Original Article
Bulletin of Pure and Applied Sciences.
Chemistry, Vol.45 C, No.2
July-December 2026: P.22-31

http://www.bpasjournals.com/chemistry
Print version ISSN 0970 4620
Online version ISSN 2320 320X

Phytochemical Profile and Therapeutic Potential of Achyranthes aspera L.

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ABSTRACT

Achyranthes aspera L., commonly known as prickly chaff flower or apamarga, is an important medicinal plant belonging to the family Amaranthaceae and is widely distributed throughout tropical and subtropical regions of Asia. The plant has a long history of application in traditional systems of medicine, particularly Ayurveda and various indigenous healthcare practices. Different parts of *A. aspera*, including roots, leaves, stems, seeds, flowers and whole plant, have been traditionally employed for the management of a wide range of ailments. The therapeutic significance of the species is closely associated with its diverse phytochemical composition. Reported phytoconstituents include saponins, alkaloids, flavonoids, terpenoids, steroids, phenolic compounds, tannins, glycosides, ecdysterone and various fatty acids and other secondary metabolites. These constituents are considered responsible for several experimentally observed biological activities, including antioxidant, antimicrobial, anti-inflammatory, analgesic, antipyretic, hepatoprotective, antidiabetic, wound-healing and immunomodulatory effects. This review summarizes the major phytochemical constituents of *A. aspera*, their distribution in different plant parts, and the evidence concerning its pharmacological and therapeutic potential. Particular emphasis is placed on the relationship between phytochemical composition and biological activity. The available evidence indicates that *A. aspera* represents a promising source of bioactive natural products; however, systematic phytochemical standardization, identification of active molecules, pharmacokinetic studies, toxicity assessment and well-designed clinical investigations are required to establish its therapeutic applications.

Keywords: Achyranthes aspera, phytochemicals, ethnomedicine, pharmacological activity, therapeutic potential.

Received on 25.08.2026, Revised on 25.09.2026, Accepted on 31.10.2026

How to cite this article: Chandra A. and Chandra A. Phytochemical Profile and Therapeutic Potential of Achyranthes aspera L.. *Bulletin of Pure and Applied Sciences-Chemistry,* 2026;45C (2), 22-31.

1. INTRODUCTION

Medicinal plants constitute an important source of bioactive natural products and have historically contributed to traditional healthcare systems as well as modern drug discovery. Among medicinal plants of the family Amaranthaceae, *Achyranthes aspera* L., commonly known as prickly chaff flower and

traditionally known as Apamarga, has received considerable attention because of its wide ethnomedicinal applications and diverse phytochemical composition [1–3]. The plant is distributed widely in tropical and subtropical regions and is particularly common in India, where different parts of the plant are used in Ayurveda and other traditional systems of medicine [1,2].

Traditionally, roots, leaves, seeds, stems and the whole plant of *A. aspera* have been employed for conditions including inflammation, wounds, digestive disorders, respiratory ailments, skin diseases, fever and urinary disorders [1,3]. A comprehensive review of the genus *Achyranthes* documented traditional applications of *A. aspera* in gynecological disorders, asthma, ophthalmic conditions, dental problems, haemorrhoids, wound healing and treatment of insect and snake bites [1]. Such traditional applications have stimulated scientific investigation into its chemical constituents and biological activities.

Phytochemical investigations have demonstrated the occurrence of several classes of secondary metabolites, including alkaloids, flavonoids, phenolic compounds, saponins, tannins, terpenoids, steroids and glycosides [2–5]. More specifically, compounds such as achyranthine, ecdysterone, oleanolic acid, spinasterol, ursolic acid and related constituents have been reported from different parts or extracts of the plant [2,3]. These compounds and compound classes may contribute to the antioxidant, antimicrobial, anti-inflammatory and other pharmacological properties reported experimentally.

The present review therefore focuses on the phytochemical profile and therapeutic potential of *Achyranthes aspera* L., emphasizing the relationship between its major bioactive constituents and reported biological activities.

2. BOTANICAL, ETHNOMEDICINAL AND PHARMACOGNOSTIC SIGNIFICANCE

Achyranthes aspera L. is an herbaceous medicinal plant belonging to the family Amaranthaceae. It is widely distributed in India and other tropical regions and is commonly encountered as a weed in cultivated fields, roadsides and wastelands [1,3]. Different geographical populations may exhibit differences in phytochemical composition because environmental conditions, soil characteristics, season, plant age and developmental stage can influence secondary-metabolite production.

