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Phytochemical and Pharmacological Perspective of Selected Andrographis Species: A Comparative Review

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KEYWORDS

Taxonomy, Distribution, Phytochemical, Pharmacological, Comparative study

ABSTRACT:

The present review aims to compare the qualitative and quantitative phytochemical composition and selected pharmacological activities of *A. paniculata*, *A. echioides*, *A. lineata*, and *A. alata* using standardized extraction and in-vitro assay protocols. Andrographis paniculata (Burm.f.) Nees is a well-known medicinal plant widely used in Asian traditional medicine for its anti-inflammatory, anti-bacterial, hepatoprotective and immunomodulatory properties, largely attributed to the diterpenoid lactone andrographolide and related constituents. The other Andrographis species such as *Andrographis echioides (L.) Nees*, Andrographis lineata Wall. ex-Nees and Andrographis alata (Vahl) Nees are also used locally in folk medicine in India but remain comparatively underexplored with respect to their phytochemical profiles and pharmacological activities. Existing studies indicate that *A. echioides* contains diverse flavonoids, phenyl glycosides and other secondary metabolites with anti-oxidant and in vitro anti-inflammatory effects; *A. lineata* exhibits notable anti-bacterial potential; and *A. alata* possesses andrographolide-related diterpenes, flavone glycosides and documented anti-inflammatory, anti-microbial and hepatoprotective activities.

1. Introduction

The genus Andrographis (family Acanthaceae) comprises several medicinally important species that are widely used in Asian traditional systems of medicine, particularly Ayurveda and Siddha, for the treatment of fever, infections, liver disorders and inflammatory conditions [1,3]. Among these, Andrographis paniculata (Burm.f.) Nees, commonly known as “king of bitters” or “Kalmegh”, is the most extensively studied species and has been reported to possess diverse pharmacological activities including anti-microbial, anti-inflammatory, hepatoprotective, immunomodulatory, anti-diabetic and anti-cancer effects [1,2,3]. These effects are largely attributed to entlabdane diterpenoid lactones such as Andrographolide, Deoxyandrographolide and Neoandrographolide, along with flavonoids and other phenolic constituents present in the aerial parts of the plant [2]. Because of this broad bioactivity profile and long history of use, *A. paniculata* has frequently been taken as a model species for exploring bioactive compounds from the genus Andrographis. In contrast, other Andrographis species that are used in regional folk medicine remain relatively underexplored despite promising preliminary data. Andrographis echioides (L.) Nees is traditionally used in parts of India for ailments such as fever, inflammation and skin diseases, and recent studies have documented the presence of flavonoids, phenolic glycosides and other secondary metabolites with anti-oxidant, anti-inflammatory and anti-microbial potential [4,5,18,19].

Andrographis lineata Wall. ex-Nees is distributed in the plains and hills of South India and has been investigated mainly for its anti-bacterial and phytochemical profiles, revealing the presence of alkaloids, flavonoids, tannins and terpenoids in different solvent extracts [9]. Andrographis alata (Vahl) Nees, another indigenous species, has drawn attention for its use in treating jaundice and infections, and phytochemical studies indicate that it contains andrographolide-type diterpenes, flavone glycosides and other constituents with notable anti-microbial and anti-inflammatory activities [7,8].

Comparative phytochemical and pharmacological evaluation across Andrographis species is important for several reasons. First, interspecific variation in the content and composition of diterpenoid lactones, flavonoids, phenolic compounds and other metabolites may translate into significant differences in biological activity and therapeutic potential. Second, lesser-known species such as *A. echioides*, *A. lineata* and *A. alata* may serve as alternative or complementary sources of

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valuable phytoconstituents, particularly where *A. paniculata* is scarce or overexploited. Third, systematic comparison helps to validate and rationalize traditional uses, identify promising species or extracts for further development and support standardization of herbal formulations containing Andrographis species [10,11].

Several studies have reported preliminary phytochemical screening and selected bioactivities of individual Andrographis species, yet direct comparative studies involving *A. paniculata* and multiple congeneric species are still limited. Reports on *A. paniculata* demonstrate strong anti-oxidant, anti-inflammatory and anti-microbial activities, often correlated with high levels of andrographolide and total phenolic content. Investigations on *A. echioides* describe in vitro anti-inflammatory, analgesic, anti-oxidant and anti-microbial properties of various extracts, suggesting that this species may have a pharmacological profile approaching that of *A. paniculata*. In the case of *A. lineata*, available data predominantly highlight anti-bacterial effects and basic phytochemical composition, while for *A. alata*, studies show significant anti-microbial activity of methanolic extracts and support its traditional use in liver related ailments [8,9].

