DOI: https://doi.org/10.66220/4mdpen52 ISSN: 3139-9266

Journal of PhytoPharmaceutical and Advanced Chemistry (JPPAC)
https://jppac.in/index.php/jppac

Review Article

Andrographis paniculata (Burm.f.) Nees: Bridging Traditional Medicine and Modern Pharmacological Applications

Naziya Parveen[1], Arvind Kumar Patel[1]*, Neha Singh[2], Pushp Raj Singh[1], Dharmendra Kumar[1], Laliteshwar Pratap Singh[1]

[1]Narayan Institute of Pharmacy, Gopal Narayan Singh University, Jamuhar, Sasaram, Rohtas-821305, Bihar, India.
[2]Teerthanker Mahaveer College of Pharmacy, Teerthanker Mahaveer University, Moradabad-244001, Uttar Pradesh, India.
*Corresponding author: akpatel4393@gmail.com

Article info:

Submitted: 24/06/2026
Revised: 15/07/2026
Accepted: 20/07/2026
Published: 27/07/2026
Manuscript ID: 00024
Subject: Phytopharmaceutical Sciences

Keywords:

Andrographis paniculata; Andrographolide; Medicinal plant; Herbal medicine; Phytochemicals; Pharmacological activities; Clinical validation.

Abstract:

Andrographis paniculata (Burm. f.) Nees is a useful medicinal plant that's used in traditional medicine for treating inflammatory, infectious, metabolic and chronic diseases. This review provides a detailed investigation of its therapeutic versatility from a critical perspective based on traditional knowledge and authentic pharmacology and clinical findings. Hosted by the platform online, a systematic literature search was performed to find related articles from PubMed, Scopus, Web of Science, ScienceDirect and Google Scholar between the years 2000 and 2025. The search was done for papers that contained information related to *Andrographis paniculata* and the information was found in clinical studies, review articles, and original research articles. This review includes 58 publications chosen from the pool of relevant ones (predefined inclusion and exclusion criteria). Numerous bioactive constituents including diterpenoid lactones, flavonoids, and phenols have been found in *Andrographis paniculata*, with andrographolide being the major bioactive marker with diverse pharmacological activities and phytochemical constituents. These studies exhibit a lot of antioxidants, anti-inflammatory, antimicrobial, immunomodulatory, antidiabetic, cardioprotective, neuroprotective and anticancer effects. Modulation of the signalling pathway, such as NF-κB, Mitogen-Activated Protein Kinase (MAPK), Janus Kinase / Signal Transducer and Activator of Transcription (JAK/STAT), and oxidative stress, is the mechanism involved in such effects. Some clinical studies have demonstrated beneficial effects on some inflammatory markers and glycaemic parameters, as well as symptomatic benefit of some diseases, with an overall positive safety profile in limited clinical studies. However, there remain a number of restrictions for several reasons, firstly due to the variation of the phytochemical constituents of the plants, and lack of standardisation and secondly due to the absence of large-scale trials. *Andrographis* paniculata demonstrates considerable therapeutic potential across a wide range of disease conditions. Additional standardisation of formulations,