The medicinal importance of *A. aspera* is closely associated with its extensive traditional use. Various parts of the plant have been used traditionally for cough, bronchitis, rheumatism, dysentery, asthma, hypertension, diabetes, skin disorders, wounds and urinary complaints [1,6]. Traditional applications also include preparations intended for digestive and inflammatory conditions [2,3]. Figure 1 shows the traditional medicinal applications of different plant parts of Achyranthes aspera L.

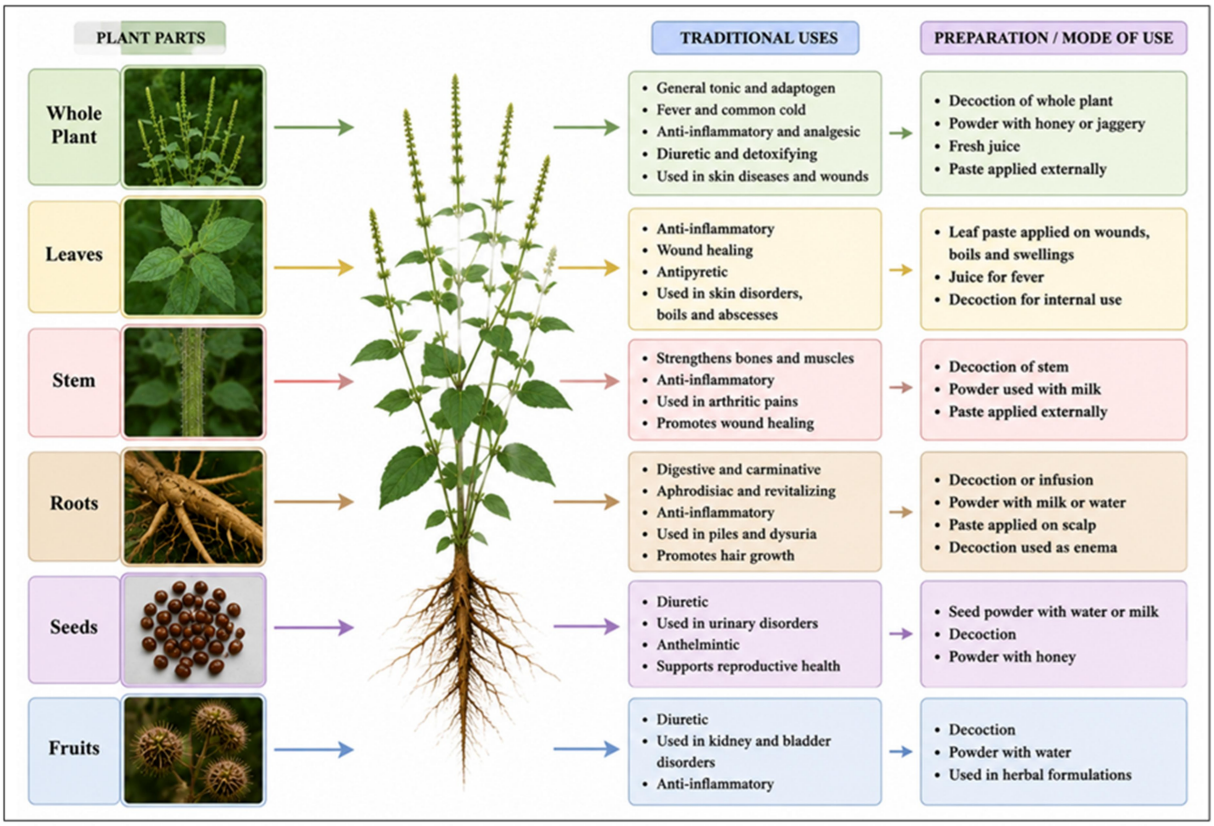


Figure 1: Traditional medicinal applications of different plant parts of Achyranthes aspera L.

Pharmacognostic investigations provide useful preliminary information for authentication and quality control of the plant material. Microscopic and preliminary phytochemical studies of the whole plant have reported sterols, flavonoids, tannins and carbohydrates [7]. Such investigations are important because correct botanical identification and standardized raw material are prerequisites for reproducible pharmacological and phytochemical studies.