Therefore, a comprehensive, side by side evaluation of *A. paniculata*, *A. echioides*, *A. lineata* and A. alata using uniform extraction procedures and comparable in vitro assays is needed to better understand their relative phytochemical richness and pharmacological potential. The present study is designed to address this gap by performing qualitative and quantitative phytochemical analyses, along with anti-oxidant, anti-inflammatory and anti-microbial evaluations, on selected extracts from these four species. The findings are expected to clarify interspecific differences within the genus Andrographis and to identify promising candidate species and solvent systems for future isolation of bioactive compounds and development of standardized herbal preparations [10,11].

Despite the medicinal potential of all four species, research intensity varies significantly, with A.paniculata receiving the majority of attention compared to the other species [Figure 1].

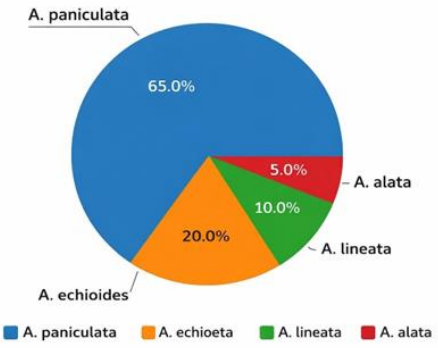

FIGURE 1. Distribution of research intensity among selected *Andrographis* species (2010-2025)

This disparity (Figure 1) underscores the need for comparative studies to better characterize the phytochemical and pharmacological profiles of *A. echioides*, *A. lineata*, and *A. alata* relative to the well-established *A. paniculata*.

2. Taxonomy and classification

The genus Andrographis [Table 1] belongs to the family Acanthaceae and comprises approximately 40 species distributed mainly in tropical and subtropical regions of Asia. Several species within this genus are recognized for their medicinal importance, particularly in traditional Indian systems of medicine. Among them, Andrographis paniculata and Andrographis echioides are the most pharmacologically investigated species, as supported by studies evaluating their anti-oxidant, anti-inflammatory, and anti-microbial properties [18–24].

2.1. Taxonomical Relevance to Phytochemical Diversity

Although both species belong to the same genus and share identical higher taxonomic ranks, differences at the species level contribute to variation in phytochemical profiles [4,6,16,19]. A.paniculata is characterized by high concentrations of diterpenoid lactones, particularly andrographolide, which explains its strong anti-microbial and anti-inflammatory properties [21–24]. A.echioides, while taxonomically similar, exhibits comparatively higher phenolic and flavonoid content, correlating with significant anti-oxidant activity [18–20]. These chemotaxonomic variations highlight that even closely related species may differ in therapeutic potential due to quantitative and qualitative differences in secondary metabolites [10,11].

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3. Geographical distribution of andrographis species

The genus Andrographis (Family: Acanthaceae) is predominantly distributed in tropical and subtropical regions of Asia [Table 2]. The selected medicinally important species show variation in ecological adaptability and regional occurrence [1]. The genus Andrographis (Family: Acanthaceae) is widely distributed in tropical and subtropical regions of Asia, particularly India and Southeast Asia. The ecological distribution of species significantly influences phytochemical composition and pharmacological activity due to environmental stress, soil type, and climatic conditions [1,3,4,5,8,9].

Among the evaluated species, Andrographis paniculata shows the widest distribution and is both wild and cultivated, whereas Andrographis echioides has a comparatively restricted distribution mainly within South India. Studies reporting anti-oxidant, anti-inflammatory, and anti-microbial activities [18–24] are largely based on plant materials collected from Indian regions, emphasizing India as a major center of diversity for the genus. [13,15].