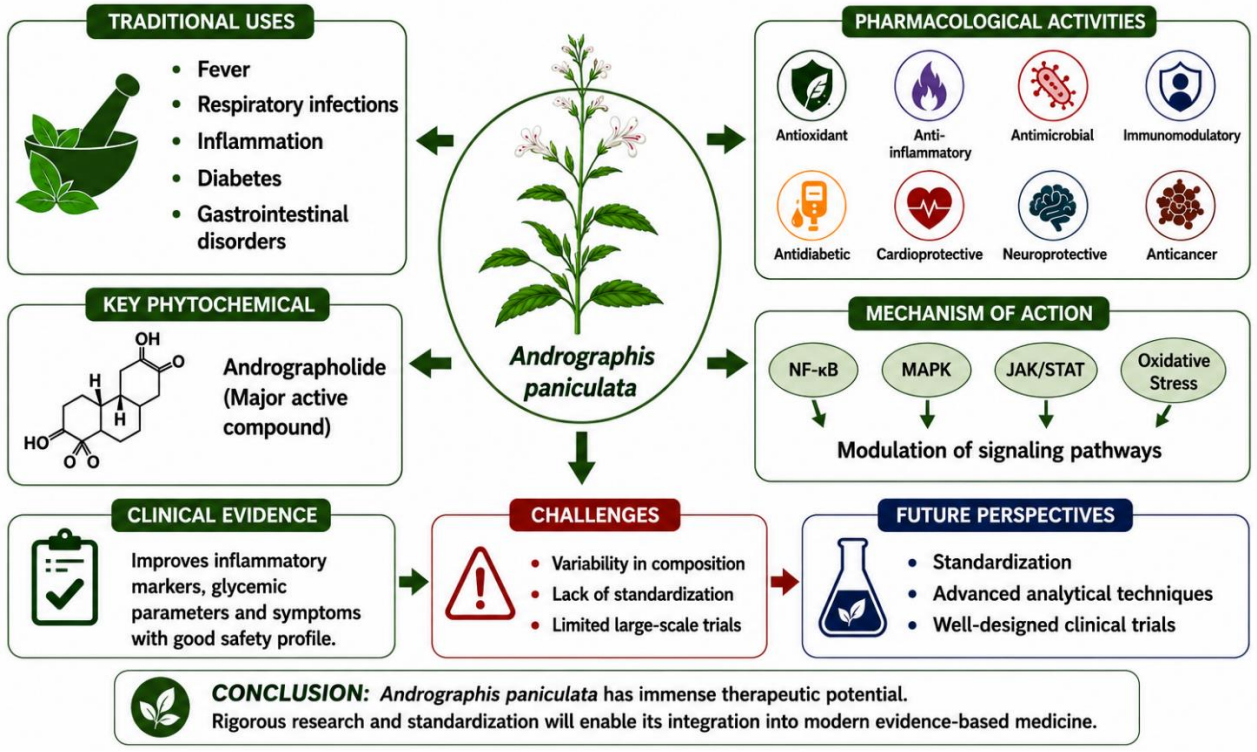
advanced analytical techniques and extensive clinical studies are needed to determine its clinical effectiveness and to include it in evidence-based medicine.

How to Cite this article: N. Parveen, A.K. Patel, N. Singh, et al. *Andrographis paniculata* (Burm.f.) Nees: Bridging Traditional Medicine and Modern Pharmacological Applications. *J. PhytoPharm. Adv. Chem.* **2026**, 01 [02], 99-121. DOI: https://doi.org/10.66220/4mdpen52

©2026 The authors

This is an Open Access article distributed under the terms of the Creative Commons Attribution (CC BY NC), which permits unrestricted use, distribution, and reproduction in any medium, as long as the original authors and source are cited. No permission is required from the authors or the publishers. (https://creativecommons.org/licenses/by-nc/4.0/)

Graphical Abstract



1. Introduction

Medicinal plants continue to play a significant role in healthcare systems worldwide. Their role in low and middle-income countries is especially strong as traditional medicine forms an integral part of primary health care services and contributes to the enhancement of access to treatment for a significant portion of the population (1). The increasing prevalence of chronic diseases, adverse drug reactions attributed to synthetic medicines, antimicrobial resistance and the skyrocketing costs of healthcare are some continuing public health problems. Therefore, the demand for natural-product-derived therapeutic alternatives as safer, economical and effective has resulted in a gradual shift (2). Many medicinal products are used as natural products. It is currently found that about 25-30% of all pharmaceutical drugs that are approved by the various authorities come from natural sources,

indicating their continued relevance in drug discovery. These have a variety of biological activities and have played a large part in the development of medically important drugs (3).