Although traditional use provides valuable evidence regarding the historical medicinal significance of *A. aspera*, it should not be considered equivalent to demonstrated clinical efficacy. Scientific validation requires chemically standardized preparations, controlled experimental studies and appropriately designed clinical investigations.

3. PHYTOCHEMICAL PROFILE OF ACHYRANTHES ASPERA L.

The medicinal significance of *A. aspera* is associated with a broad spectrum of secondary metabolites. Reviews of its phytochemistry have reported alkaloids, flavonoids, saponins, tannins, terpenoids, steroids, glycosides, phenolic compounds and other constituents, as shown in Fig. 2 [1–5].

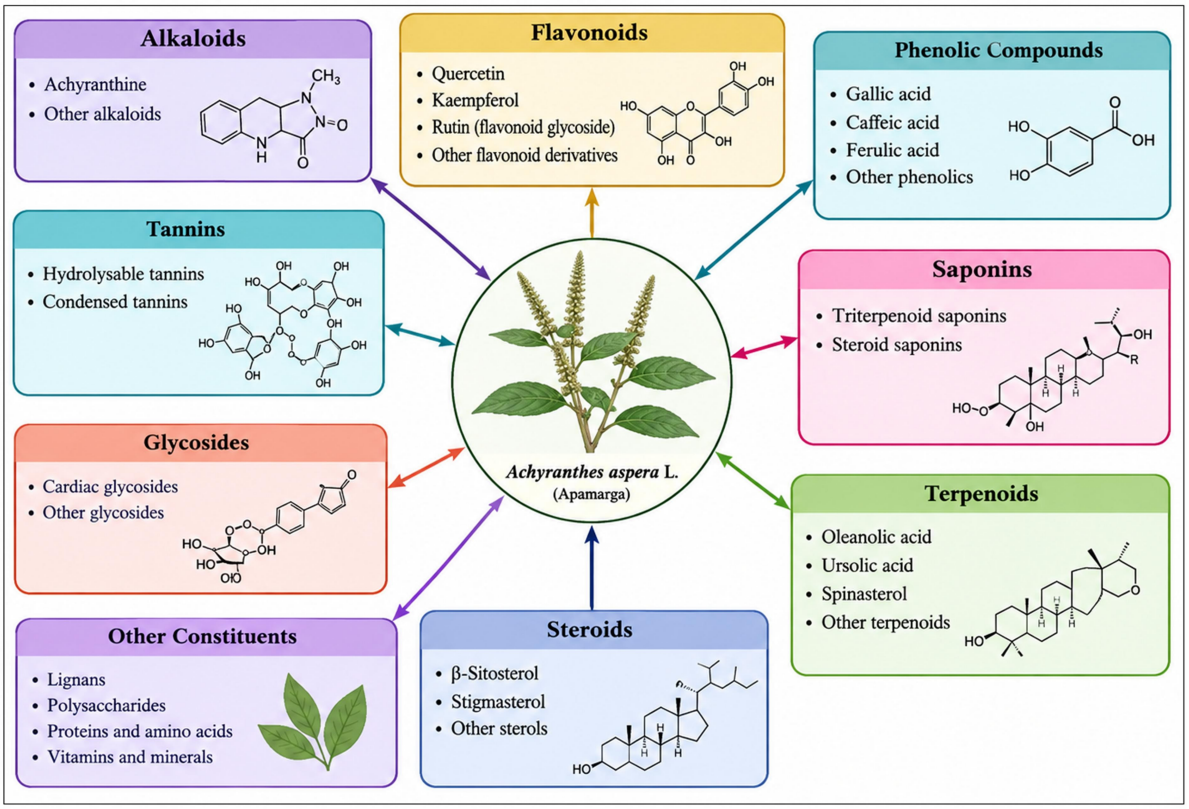


Figure 2: Schematic representation of the major phytochemical constituents reported in *Achyranthes aspera* L.

3.1 Alkaloids

Alkaloids are nitrogen-containing secondary metabolites that frequently exhibit significant biological activities. Alkaloid-containing fractions have been reported in *A. aspera*, and achyranthine is among the characteristic constituents associated with the species [2,3]. Alkaloids may contribute to antimicrobial, analgesic, anti-inflammatory and other biological effects, although the contribution of individual alkaloids requires compound-specific investigation.