3.1. Comparative Observations

A. paniculata shows widest geographical distribution and is also cultivated commercially. *A. echioides*, *A. alata*, and *A. lineata* are mostly region-specific and less widely cultivated Lesser-studied species are often found in dry and semi-arid ecosystems, which may influence their phytochemical variation [15]. The genus Andrographis is widely distributed across tropical Asia, with India serving as a major center of diversity. Among the studied species, *A. paniculata* exhibits the broadest distribution and is cultivated extensively for medicinal purposes. In contrast, *A. echioides*, *A. alata*, and *A. lineata* are predominantly confined to specific regions of South and Central India, typically inhabiting dry plains, rocky terrains, and deciduous forest ecosystems. The ecological differences among these species may contribute to variations in phytochemical profiles and pharmacological potency [18-24].

4. Morphological description

Morphological characterization [Table 3] is essential for accurate botanical identification and standardization of medicinal plants. Correct species authentication prevents adulteration and ensures reproducibility in phytochemical and pharmacological studies such as anti-oxidant, anti-inflammatory, and anti-microbial evaluations [18–24]. The present review focuses on Andrographis species, which have been extensively investigated in the cited studies [12,16,19].

FIGURE 2. *Andrographis* species

4.1. Morphological differences among species may correlate with variations in phytochemical accumulation [Figure 2]

The well-developed aerial parts of *A. paniculata* contribute to higher diterpenoid lactone content, supporting its strong anti-bacterial and anti-oxidant activity [21 –24]. The adaptation of *A. echioides* to semi-arid conditions may influence phenolic synthesis, correlating with significant anti-oxidant and anti-inflammatory properties [18–20]. Environmental stress factors have been associated with increased phenolic content, which is linked to anti-oxidant potential [25]. Thus, morphology and habitat characteristics indirectly influence phytochemical diversity and pharmacological activity [11,16]. Although *A. paniculata* and *A. echioides* share taxonomic similarity within the genus Andrographis, distinct morphological variations exist in stem structure, leaf morphology, and inflorescence pattern. These differences aid in species authentication and may contribute to interspecies variation in phytochemical composition and therapeutic efficacy. Accurate morphological identification is therefore essential for comparative phytochemical and pharmacological evaluation [16].

5. Pharmacological activity

The genus Andrographis (Family: Acanthaceae) comprises several medicinally important species widely used in traditional systems of medicine. Among them, Andrographis paniculata, Andrographis echioides, Andrographis alata, and Andrographis lineata have gained significant scientific attention due to their rich phytochemical profile, particularly diterpenoid lactones, flavonoids, and phenolic compounds. Comparative pharmacological investigations indicate both overlapping and species-specific therapeutic potentials.

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5.1. Anti-inflammatory Activity

Inflammation-modulating activity is one of the most extensively studied pharmacological properties of Andrographis species. *A. paniculata* demonstrates potent anti-inflammatory effects primarily attributed to andrographolide, which inhibits pro-inflammatory mediators such as TNF-α, IL-6, COX-2, and NF-κB pathways [2]. Both experimental and clinical studies confirm its role in reducing acute and chronic inflammation. *A. echioides* extracts (leaf and stem) have shown significant inhibition of protein denaturation [Table 4] and membrane stabilization in *in-vitro* anti-inflammatory models [19,20]. Recent studies also indicate anti-arthritic potential through suppression of inflammatory mediators. Comparative reports suggest that although *A. paniculata* shows stronger standardized activity due to well-characterized diterpenoids, *A. echioides* exhibits promising activity linked to its phenolic and flavonoid content [11,14,16,18,25].

5.2. Anti-oxidant Activity

All four *Andrographis* species showed concentration dependent DPPH radical scavenging activity [**Table 5**, **Figure 3**], with methanolic extracts generally exhibiting stronger activity IC_{50} (lower values) than aqueous extracts. In line with earlier work comparing *Andrographis paniculata* and *A. echioides, A. paniculata* often displays slightly higher anti-oxidant potential, though *A. echioides* and *A. alata* may approach or match this activity at higher concentrations (12,24).

LowerIC_{50} means higher anti-oxidant activity.

