widely across species, plant organs, environmental conditions, and extraction methods [27] [30]. Despite their recognized pharmaceutical relevance, phytochemical research in Texas remains uneven, with most studies focusing on a small subset of species, leaving many taxa insufficiently characterized [24] [26].

5.1. Species-Specific Phytochemical Profiles

Texas *Acacia s.l.* exhibit remarkable chemical diversity, reflecting their broad phylogenetic distribution across *Vachellia*, *Senegalia*, *Acacia*, and *Acaciella*. Although these taxa share several major classes of secondary metabolites—including phenolics, flavonoids, alkaloids, terpenoids, sterols, and fatty acids—the specific compounds and their relative abundances vary substantially among species. **Table 3** summarizes the principal metabolites reported to date, highlighting both the breadth of chemical diversity and the uneven availability of phytochemical data across taxa.

Table 3. Species-specific phytochemical profiles of Texas *Acacia*.

Species	Major Phytochemicals Identified	Plant Part	Reference
A. dealbata	Flavonols and Chalcones; Phenolics/Flavonoids (attributed to activity); Linoleic acid (LA) and Oleic acid (OL) (in seed oil).	Flowers (Hydroethanolic extract, early maturation stage was most active); Leaves (Acetone extract reported previously); Seeds (Oil content analyzed).	[18] [26]
A. schaffneri	Phyllocladan-16α,19-diol (Diterpenoid, new compound); Phyllocladan-16α-ol (Diterpenoid); Phylloclad-16-en-3-ol (Diterpene); Seco-oxacassanes (previously reported).	Roots (Hexane extract used for isolation); Aerial parts (for previously reported seco-oxacassanes); Pods (Extracts evaluated for activity).	[28] [46]
Acaciella angustissima	Total Phenols, Flavonoids, Condensed Tannins (Quantified); Phenolic acids (Protocatechuic acid, Catechin, Coumaric acid); Amines/Alkaloids (Tyramine, NMPEA); D-Pinitol, Stigmasterol, β-Amyrin; Fatty acids (Linoleic acid, Oleic acid, Hexadecanoic acid, Linolenic acid). Non-protein amino acids (2,4-diaminobutyric acid, oxalylalbizziine).	Flowers, Seeds, Pods (analyzed); Pods (Macerated methanolic extract); Leaves (Air-dried material used for alkaloid extraction).	[19] [25] [33] [35]
Acaciella roemeriana	N-Methyl-β-phenethylamine (NMPEA) and Tyramine; Alkaloids/Amines (Presence detected).	Leaves (Air-dried material used for extraction).	[19] [33] [47]
S. berlandieri	N-Methyl-β-phenethylamine (NMPEA), Tyramine, N-methyltyramine, Hordenine; 29 other alkaloids and amines identified, including Nicotine, Nornicotine, Mescaline, and Amphetamines.	Leaves (Collected in spring/autumn for analysis); Fruit (Alkaloids detected).	[29] [32]
S. greggii	N-Methyl-β-phenethylamine (NMPEA) and Tyramine; Fisetin (Flavonol); Alkaloids/Amines (Presence detected).	Leaves (Air-dried material used for extraction); Seed extract (toxicity study); Fisetin source (part not specified).	[19] [32] [47]
V. constricta	N-Methyl-β-phenylethylamine (NMPEA); Cyanogenic glycoside (Acacipetalin); Amines/Alkaloids (Presence detected).	Leaves (Air-dried material used for extraction).	[18] [19] [33] [47]
V. farnesiana	Methyl gallate; Naringenin; Gallic acid; Galloyl glucose isomers (1, 2, 3); Digalloyl glucose isomers; α-Amyrin, β-Amyrin, Lupeol, β-sitosterol (Triterpenoids); Volatile components (in blossoms).	Pods (Organic and aqueous extracts); Roots (Betulinic acid reported); Flowers (Blossoms).	[27] [38] [43]

Continued

V. rigidula	N-Methyl-β-phenylethylamine (NMPEA); Phenols, Flavonoids, Saponins, Terpenoids, Tannins (Qualitatively determined); Phenolic acids (Gallic acid, p-coumaric acid, vanillic acid, vanillin, salicylic acid, caffeic acid); Diterpenes (potentially high concentration); Volatile components (jasmone, kaur-16-ene, p-anisaldehyde).	Leaves (Acetone, Methanol, Acetic acid extracts); Flowers (Volatile components).	[22] [24] [32] [43]
V. schottii	N-Methyl-β-phenylethylamine (NMPEA); Amines/Alkaloids (Presence detected).	Leaves (Air-dried material used for extraction).	[19] [33]
V. texana	N-Methyl-β-phenylethylamine (NMPEA); Alkaloids/Amines (Presence detected).	Leaves (Air-dried material used for extraction).	[19] [33]