3.2 Flavonoids and Phenolic Compounds

Flavonoids and phenolic compounds are important components of many medicinal plants because of their redox-related biological properties. Phytochemical investigations have demonstrated flavonoids and phenolic constituents in *A. aspera* extracts [4,5,8]. Ethanolic leaf extracts have also been investigated using chromatographic and spectroscopic approaches for their bioactive constituents and antioxidant properties [8].

The antioxidant potential of these compounds is generally associated with their ability to interact with reactive oxygen species and other free radicals. However, the antioxidant capacity of a crude plant extract cannot be attributed exclusively to total phenolic or flavonoid content without appropriate isolation and mechanistic studies.

3.3 Saponins

Saponins constitute another important phytochemical group in *A. aspera*. Triterpenoid saponins have been identified as major bioactive constituents within the genus *Achyranthes* [1]. A bioassay-guided study of *A. aspera* demonstrated that a triterpenoid-saponin-rich fraction exhibited anti-inflammatory and antioxidant effects in a carrageenan-induced experimental model; oleanolic acid was identified from the active fraction [9].

3.4 Terpenoids, Steroids and Ecdysteroids

Terpenoid and steroidal compounds contribute substantially to the chemical diversity of *A. aspera*. Reported compounds include oleanolic acid, ursolic acid and spinasterol, while ecdysterone (20-hydroxyecdysone) has also been reported among the characteristic constituents [2,3].

Recent research has further investigated α-spinasterol isolated from *A. aspera*. In an experimental inflammatory model, α-spinasterol affected inflammatory mediators and signaling pathways involving NF-κB and Nrf2/HO-1, providing additional evidence for the biological importance of steroidal constituents [10].

3.5 Tannins and Glycosides

Tannins and glycosides have also been detected in different extracts of *A. aspera* [4,5]. Aerial-part extracts have demonstrated the presence of phenolics, saponins, tannins, alkaloids, flavonoids, cardiac glycosides and steroids, with differences depending on the extraction solvent [5]. Such findings demonstrate that extraction methodology can substantially influence the apparent phytochemical profile of the plant.

4. THERAPEUTIC AND PHARMACOLOGICAL POTENTIAL

The pharmacological significance of *A. aspera* has been investigated using in-vitro and in-vivo experimental models. Reported activities include antioxidant, antimicrobial, anti-inflammatory, analgesic, hepatoprotective, antidiabetic, wound-healing and immunomodulatory effects, as shown in Fig. 3 [1–5].