Andrographis paniculata (Burm. f.) has attracted considerable scientific attention (King of bitters) or Kalmegh as a product, due to its higher traditional uses and multiple medicinal effects. This plant has been traditionally used to treat multiple ailments for centuries in Ayurvedic, Traditional Chinese Medicine and Unani medicine, such as fever, respiratory tract infections, inflammation, diabetes and gastrointestinal disorders (4). The medicinal properties of A. paniculata are attributed to various compounds it has, such as diterpenoid lactones, flavonoids, polyphenols and other secondary metabolites.These compounds are mainly bioactive, and andrographolide is the major compound found to have numerous pharmacological activities of this plant (5).

Recent studies indicate that the global herbal medicine market has exceeded USD 180 billion and is expected to continue growing due to the increasing demand for plant-based healthcare products.Bn, which is expected to exhibit a stable growth rate as a result of the increased demand for plant-based health care products from customers. High performance liquid chromatography, liquid chromatography-mass spectrometry (LC-MS) and metabolomic techniques, for example, have been developed and used to systematically assess and standardize medicated plants and strengthen the scientific evidencefor traditional therapeutic uses (6). A. paniculata has been shown to have significant antioxidant activity, as well as anti-inflammatory, antimicrobial, immunomodulatory, antidiabetic, cardioprotective, neuroprotective and anticancer properties in various in vitro and animal studies (7). They regulate various signalling pathways such as Nuclear Factor Kappa B(NF-κB), Mitogen-Activated Protein Kinase (MAPK), Janus Kinase / Signal Transducer and Activator of Transcription(JAK/STAT) pathway and oxidative stress-related pathways to exert these pharmacological activities (8).

This review combines traditional medicinal knowledge with modern pharmacological evidence to evaluate the therapeutic versatility of *Andrographis paniculata*. In addition, it aims to collate the phytochemical profile, biological activities and molecular mechanisms of action of the plant in order to identify current research gaps and explore foresight for further evidence-based development of herbal therapeutics.

Some review articles have been published on the phytochemistry and pharmacological properties of A. paniculata, but most of them have concentrated on the therapeutic effects of specific bioactive constituents or therapeutic applications at a time. The present review is more comprehensive and updated which has taken the ethnomedicinal knowledge, phytochemical composition, pharmacological mechanisms, clinical studies, current limitations and future research perspectives in one line. In addition, the recent literature is included, structure–activity relationships are discussed, available evidence is critically assessed and challenges to standardization and clinical translation are highlighted, thus providing a more comprehensive view that should help to drive future pharmaceutical research and therapeutic development.

2. Methodology

The study was carried out by a thorough literature search aimed at summarizing the ethnomedicinal use, phytochemical constituents, pharmacological potential, clinical studies, constraints, and prospects of *Andrographis paniculata*. Major electronic databases (such as PubMed, Scopus, Web of Science, ScienceDirect and Google Scholar) were used to retrieve relevant literature. Keywords used to conduct the search were: "*Andrographis paniculata*", "andrographolide", "medicinal plant", "phytochemistry", "pharmacological activities", "clinical studies", "traditional medicine", "herbal medicine", "antioxidant", "anti-inflammatory", and "natural products" (9).

Most of the literature search was done of articles from year 2000 to 2025. Only English language original research articles, review articles, clinical studies and authoritative reports were considered for inclusion. All studies

DOI: https://doi.org/10.66220/4mdpen52 ISSN: 3139-9266

pertaining to the phytochemistry, pharmacological mechanisms, therapeutic applications, clinical evidence and safety of *Andrographis paniculata* were included. Conference abstracts, publications in duplicate, non-English articles that aren't translated and studies that didn't contain adequate scientific information were excluded, as well as unrelated publications.