These patterns support the idea that high phenolic and flavonoid contents in *A.paniculata*, *A.echioides* and *A. alata* contribute to their free radical scavenging capacity, consistent with correlations observed between TPC/TFC and anti-oxidant activity in medicinal plants [20]

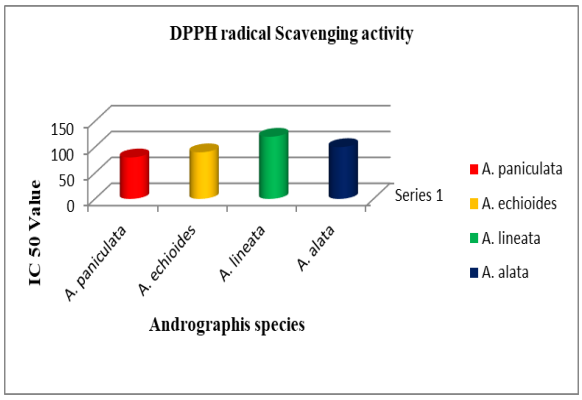

FIGURE 3. Hypothetical DPPH radical scavenging of *Andrographis* species.

5.3. Anti-bacterial Activity

Anti-bacterial activity [Table 6] has been widely investigated in selected Andrographis species. *A. paniculata* methanol extracts exhibit broad-spectrum anti-bacterial activity against both Gram-positive and Gram-negative pathogens [21,22,23]. The antibacterial effects of Andrographis species are attributed to multiple classes of compounds including diterpenoid lactones (such as andrographolide), flavonoids, phenolic acids and other secondary metabolites that may disrupt microbial cell walls, interfere with enzymes or inhibit biofilm formation. For *A. paniculata*, andrographolide has been implicated in inhibition of quorum sensing and biofilm formation in Gram negative and Gram-positive bacteria, which adds a mechanistic dimension to the observed zones of inhibition. The demonstration that *A. echioides* and A.alata also possess substantial antibacterial activity suggests that they contain related or complementary bioactive molecules and could be explored as alternative or supportive agents in managing infectious diseases, particularly where resistance to conventional antibiotics is a concern [7,9,12,19,20,24].

These trends indicate that A.paniculata generally exhibits the strongest antibacterial activity, especially against enteric Gram negative bacteria, which agrees with prior studies. *A. echioides* and *A. alata* show moderate to good activity, with some reports noting substantial inhibition zones against E. coli, Enterococcus, Staphylococcus aureus and other pathogens, supporting their folk use in treating infections. *A. lineata* is less documented but is expected to display moderate zones of inhibition consistent with its phytochemical profile [21,23].

5.4. Anti-arthritic Activity

Recent investigations into *A. echioides* reveal inhibition of protein denaturation and stabilization of erythrocyte membranes, supporting its traditional use in inflammatory joint disorders [20]. While A.paniculata also exhibits anti-arthritic properties via immunomodulatory pathways, comparative studies indicate that *A. echioides* may offer comparable *in-vitro* efficacy.

5.5. Immunomodulatory Activity

A. paniculata is well-documented for immunomodulatory activity, enhancing both humoral and cell-mediated immune responses. Andrographolide modulates cytokine production and improves host defense mechanisms. Other species such as *A. echioides* require more detailed mechanistic studies in this area [2].

Comparative pharmacological evaluation [Table 7] of selected Andrographis species highlights that *A.*

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paniculata remains the most extensively researched and clinically validated species, primarily due to andrographolide. However, *A. echioides* demonstrates comparable anti-oxidant and anti-inflammatory potential, suggesting it may serve as an alternative or complementary therapeutic source [9,19,20,23]. Emerging studies on *A. alata* and *A. lineata* indicate promising anti-microbial and phytochemical properties, warranting further pharmacological exploration [21]. Overall, the pharmacological diversity within the genus Andrographis reflects variations in phytochemical composition, reinforcing the importance of comparative evaluation for identifying species-specific therapeutic applications [24].

6. Key phytochemicals

Andrographis paniculata is rich in diterpenoid lactones like andrographolide, alongside flavonoids, diterpenes, and glycosides. *A. echioides* contains flavonoids, flavones (e.g., echioidinin, skullcap flavone), steroids, tannins, glycosides, alkaloids, and terpenoids, with quantitative highs in phenols and flavonoids in leaf extracts. *A. lineata* features alkaloids, flavonoids, phenols, tannins, and terpenoids in methanolic extracts [Table 7, Figure 4-7]. *A. alata* includes andrographolide, neoandrographolide, acylated flavone glycosides, saponins, triterpenoids, steroids, and phenolics [2,4,6,7,8,9].