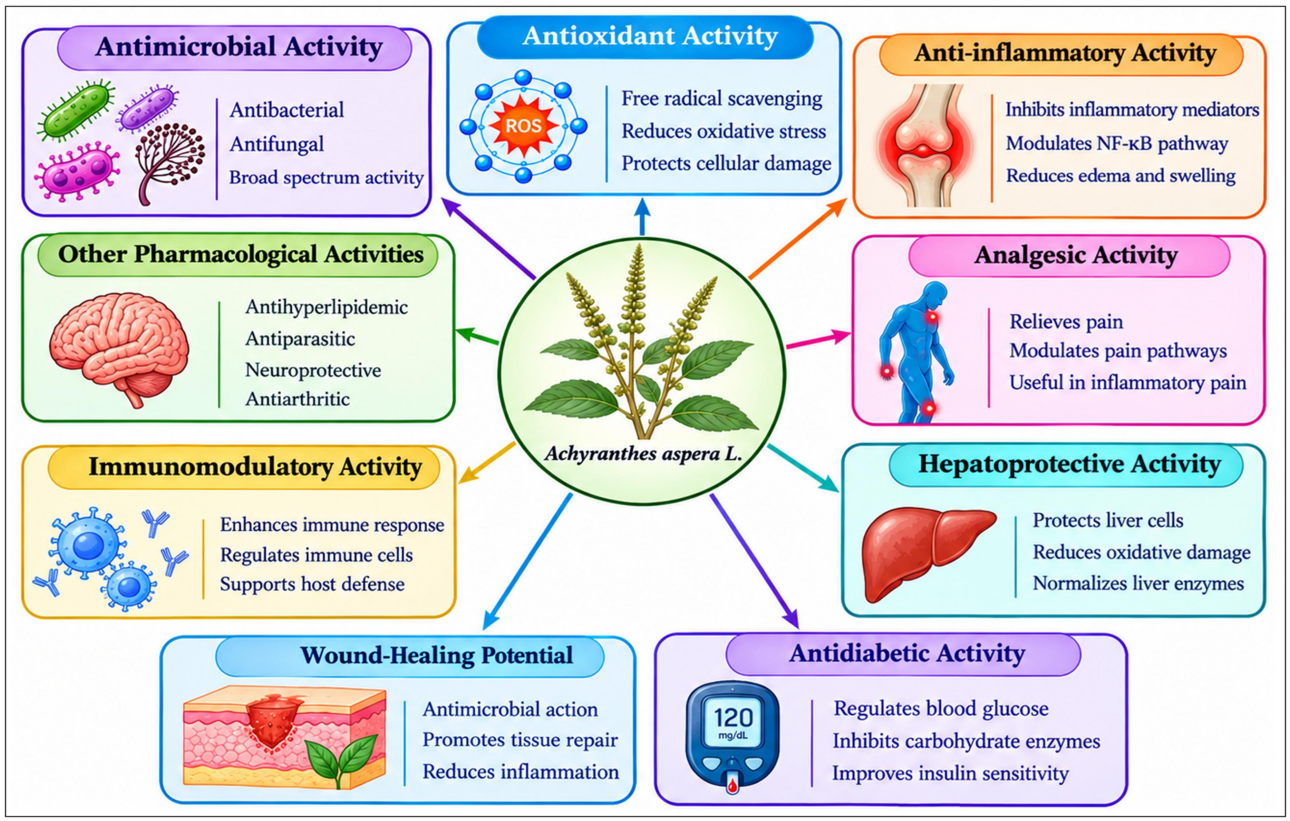


Figure 3: Schematic representation of the therapeutic and pharmacological potential of *Achyranthes aspera* L.

4.1 Antioxidant Activity

Oxidative stress is associated with excessive production of reactive oxygen species and can contribute to cellular and tissue damage. Extracts of *A. aspera* have demonstrated free-radical-scavenging and related antioxidant activities [4,8,11]. Methanolic extracts have shown antioxidant activity in DPPH-based assays, with activity varying according to extraction conditions [11].

Phenolic and flavonoid compounds are likely contributors to these effects, although saponins and other metabolites may also participate. The antioxidant findings provide a possible biochemical basis for some traditional applications but require further biological validation.

4.2 Antimicrobial Activity

Several investigations have reported antibacterial and antifungal activity of *A. aspera* extracts. Root and shoot extracts have demonstrated activity against selected bacterial and fungal organisms [12]. More recent studies have also shown dose-dependent antibacterial

effects of aerial-part extracts against organisms including *Bacillus subtilis, Escherichia coli, Staphylococcus aureus, Klebsiella pneumoniae* and *Pseudomonas aeruginosa* [5].

The antimicrobial effects may involve several phytochemical classes acting through different mechanisms, including effects on microbial membranes and cellular metabolism. However, antimicrobial activity observed in laboratory assays should not automatically be interpreted as clinical efficacy.

4.3 Anti-inflammatory Activity

Anti-inflammatory activity is among the better investigated pharmacological properties of *A. aspera*. Alcoholic root extracts have demonstrated activity in carrageenan-induced paw edema and cotton-pellet granuloma models [13]. Another study reported anti-inflammatory activity of aqueous leaf and whole-plant extracts and identified flavonoids, alkaloids, saponins and triterpenoids among the major phytochemical groups [6].

At the molecular level, ethanolic extract of *A. aspera* has been reported to reduce inflammatory signaling involving NF-κB and upstream Src and Syk kinases [14]. These findings provide a possible mechanistic explanation for some of the anti-inflammatory effects observed in experimental models.

4.4 Wound-Healing Potential

Traditional use of *A. aspera* includes applications related to wounds and skin conditions [1,2]. Experimental studies have investigated its wound-healing potential alongside antioxidant and antibacterial properties. Methanolic and aqueous extracts have demonstrated antibacterial and wound-healing-related effects in experimental investigations [11].

The potential wound-healing activity may involve multiple processes, including reduction of microbial burden, modulation of inflammation and protection from oxidative damage. Further studies using standardized formulations and clinically relevant wound models are needed.