The full text was subsequently screened for relevance of potentially eligible articles, after screening of duplicate and irrelevant articles by title and abstract. Finally, 60 references which directly supported the goals of this review were selected for qualitative synthesis. Literature selection was carried out by applying systematic literature review that has general principles to ensure the literature selection process to be transparent and comprehensive. The illustrations were prepared using GraphPad Prism and Microsoft PowerPoint (Figure 1) (10).

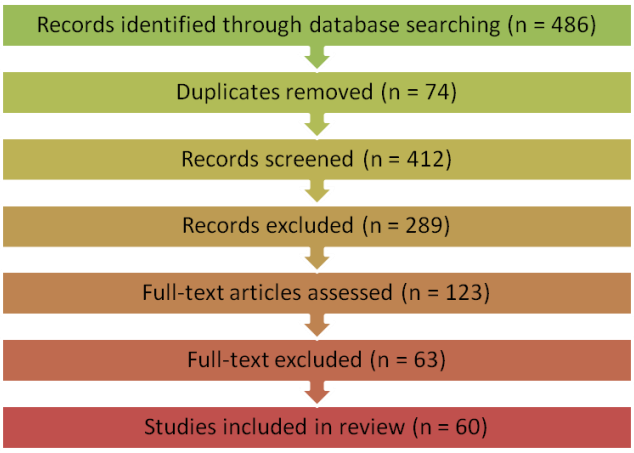


Figure 1. PRISMA flow diagram illustrating the literature search and study selection process adopted for this review.

3. Botanical Description and Taxonomy

Andrographis paniculata (Burm. f) is an annual herbaceous plant belonging to the family Acanthaceae. Due to its extremely bitter taste, it is called the "King of Bitters" plant. 'This is an erect, branching herb growing to 30-110 cm. The stem is slender, green, quadrangular and glabrous; the leaves are simple, opposite-lanceolate to ovate-lanceolate, 2-12 cm long,1-3 cm wide. It has small, tube-shaped flowers that are white and have purple or pink markings in terminal and axillary panicles. Fruits: Linear-Oblong; 1.5-2.5 cm in length, elongated, containing numerous yellowish- brown seeds. It is defined by the presence of unique bitter principles, especially diterpenoid lactones, that account for its medicinal potential (8).

The plant originally was only from India and Sri Lanka, but again became naturalised in most parts of tropical and subtropical Asia, including China in the south; it is widely spread to Thailand, Malaysia, Indonesia and other Southeast Asian countries. Due to its value in medicine, it has also been naturalised in some Caribbean islands, Central America and Australia (4).

A. paniculata grows best in warm and humid climatic conditions where the average temperature ranges from 25°C to 30°C, preferably cultivated on loamy/sandy soil with a pH between 5.5 and 7.5. Its most utilised form is seeds that, under conditions conducive to germination (18-20 °C), have a high percentage of adult plants. Bioactive constituents of the plant are maximum during its flowering stage, and generally, the crop matures in 90-120 days after sowing. A. paniculata is now of considerable economic importance in the herbal pharmaceutical industry, mainly because of its rapid growth, easy cultivability and broad therapeutic applications (5).

DOI: https://doi.org/10.66220/4mdpen52 ISSN: 3139-9266

4. Phytochemical Profiling of Andrographis paniculata

The phytochemical composition of *Andrographis paniculata* has been extensively investigated with the identification of a wide variety of bioactive molecules from different parts of the plant (seeds, aerial parts, roots, stem and leaves). These phytoconstituents are predominantly classified into the major chemical classes such as diterpenoid lactones, flavonoids, polyphenols, xanthones and quinic acids, these being the principal contributors to the diverse pharmacological activities of the plant. The phytochemicals, including many diterpenoid lactones like andrographolide, neoandrographolide, deoxyandrographolide and 14-deoxy-11,12-didehydroandrographolide, are useful phytol markers for many of the pharmacological potentialities of the plant (4).