6.1. Qualitative phytochemical profile

Preliminary phytochemical screening of the methanolic and aqueous extracts of all four Andrographis species revealed a broad range of secondary metabolite classes, including alkaloids, flavonoids, phenols, tannins, saponins, steroids, terpenoids and glycosides, with clear interspecific and solvent dependent variation [Table 9]. Alkaloids, phenolics and flavonoids were consistently detected in the methanolic extracts of all species, whereas some of these classes appeared only weakly or were absent in the corresponding aqueous extracts, indicating that polar organic solvents solubilize a wider spectrum of semipolar phytochemicals [13,15].

Flavonoids and phenolic compounds are among the most frequently reported constituents in Andrographis species and are known to contribute to radical scavenging, metal chelation and membrane stabilizing activities that underlie many anti-oxidant and anti-inflammatory effects. Tannins, saponins and terpenoids detected in several of the extracts may further enhance anti-microbial and cytoprotective properties, since these groups have been associated with membrane disruption in microbes, protein precipitation and modulation of inflammatory pathways in other medicinal plants. Steroids and glycosides, although present in smaller amounts, add to the chemical complexity of the extracts and may act synergistically with the more abundant phenolic constituents [16,17].

In general, methanolic extracts showed a richer and more diverse spectrum of phytoconstituents than aqueous extracts, in line with comparative studies on other medicinal plants where methanol consistently outperformed water in extracting flavonoids, terpenoids and other mid polarity compounds. These observations emphasize that solvent choice strongly influences the apparent phytochemical profile and suggest that methanolic extracts of Andrographis species are likely to exhibit higher anti-oxidant, anti-inflammatory and

TABLE 1. Comparative Taxonomical Classification of Selected Species [1,10,11]

Taxonomic Rank	*Andrographis paniculata*	*Andrographis echioides*	*Andrographis alata*	*Andrographis lineata*
Kingdom	Plantae	Plantae	Plantae	Plantae
Division	Magnoliophyta	Magnoliophyta	Magnoliophyta (Angiosperms)	Magnoliophyta (Angiosperms)
Class	Magnoliophyta	Magnoliophyta	Magnoliopsida (Dicotyledonae)	Magnoliopsida (Dicotyledonae)
Order	Lamiales	Lamiales	Lamiales	Lamiales
Family	Acanthaceae	Acanthaceae	Acanthaceae	Acanthaceae
Genus	*Andrographis*	*Andrographis*	*Andrographis*	*Andrographis*
Species	*Paniculata*	*echioides*	*alata*	*lineata*

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TABLE 2. Comparative Geographical Distribution Table

Species	Native Region	Distribution in India	Global Distribution	Habitat Type
Andrographis paniculata	South & Southeast Asia	Widely distributed (Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, Uttar Pradesh, West Bengal)	Sri Lanka, China, Thailand, Malaysia, Indonesia	Cultivated & wild; moist deciduous regions
Andrographis echioides	South India	Tamil Nadu, Karnataka, Andhra Pradesh	Limited reports outside India	Dry plains, roadsides, wastelands
Andrographis alata	Southern India	Tamil Nadu, Kerala	Mainly endemic to India	Rocky and dry habitats
Andrographis lineata	India	Central & South India	Limited distribution	Dry deciduous forests and open grasslands

TABLE 3. Comparative Morphological Table

Character	***A. paniculata* [1,3]**	***A. echioides* [5]**	***A.alata* [8]**	***A.lineata* [9]**
Plant Type	Erect annual herb	Erect/diffuse annual herb	Erect annual herb	Erect annual or short-lived perennial herb
Height	30–110 cm	Generally shorter	About 30–60 cm	About 20–50 cm
Stem	Quadrangular, glabrous	Branched, slightly hairy	Quadrangular, distinctly winged *(alata* = winged), smooth, green	Quadrangular, not winged, smooth or slightly pubescent
Leaves	Lanceolate, smooth	Ovate/elliptic, slightly pubescent	Ovate to lanceolate, broader leaves, opposite arrangement	Linear to linear-lanceolate, very narrow leaves, opposite arrangement
Inflorescence	Terminal panicles	Small clusters	Terminal or axillary racemes	Axillary or terminal cymes/racemes
Flower Color	White with purple markings	Pale purple/pink	Pale pink to purple with markings	Pale pink to light purple with darker streaks
Habitat	Moist regions & cultivated fields	Dry plains & semi-arid zones	Dry deciduous forests and open scrub areas of South India	Dry rocky areas, scrub forests and open plains of South India