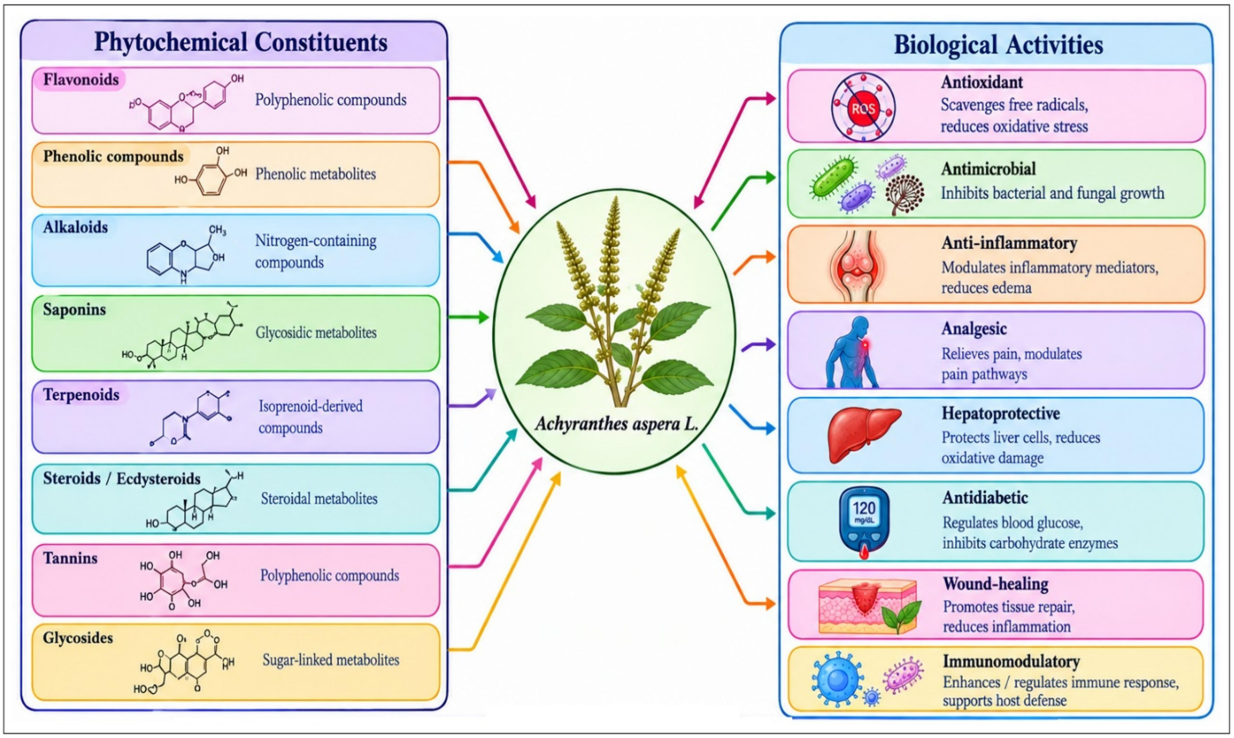
4.5 Metabolic and Other Pharmacological Activities

Experimental and review literature has reported additional biological activities, including antidiabetic, antihyperlipidemic, hepatoprotective, antiarthritic, immunomodulatory, antiparasitic and neuroprotective effects [1–4,15]. Recent research has particularly highlighted the potential neuroprotective effects of *A. aspera* and its possible influence on oxidative stress, inflammatory signaling, mitochondrial function and neuronal survival [15-17].

These findings broaden the potential therapeutic relevance of the plant but remain predominantly preclinical. Consequently, they should be considered evidence of therapeutic potential rather than established clinical indications.

5. RELATIONSHIP BETWEEN PHYTOCHEMICAL CONSTITUENTS AND BIOLOGICAL ACTIVITIES

The therapeutic potential of *A. aspera* is likely to result from the combined action of several phytochemical constituents rather than from a single compound. Figure 4 shows the schematic representation of the relationship between the major phytochemical constituents of *Achyranthes aspera* L. and their reported biological activities.



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Figure 4: Schematic representation of the relationship between the major phytochemical constituents of *Achyranthes aspera* L. and their reported biological activities.