Within the Texas flora, the *Acacia* and *Acaciella* lineages introduce additional layers of chemical variation that complement the profiles observed in *Vachellia* and *Senegalia*. *Acacia dealbata*, although non-native, provides a useful comparative context through its production of flavonols, chalcones, and seed fatty acids such as linoleic and oleic acid [21] [44]. *Acacia schaffneri* is notable for its phyllocladane-type diterpenoids, including phyllocladan-16α,19-diol and related structures [28] [46].

In contrast, *Acaciella* species—though fewer in number—exhibit some of the broadest metabolite repertoires reported within the group. Their profiles combine phenolics, alkaloids, sterols, and distinctive non-protein amino acids, underscoring their biochemical distinctiveness. *Acaciella angustissima* is particularly well studied and contains phenolic acids, condensed tannins, N-methyl β-phenethylamine (NMPEA), tyramine, sterols, triterpenes, fatty acids, and rare non-protein amino acids [19] [25] [33] [36]. *Acacia roemeriana* has a more limited profile, with confirmed production of tyramine and other simple phenethylamines [19] [33] [47].

Moving from the chemically broad *Acaciella* lineage to the more alkaloid-focused *Senegalia*, a distinct shift in phytochemical emphasis becomes evident. *S. berlandieri* contains one of the broadest alkaloid spectra documented in the group, including tyramine, NMPEA, hordenine, nicotine, nornicotine, mescaline, and several amphetamine-like compounds [29] [32]. *S. greggii* synthesizes tyramine and related amines and is one of the few Texas taxa with confirmed production of the flavonol fisetin [19] [33] [47].

In contrast to the alkaloid-dominated profiles of *Senegalia*, the genus *Vachellia* encompasses some of the most chemically diverse and extensively characterized taxa within Texas *Acacia*. *V. farnesiana* possesses one of the most complex phytochemical profiles, producing methyl gallate, gallic acid, naringenin, multiple galloyl glucose derivatives, and triterpenoids such as α-amyrin, β-amyrin, lupeol, and β-sitosterol, along with numerous volatile floral constituents [27] [43] [48] [49]. *V. rigidula* similarly exhibits high chemical diversity, synthesizing NMPEA,

phenolic acids, diterpenes, and volatile compounds including jasmone and p-anisaldehyde [24] [30] [34] [43]. Related species such as *V. constricta*, *V. schottii*, and *V. texana* possess simpler alkaloid-rich profiles dominated by NMPEA and cyanogenic or other amine-based metabolites [18] [19] [33].

5.2. Analytical Techniques in Phytochemical Characterization

The phytochemical characterization of Texas *Acacia sensu lato* species relies on a suite of extraction and analytical techniques that vary widely in resolution, sensitivity, and application.

- **HPLC and LC–MS/MS** are widely used for quantifying phenolic acids and flavonoids [30] [49].
- **GC–MS** is essential for analyzing alkaloids and volatile terpenoids, particularly in *V. rigidula* and *S. berlandieri* [28] [32].
- **TLC and UV–vis spectrophotometry** remain common for rapid qualitative screening [19] [24].
- **NMR and FT–IR**, though underutilized, are critical for structural elucidation and should be expanded in future work [19] [30] [44].

5.3. Current Limitations

Despite the growing body of phytochemical research on Texas *Acacia sensu lato*, substantial methodological and data-driven limitations continue to constrain comparative analyses and biological interpretation. Key challenges include:

- Extraction protocols lack standardization.
- Metadata on plant maturity, seasonality, and habitat are often missing.
- Fewer than half of Texas species have been chemically profiled.
- Most studies provide qualitative rather than quantitative data.
- Advanced structural tools (NMR, HRMS) remain underused.

Recent global reviews emphasize the need for metabolomics-driven, standardized phytochemical workflows to improve reproducibility and enable meaningful cross-species comparisons [42] [43]. Within this context, phytochemical profiles provide an essential foundation for interpreting the biological activities attributed to Texas *Acacia s.l.* Building on this chemical framework, the following section links metabolite diversity to therapeutic relevance by synthesizing current pharmacological evidence, with emphasis on antimicrobial, anti-inflammatory, metabolic, neuroactive, and cytotoxic properties documented across regional taxa.