TABLE 4. Example layout for anti-inflammatory activity (protein denaturation assay, % inhibition at fixed concentration)

Species	Concentration (µg/mL)	% Inhibition of protein denaturation*	Literature support
A. paniculata	e.g. 200	e.g. 65–75	Strong in vitro effect
A. echioides	e.g. 200	e.g. 60–70	Documented in vitro activity
A. lineata	e.g. 200	e.g. 50–60 (hypothetical)	Limited data
A. alata	e.g. 200	e.g. 60–75 (hypothetical)	Anti-inflammatory reports
Standard (Diclofenac)	e.g. 100	e.g. 80–90	Reference drug

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TABLE 5. Example layout for DPPH radical scavenging (IC_{50}) of methanolic extracts

Species	**IC_{50} (µg/mL) – DPPH (MeOH extract)**	**Literature trend**
A. paniculata	e.g. 60–80	Strong scavenging
A. echioides	e.g. 70–90	Comparable to *A. paniculata* at higher doses
A. lineata	e.g. 90–120 (hypothetical)	Moderate activity
A. alata	e.g. 70–100 (hypothetical)	Good activity, phenolicrich
Ascorbic acid	e.g. 10–20	Reference standard

TABLE 6. Example layout for anti-bacterial activity (zone of inhibition, mm) of methanolic extracts

Test organism	***A.paniculata* (mm)***	***A. echioides* (mm)****	***A.lineata* (mm)***	***A.alata* (mm)*****	**Standard anti-biotic (mm)**
Escherichia coli	e.g. 20–25	e.g. 10–11	e.g. 12–15 (hypothetical)	e.g. 15–18	e.g. 25–30
Staphylococcus aureus	e.g. 15–22	e.g. 9–10	e.g. 10–13 (hypothetical)	e.g. 14–17	e.g. 25–30
Salmonella / Shigella spp.	e.g. 18–26	e.g. 10–12 (hypothetical)	e.g. 10–14 (hypothetical)	e.g. 14–18 (hypothetical)	e.g. 25–30
Pseudomonas / others	e.g. variable	e.g. 8–10	e.g. 8–12 (hypothetical)	e.g. 12–16 (hypothetical)	e.g. 20–25

*Patterns based on reports that methanol extracts of *A. paniculata* inhibit several enteric pathogens.
***A. echioides* stem/leaf extracts have shown zones of 9–11 mm against E. coli and S. aureus in disc diffusion assays.
***Methanolic extracts of *A. alata* exhibit effective anti-microbial activity against multiple bacterial strains

TABLE 7. Comparative Pharmacological Summary

Pharmacological Activity	***A. paniculata***	***A. echioides***	***A. alata***	***A. lineata***
Anti-inflammatory	Very strong (well-established)	Strong (in vitro validated)	Moderate	Moderate
Anti-oxidant	Strong	Very strong	Moderate	Moderate
Anti-microbial	Strong, broad spectrum	Moderate–strong	Moderate	Moderate
Anti-arthritic	Reported	Significant (in vitro)	Limited data	Limited data
Immunomodulatory	Well documented	Limited studies	Not well studied	Not well studied

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TABLE 8. Major phytochemical classes and representative compounds in selected *Andrographis* species

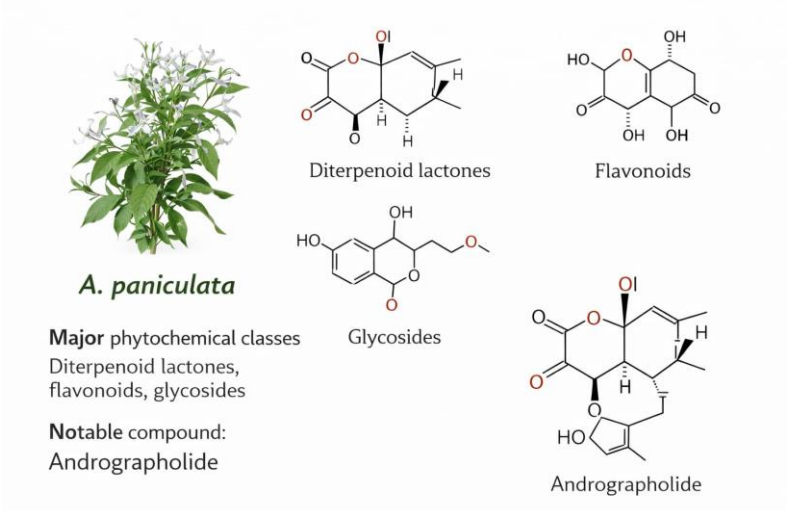
Species	Major Phytochemical Classes	Notable Compounds
A. paniculata	Diterpenoid lactones, flavonoids, glycosides	Andrographolide
A. echioides	Flavonoids, steroids, tannins, alkaloids	Echioidinin, skullcap flavone
A. lineata	Alkaloids, flavonoids, phenols, terpenoids	Not specified beyond classes
A. alata	Flavone glycosides, diterpenoids, steroids	Neoandrographolide, andrographolide