Evidence from bioassay-guided fractionation is particularly important because it can connect chemical constituents with biological effects. For example, the isolation of oleanolic acid from a biologically active saponin-rich fraction provides stronger evidence for a phytochemical–activity relationship than simple qualitative phytochemical screening [9].

Similarly, experimental work with α-spinasterol has demonstrated effects on inflammatory cytokines and NF-κB/Nrf2-related signaling, providing a more specific mechanistic link between an isolated constituent and biological activity [10].

Nevertheless, the possibility of synergistic interactions among phytochemicals should not be overlooked. Crude extracts may contain numerous compounds whose combined effects differ from those of individual isolated molecules. Therefore, future research should combine metabolomic profiling, bioassay-guided fractionation and molecular pharmacology. The major phytochemical–activity relationships reported in the literature can be summarized in Table 1:

Table 1: The major phytochemical–activity relationships reported in the literature.

Phytochemical group/compound	Reported or proposed biological relevance
Flavonoids	Antioxidant, anti-inflammatory, antimicrobial
Phenolic compounds	Antioxidant and antimicrobial
Saponins	Anti-inflammatory, antioxidant and immunomodulatory potential
Alkaloids	Antimicrobial and other pharmacological activities
Oleanolic acid	Anti-inflammatory and antioxidant-related activity
Ecdysterone	Diverse biological and pharmacological potential
α-Spinasterol	Anti-inflammatory and redox-related activity
Tannins	Antioxidant and antimicrobial potential
Terpenoids	Anti-inflammatory and antimicrobial potential

6. RESEARCH GAPS, SAFETY AND FUTURE PERSPECTIVES

Although substantial evidence supports the pharmacological potential of *A. aspera*, several limitations remain. A major limitation is the lack of uniformity in extraction procedures, plant material, geographical origin, dosage and experimental models among published studies [1–5]. Such variability makes direct comparison of results difficult.

Another important research gap is the limited number of studies establishing clear structure–activity relationships. Identification of phytochemicals through qualitative screening is insufficient to establish their therapeutic role. Advanced techniques such as HPLC, LC–MS/MS, GC–MS, FTIR and NMR should be employed for accurate chemical characterization and quantitative standardization.

Safety evaluation is equally important. Experimental investigations have provided preliminary information regarding the safety of certain extracts, but comprehensive long-term toxicity, reproductive toxicity, pharmacokinetic and herb–drug interaction studies remain necessary [1,6,16]. The safety profile of a standardized extract may also differ from that of an isolated compound or traditional crude preparation.

Future investigations should therefore emphasize:

1. standardized cultivation and collection of plant material;
2. quantitative phytochemical profiling;
3. isolation of pharmacologically active compounds;
4. metabolomic and molecular-level characterization;
5. bioassay-guided fractionation;
6. pharmacokinetic and bioavailability studies;
7. comprehensive toxicological evaluation;
8. investigation of synergistic interactions;
9. development of standardized formulations; and
10. appropriately designed clinical trials.

Such an integrated approach would help bridge the gap between ethnomedicinal knowledge, experimental pharmacology and evidence-based therapeutic development.

7. CONCLUSION

Achyranthes aspera L. is a phytochemically diverse medicinal plant with a long history of traditional use. Its major reported

phytochemical groups include flavonoids, phenolic compounds, alkaloids, saponins, tannins, terpenoids, steroids, glycosides and ecdysteroid-type constituents. Compounds such as oleanolic acid, ecdysterone and α-spinasterol provide important examples of constituents that may contribute to the biological activities of the plant. Experimental evidence indicates that *A. aspera* possesses antioxidant, antimicrobial, anti-inflammatory and wound-healing potential, while additional studies have reported antidiabetic, hepatoprotective, immunomodulatory and neuroprotective effects. Among these, anti-inflammatory activity has been supported by both animal models and mechanistic investigations involving inflammatory signaling pathways

Overall, *A. aspera* represents a promising source of biologically active natural products. However, most available evidence remains preclinical, and the therapeutic significance of individual constituents and standardized extracts requires further validation. Future research integrating phytochemical standardization, advanced analytical techniques, molecular pharmacology, pharmacokinetics, toxicity studies and clinical evaluation will be essential for determining the extent to which the traditional therapeutic potential of *A. aspera* can be translated into scientifically validated applications.

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