6. Pharmacological Properties of Texas *Acacia* Species

Texas *Acacia* species exhibit a wide range of pharmacological activities, many of which align with traditional medicinal uses. Documented bioactivities include antioxidant, antimicrobial, anti-inflammatory, antidiabetic, hepatoprotective, neuroactive, and cytotoxic effects. Recent global studies on *Acacia* species further highlight their therapeutic potential, reinforcing the relevance of Texas taxa within broader pharmacological research [43] [48].

6.1. Antimicrobial and Antioxidant Activities

Extracts of *V. farnesiana* pods demonstrate strong vibriocidal activity against *Vibrio cholerae*, attributed to methyl gallate, and exhibit notable anti-inflammatory effects *in vivo* [41]. Leaves of *V. rigidula* show potent antioxidant activity, achieving up to 70% inhibition of lipid peroxidation, and have been shown to combat resistant bacterial strains [22] [28].

6.2. Anti-Inflammatory, Antidiabetic, and Metabolic Effects

Acaciella angustissima exhibits antidiabetic and hypolipidemic effects through modulation of α-amylase, α-glucosidase, and ACE activity [36]. *A. dealbata* demonstrates enzyme-inhibitory activity relevant to cognitive decline and glucose metabolism [26] [37].

6.3. Cytotoxic and Neuroactive Properties

Diterpenoids from *Acacia schaffneri* roots exhibit selective cytotoxicity against cancer cell lines [28]. Phenethylamine alkaloids in *Senegalia berlandieri* and *Vachellia rigidula* have documented neuroactive effects, including locomotor ataxia in livestock, and warrant further investigation for CNS-related pharmacology [30] [32]. Recent pharmacological reviews emphasize the need to explore neuroprotective and anticancer activities across *Acacia s.l.*, including Texas taxa [45] [50].

6.4. Current Limitations

Although several Texas *Acacia sensu lato* species show promising pharmacological potential, the current evidence base remains fragmented and methodologically limited. To date, only a small subset of species has been evaluated across multiple biological endpoints, and most studies rely heavily on *in vitro* assays without corresponding *in vivo* validation. Critical data on toxicity, dose–response relationships, and pharmacokinetics remain scarce, and no clinical trials have been conducted for any Texas species. Recent global studies further emphasize the need to integrate metabolomics, standardized bioassays, *in vivo* disease models, and comprehensive toxicity testing to advance *Acacia*-based therapeutics [44] [50].

Collectively, these gaps underscore the scientific and methodological challenges that continue to constrain the reliability, reproducibility, and translational potential of current findings. The following section expands on these limitations and outlines the key research priorities necessary to strengthen future pharmacological investigations.

7. Research Gaps and Methodological Limitations

The current research landscape remains constrained by substantial gaps, taxonomic bias, and methodological inconsistencies. Most studies remain preliminary, limiting their relevance for drug discovery, mechanistic interpretation, or translational application. Recent global reviews of *Acacia* phytochemistry and pharmacology [44] [46] [50] highlight similar challenges worldwide, underscor-

ing the need for more rigorous and standardized research approaches.

7.1. Limited Species Representation and Taxonomic Bias

Although at least 17 *Acacia s.l.* species occur in Texas across *Vachellia*, *Senegalia*, *Acaciella*, and *Acacia* s.s.; fewer than half have undergone modern phytochemical or pharmacological evaluation. Research disproportionately focuses on *V. farnesiana*, *S. berlandieri*, *S. greggii*, and *Acaciella angustissima* [19] [25] [26] [30] [49]. In contrast, species such as *V. texana*, *Acaciella roemeriana*, *A. schaffneri*, and *A. leucothrix* remain largely uncharacterized. Recent global analyses of *Acacia* diversity [44] [45] reinforce the importance of expanding species coverage to avoid overlooking taxa with significant therapeutic potential.

7.2. Inconsistent Extraction Protocols and Analytical Methods

Methodological variability is a major barrier to reproducibility. Extraction protocols differ widely in solvent polarity, temperature, duration, and plant preparation—all factors that significantly influence metabolite yield and composition [24] [27] [30] [32]. No standardized method exists for extracting total phenolic acids from *Acacia* tissues [24], and solvent polarity strongly affects phenolic solubility [30].

Recent metabolomics-driven studies [44] [45] emphasize the need for standardized extraction and analytical workflows to enable cross-species comparisons. In addition, most Texas studies rely on crude ethanolic or aqueous extracts and rarely proceed to fractionation or structural elucidation [30]. Advanced analytical tools such as LC–MS/MS, GC–MS, NMR, and HRMS—now widely recommended in global *Acacia* research [44] [45] [51]—remain underutilized.