Its antioxidant and anti-inflammatory activity is mainly contributed by flavonoids and phenolic compounds, while its antimicrobial, immunomodulatory, antidiabetic, cardioprotective, neuroprotective and anticancer activity is due to diterpenoid lactones in it. These phytochemicals have different concentrations and distributions in different parts of the plant, geographical origin, environmental conditions and various post-harvest methods. This is a sign of variability and standardisation of cultivation, extraction and quality control methods are of great importance for a better uniformity of the pharmacological action (5).

Recent advances in chromatographic and spectroscopic techniques such as high-performance liquid chromatography (HPLC), liquid chromatography–mass spectrometry (LC-MS), gas chromatography-mass spectrometry (GC-MS) and nuclear magnetic resonance (NMR) spectroscopy can be used to characterise these bioactive compounds in a more detailed fashion. Therefore, a more thorough characterisation of phytochemicals is needed to elucidate the therapeutic potential of A. paniculata to support quality standardisation and guide formulation of herbal products based on evidence. These phytoconstituents and their biological activities are summarised in Table 1 (5).

Table 1. Phytochemical composition of *Andrographis paniculata* across different plant parts.

Plant Part	Phytoconstituent Class	Major Compounds Identified	Analytical Method	Reported Biological Activities	Ref.
Leaves	Diterpenoid lactones	Andrographolide, Neoandrographolide, 14-deoxyandrographolide	HPLC, LC-MS/MS	Anti-inflammatory, Antidiabetic, Antimicrobial, Immunomodulatory	(4,5)
	Flavonoids	Luteolin, Apigenin, Quercetin	HPLC, LC-MS	Antioxidant, Anti-inflammatory	
	Polyphenols	Caffeic acid, Ferulic acid	HPLC, GC-MS	Free radical scavenging	
Stem	Diterpenoids	Andrographolide, Deoxyandrographolide	LC-MS/MS	Anti-inflammatory, Anticancer	(7,8)
	Flavonoids	Quercetin derivatives	HPLC, LC-MS	Antioxidant	
	Glycosides	Various glycosidic compounds	HPLC, LC-MS/MS	Immunomodulatory	
Roots	Phenolic compounds	Phenolic acids, Tannins	HPLC, LC-MS/MS	Antioxidant, Antimicrobial	(6)
	Alkaloids	Minor alkaloidal fractions	GC-MS, LC-MS/MS	CNS activity	
Whole plant	Diterpenoid lactones	Andrographolide, Neoandrographolide	HPLC	Broad-spectrum pharmacological activity	(11)
	Saponins	Triterpenoid saponins	HPLC, LC-MS/MS	Antidiabetic, Immunomodulatory	
	Essential oils	Volatile fractions	GC-MS	Antimicrobial activity	

DOI: https://doi.org/10.66220/4mdpen52 ISSN: 3139-9266

The pharmacological properties of *Andrographis paniculata* has been found to be linked to the structure of its major phytoconstituent, diterpenoid lactones like andrographolide. Andrographolide contains the α, β-unsaturated γ-lactone ring and several hydroxyl functional groups, enabling it to interact with a variety of molecular targets that play roles in inflammation, oxidative stress, apoptosis and immune regulation. Structural changes on andrographolide have been described to affect its bioavailability, stability and pharmacological activity. Similarly, flavonoids and phenolic compounds give a significant contribution to their antioxidant activity primarily because of the hydroxyl group, which can well trap the ROS and prevent their oxidation. So, the medicinal activities of A. paniculata can be greatly affected by its chemical structure and constituents.

5. Ethnomedicinal and Traditional Uses

Ethnomedicinal & Medicinal importance of *Andrographis paniculata* has been well documented for centuries in many traditional systems of medicine like Ayurveda, Unani and Traditional Chinese Medicine (TCM). The plant known as Kalmegh in Ayurveda and Bishuchur (bitter & cooling) due to its "Tikta Rasa" (Taste) and "Sheetala" or "cooling therapeutic plant." It has been used traditionally in the treatment of fever, liver disorders, inflammation, infections and digestive disturbances and is thought to balance the physiological derangements related to Pitta and Kapha doshas (8). In Traditional Chinese Medicine, it is regarded as one with heat-clearing and detoxifying effects and used to manage infections, fever, sore throat and inflammation by regulating energy flow within the body and organ function (4).