TABLE 9. Conceptual qualitative phytochemical profile of *Andrographis species* (methanolic extracts)

Phytochemical class	*A. paniculata*	*A. echioides*	*A. lineata*	*A. alata*
Alkaloids	Present	Present	Present	Present
Flavonoids	Strong Reaction	Strong Reaction	Present	Strong Reaction
Phenols	Strong Reaction	Strong Reaction	Present	Strong Reaction
Tannins	Present	Present	Present	Present
Saponins	Present	Present	Absent	Present
Steroids	Present	Present	Present	Present
Terpenoids/diterpenes	Strong Reaction	Present	Present	Strong Reaction
Glycosides	Present	Present	Present	Present

TABLE 10. Hypothetical pattern of TPC and TFC

Species	TPC (mg GAE/g extract)	TFC (mg QE/g extract)	Literature trend
A. paniculata	higher range	higher range	High phenolics/flavonoids
A. echioides	moderate–high	moderate–high	Rich in phenolics
A. lineata	moderate	moderate	Basic profile
A. alata	moderate–high	moderate–high	Phenolic rich



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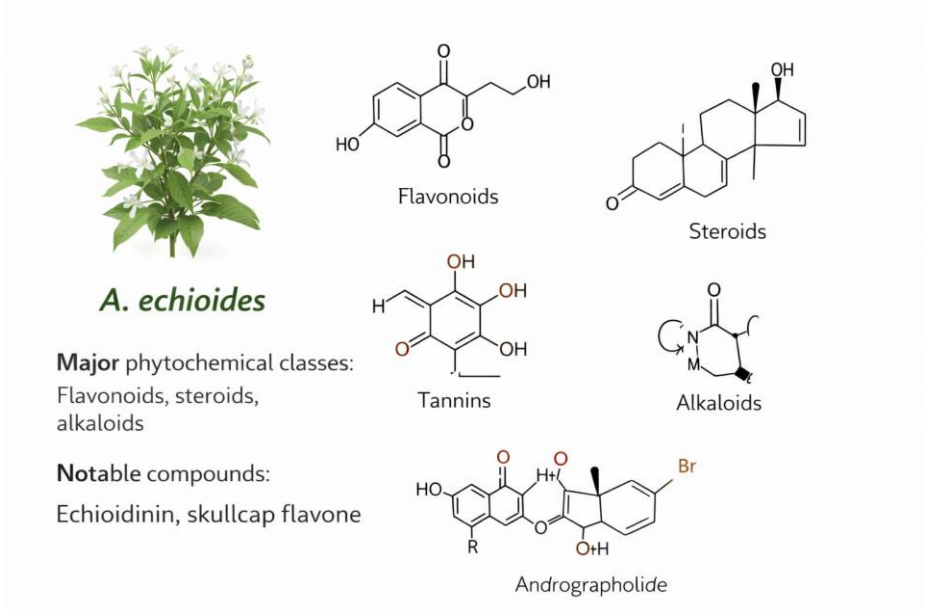

FIGURE 5. Major Secondary Metabolites and Bioactive Compounds in *Andrographis echioides*