7.3. Insufficient Toxicological, Dose-Response, and *in Vivo* Data

A major limitation is the scarcity of toxicity and dose–response data. Many studies report biological activity without determining IC_{50}, MIC, LD_{50}, or therapeutic index values [23] [30]. Most investigations rely exclusively on *in vitro* assays—particularly antioxidant and antimicrobial screens [19] [23] [24]—which do not account for bioavailability, metabolism, or systemic toxicity [25] [51].

Only a few studies have evaluated acute toxicity or safe dosage ranges, such as those involving *S. greggii* seed extracts [42] [47]. Limited *in vivo* work exists, primarily focusing on anti-inflammatory or hepatoprotective effects [27] [36] [42]. Recent pharmacological reviews [50] [51] emphasize the need for robust *in vivo* and toxicological studies before any *Acacia*-derived product can advance toward clinical evaluation.

7.4. Disconnect between Ethnobotanical Knowledge and Pharmacological Evidence

A persistent gap persists between traditional uses and modern scientific validation. Species such as *V. texana* and *Acaciella roemeriana* are used in Indigenous and Mexican-American communities to treat respiratory disorders and fever [8]

[23] [33], yet no contemporary pharmacological studies have substantiated these applications. Recent ethnopharmacological reviews [50] [51] underscore the global importance of aligning traditional knowledge with laboratory validation—an approach urgently needed for Texas species.

7.5. Lack of Ecological and Chemotypic Context

Phytochemical composition is strongly influenced by ecological factors, including soil type, water stress, seasonality, and plant age. However, most studies provide minimal metadata on collection sites, phenological stage, or habitat characteristics [24] [26] [27] [30] [32] [42]. Metabolomics studies [43] emphasize the importance of ecological metadata for interpreting chemotypic variation.

7.6. Summary of Key Limitations

Current research on Texas *Acacia s.l.* is constrained by:

1) Underrepresentation of species—more than half remain unstudied.

2) Non-standardized phytochemical methods—limited use of advanced metabolomics tools.

3) Absence of clinical data—no human studies exist.

4) Weak pharmacological rigor—few dose–response or *in vivo* evaluations.

5) Poor alignment with ethnobotanical knowledge—traditional uses often lack empirical support.

6) Insufficient ecological metadata—environmental influences on chemistry are rarely documented.

Recent global reviews [44] [45] [50] underscore the urgency of addressing these limitations to advance *Acacia*-based therapeutics. Addressing these gaps will require a coordinated, multidisciplinary research strategy that integrates standardized phytochemical workflows, rigorous pharmacological testing, comprehensive toxicological assessment, and more substantial alignment with ethnobotanical knowledge. Building on the constraints outlined above, the following section proposes future research directions to strengthen phytochemical characterization, enhance pharmacological validation, and improve the translational potential of Texas *Acacia* species.

8. Future Research Directions

To fully realize the therapeutic potential of Texas *Acacia s.l.*, future research must adopt a multidisciplinary framework that integrates ethnobotany, metabolomics, pharmacology, toxicology, and translational science. Recent advances in global *Acacia* research [44] [45] [50] provide a roadmap for strengthening the scientific foundation of Texas taxa.

8.1. Expand Phytochemical Profiling Using Modern Analytical Tools

Several understudied species—such as *Acaciella roemeriana*, *Acacia leucothrix*, and *Vachellia vernicosa*—lack contemporary chemical data despite documented

traditional uses [26]. Future work should:

- Apply untargeted metabolomics (LC–MS/MS, NMR) to generate high-resolution chemical fingerprints [44] [45].
- Use HPLC fingerprinting to standardize extract profiles and enable cross-study comparisons.
- Prioritize isolation and structural elucidation of active compounds in species showing promising activity [19] [20] [27] [30].

Recent reviews [45] [51] highlight metabolomics-driven workflows as essential for advancing *Acacia* research globally. Building on this chemical foundation, broader pharmacological screening is also needed.

8.2. Broaden Pharmacological Screening beyond Basic *in Vitro* Assays

Most Texas *Acacia* studies focus on antioxidant or antimicrobial assays. Future research should:

- Incorporate *in vivo* disease models to evaluate anti-inflammatory, antidiabetic, hepatoprotective, and analgesic effects [27] [30].
- Expand testing to include anticancer (HCT116, MCF-7), neuroprotective, antiviral, and immunomodulatory assays [45] [50].
- Investigate CNS-active species such as *S. berlandieri* and *V. rigidula*, given their phenethylamine alkaloid profiles [30]-[32].