Different parts of A. paniculata, such as leaves, stem, and whole aerial part, are therapeutically significant and have been used in numerous traditional formulations. These preparations are often used as decoctions, powders and eventually crude extracts, which are consumed by mouth to treat febrile illness, gastrointestinal disorders and respiratory tract infections. Root and bark-based preparations are usually taken by decoction, while the leaf part is used mostly as a powdered extract in doses according to the therapeutic need (5).

A. paniculata has been indicated traditionally for the treatment of gastrointestinal conditions such as diarrhoea, dysentery and indigestion largely because of its anti-inflammatory and antimicrobial actions. And it is also used in treating respiratory infections, fever and systemic inflammation. The plant is commonly used in traditional practice for immune system improvement and infection-associated complication prevention, which has become significant in the areas of metabolic and cardiovascular health. In addition, it is traditionally recognised because of its immunostimulant and protection against infectious diseases properties, which can be attributed to bioactive diterpenoid constituents, particularly andrographolide (11).

The extensive ethnomedicinal applications reveal the traditional importance of *Andrographis paniculata* and justify its further research in modern pharmacological studies for potential therapeutic agents based on scientific evidence.

6. Pharmacological Activities of Andrographis paniculata

The diverse phytoconstituents such as diterpenoid lactones (andrographolide, neo andrographolide and deoxyandrographolide), flavonoids and phenolic compounds of *Andrographis paniculata* are mainly responsible for its pharmacological activities. These bioactive agents have multi-target interactions and strong pharmacological activity on many physiological systems. Several mechanisms are responsible for the biological activities of Andrographis paniculata, including antioxidant, anti-inflammatory, immunomodulatory and enzyme. regulation that has been well characterised in both in vitro and vivo studies (Figure 2)

DOI: https://doi.org/10.66220/4mdpen52 ISSN: 3139-9266

This indicates that structure-diversity of phytochemicals plays an important role in the range of pharmacological activities of A. paniculata. Anti-inflammatory, immunomodulatory, antiviral and anticancer activities are mostly through diterpenoid lactones especially andrographolide while the antioxidant and the cytoprotective activities are mostly through flavonoids and phenolic compounds. These structure–activity relationships are very useful for understanding the molecular mechanism of the therapeutic action of this medicinal plant and could be helpful in the rational formulation of standardized phytopharmaceutical products (7).

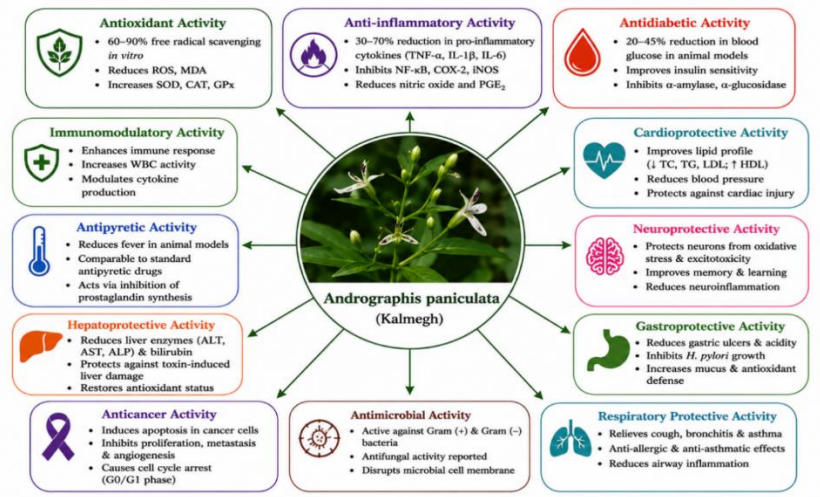


Figure 2. Pharmacological activities of Andrographis paniculata, highlighting its diverse therapeutic effects.