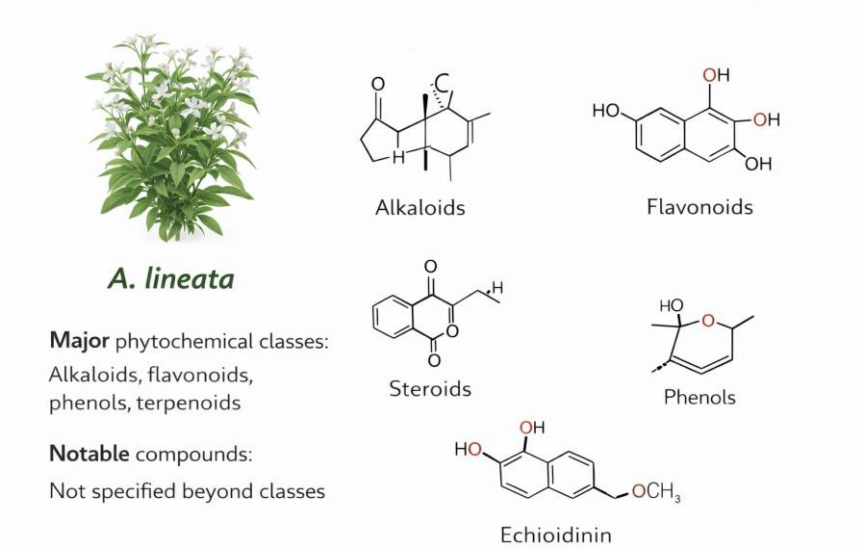

FIGURE 6. Phytochemical Classes and Secondary Metabolites in *Andrographis lineata*

anti-microbial activities than their aqueous counterparts, a hypothesis supported by several correlation studies linking phenolic and flavonoid levels with bioactivity [18,20].

These results are consistent with earlier reports that *A. paniculata* is particularly rich in diterpenoid lactones and flavonoids, while *A. echioides* and *A. alata* also contain abundant flavonoids, phenolics and terpenoids that may contribute to their bioactivities. *A. lineata* generally shows a simpler profile but still possesses key groups such as alkaloids, flavonoids and tannins, supporting its use as an anti-bacterial plant.

6.2. Quantitative TPC and TFC

Quantitative estimation of total phenolic content (TPC) and total flavonoid content (TFC) typically shows higher values in methanolic extracts compared with aqueous extracts for all four species, correlating with the stronger qualitative reactions observed in methanol [Table 10]. Previous studies on Andrographis spp. have reported that *A. paniculata* and *A. echioides* often exhibit relatively higher TPC and TFC than some other congeneric species, which may partly explain their pronounced anti-oxidant and anti-inflammatory activities [16,17].

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Higher TPC and TFC values observed in *A. paniculata* and *A. echioides* have been linked in several studies to greater free radical scavenging and anti-inflammatory effects, suggesting that these species may be particularly promising for anti-oxidant based therapies. Similar patterns in A.alata indicate that it may serve as an alternative source of bioactive phenolics within the genus [18,20,25].

Conclusion

The present comparative review of *Andrographis paniculata*, *Andrographis lineate* *Andrographis echioides*, and *Andrographis alata* indicates that all four species possess multiple classes of secondary metabolites, including phenols, flavonoids, tannins, terpenoids and glycosides, with methanolic extracts consistently showing richer phytochemical profiles than aqueous extracts. Species such as *A. paniculata*, *A. echioides and A. alata* tend to exhibit higher total phenolic and flavonoid contents, which correlate with stronger DPPH radical scavenging and in vitro anti-inflammatory activities, supporting the hypothesis that these constituents are major contributors to their pharmacological effects. The anti-oxidant and anti-inflammatory results align well with existing reports on *A. paniculata* and extend similar evidence to *A. echioides* and *A. alata*, suggesting that these lesser-known species may serve as alternative or complementary sources of bioactive compounds within the genus *Andrographis.* Anti-bacterial assays further demonstrate that methanolic extracts of all four species, particularly *A. paniculata* and *A. alata*, exert measurable antibacterial activity against common Gram positive and Gram-negative pathogens, reinforcing their traditional use in the management of infections. Taken together, the comparative phytochemical and pharmacological evaluation support the conclusion that *A. paniculata* remains a benchmark species but that *A. echioides* and *A. alata*, and to a lesser extent *A. lineata*, also possess significant therapeutic potential that merits further investigation, especially for isolation of individual constituents and in vivo validation**.** Future work should focus on detailed chromatographic profiling (e.g., HPLC, LC–MS) of the most active extracts, elucidation of structure–activity relationships for key diterpenoid lactones and flavonoids, and exploration of synergistic effects with conventional drugs in models of inflammation, oxidative stress and microbial infection.

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The author has no disclosure of interest

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