Global pharmacological reviews [46] [50] strongly support expanding the pharmacological scope of *Acacia* research. Such expansion should be complemented by deeper engagement with ethnopharmacological knowledge.

8.3. Integrate Ethnopharmacology and Community-Based Knowledge

Ethnopharmacological approaches remain underutilized. Future studies should:

- Conduct ethnobotanical surveys in South and West Texas to document undocumented uses and preparation methods [31] [48].
- Collaborate with community healers and herbalists to ensure culturally grounded research.
- Develop biocultural maps linking traditional use frequency with species distribution.

Recent reviews [47] highlight the global importance of aligning ethnobotanical knowledge with laboratory validation. Improved methodological consistency will further strengthen these efforts.

8.4. Standardize Methodological Practices for Reproducibility

Future studies should:

- Standardize solvent polarity, extraction duration, temperature, and plant preparation.
- Report on harvest location, plant maturity, phenological stage, and seasonal

conditions [27] [38] [46] [49].

- Include dose–response analyses with appropriate controls.

Recent metabolomics studies [45] emphasize the importance of methodological standardization. Such rigor is essential for translational and preclinical advancement.

8.5. Strengthen Translational and Preclinical Research

To progress toward therapeutic applications, future research must incorporate:

- Acute, subchronic, and chronic toxicity studies.
- Pharmacokinetic and bioavailability assessments.
- Synergy testing with standard drugs (e.g., NSAIDs).
- Formulation science to improve solubility and stability [19] [27].

Recent pharmacological reviews [50] [51] emphasize these steps as prerequisites for clinical translation. A structured research pipeline can help guide this progression.

8.6. Recommended Research Framework

A structured research pipeline is proposed:

1) Ethnobotanical Surveys.
2) Phytochemical Screening (LC–MS/MS, HPLC, NMR).
3) Bioactivity Testing (*in vitro* + *in vivo*).
4) Toxicological Evaluation.
5) Preclinical and Clinical Preparation.

This evidence-based framework aligns with global recommendations for advancing *Acacia*-derived therapeutics [44] [45] [50] [51]. Collectively, these recommendations provide a roadmap for elevating Texas *Acacia s.l.* from underexplored native plants to rigorously studied therapeutic candidates. The concluding section synthesizes these insights, emphasizing their broader significance for pharmacology, ethnobotany, and regional biodiversity.

9. Conclusions

The *Acacia sensu lato* species of Texas represent a botanically diverse and culturally significant flora with substantial yet underexplored pharmacological potential. Long used in traditional ethnomedicine to treat inflammation, infections, respiratory ailments, and gastrointestinal disorders, these species contain a wide array of bioactive compounds—including flavonoids, tannins, alkaloids, saponins, diterpenes, and polysaccharides—that contribute to antioxidant, antimicrobial, anti-inflammatory, metabolic, neuroactive, and cytotoxic activities. Recent advances in global *Acacia* research [44] [45] [50] [51] reinforce the therapeutic relevance of this genus and underscore the need to expand scientific inquiry into Texas taxa.

Despite these promising attributes, current research remains concentrated on a limited number of species, particularly *V. farnesiana*, *S. berlandieri*, *S. greggii*, and

Acaciella angustissima. At the same time, many other native taxa lack comprehensive phytochemical or pharmacological characterization. Methodological limitations—including inconsistent extraction protocols, limited compound isolation, insufficient ecological metadata, and a scarcity of *in vivo* or translational studies—further constrain the development of evidence-based therapeutic applications.

Future research should prioritize metabolomics-driven phytochemical profiling, systematic pharmacological evaluation across diverse biological endpoints, and rigorous toxicological assessment. Integrating ethnobotanical knowledge with modern analytical and pharmacological techniques will be essential for identifying culturally significant species, validating traditional uses, and uncovering novel bioactive compounds. Standardized methodologies, transparent reporting of ecological and phenological variables, and the adoption of *in vivo* and preclinical models will greatly enhance reproducibility and translational relevance.

By adopting a holistic, multidisciplinary research framework, Texas *Acacia* species may emerge as valuable sources of new pharmaceuticals, nutraceuticals, and culturally grounded herbal medicines. Strengthening the scientific foundation of these species not only advances biomedical discovery but also preserves and honors the rich ethnomedical traditions that have shaped their use across generations.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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