6.1 Antioxidant Activity

Background: 'Oxidative stress is a major mechanism involved in the pathogenesis of most chronic disorders, and *Andrographis paniculata* has shown strong antioxidant activity. The plant extract shows high free-radical scavenging activity in DPPH and ABTS by inhibiting 60% to 88% at the concentrations of 50-250 µg/mL, indicating it has a notable antioxidant capacity (8). This activity is primarily due to its richness in phytochemical components, including andrographolide, flavonoids and phenolic compounds. The phenolic total content has been reported to be in the range of 75-170 mg GAE/g extract, and flavonoid content ranges from 35-90 mg QE per gram extract. Moreover, A. paniculata significantly reduces the damage from lipid peroxidation (45-80%) and therefore confers protection on cellular membranes from oxidants. It has been shown to increase the activity of appropriate endogenous antioxidant enzymes, like superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx), indicating that the extract can work as a direct free-radical scavenger or also as an enzyme-based indirect defence mechanism (12).

6.2 Anti-inflammatory Activity

Anti-inflammation is one of the independent factors responsible for various disease processes, and *Andrographis paniculata* is highly active against inflammation. 'The extract of this plant has been reported by experiments to reduce the levels of pro-inflammatory cytokines.However, the production of AP-1 transcription factors was reduced by 35-70% under different inflammatory conditions such as TNF-a, IL-1β, and IL-6 (13). The anti-inflammatory activity of the extract is believed to occur through the inhibition of two important inflammatory mediators, cyclooxygenase-2 (COX-2) and inducible nitric oxide synthase (iNOS), with up to 40-65% at 100-400mg/kg bw, primarily by its potent compound, called andrographolide, which is a well-known component of the extract of Androgynum. Aside from that, A. paniculata also blocks activation of several proinflammatory signalling

DOI: https://doi.org/10.66220/4mdpen52 ISSN: 3139-9266

pathways, such as nuclear factor-kappa B (NF-κB) and mitogen-activated protein kinase (MITOGEN-ACTIVATED PROTEIN KINASE (MAPK)), which eventually leads to a decrease in inflammatory mediators and thus improved protection against tissue damage. These pathways are modulated by this and could lead to this effect in inflammatory and autoimmune diseases (14).

Most experimental works have consistently shown high anti-inflammatory activity, but some differences have been observed according to the other variables used such as solvent of extraction, concentration of andrographolide, doses administered and the models used. In addition, most of the evidence available is in vitro and animal studies, and there is limited robust and multicenter randomized clinical trial evidence. Standardised formulation and appropriate human trials are needed to prove clinical efficacy and safety (13).

6.3 Antimicrobial Activity

A. paniculata showed considerable antimicrobial activity against different bacterial and fungal pathogens. The leaves of the plant have been reported as showing activity against both Gram-positive and Gram-negative bacteria with a minimum inhibitory concentration (MIC) from 50 to 500 μg/mL, as found in various studies, predominantly in methanolic and ethanolic extracts. The extraction materials have demonstrated significant antimicrobial activity against bacteria such as Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa and Bacillus subtilis. In addition, antifungal testing showed significant inhibition of pathogenic fungi, resulting in a reduction in fungal growth between 40% and 85% for Candida albicans and a significant reduction of all Aspergillus spp.Moreover, antifungal studies demonstrated significant inhibitory effects on pathogenic fungi, Candida albicans and other Aspergillus spp. (40-85 % inhibition). Its three bioactive compounds, andrographolide and other diterpenoid lactones, have been shown to exert their inhibitory activity by disrupting the cell membrane of microbes, inhibiting key metabolic enzymes and interfering with the DNA and RNA synthesis of target microbes. In combination, all these mechanisms contribute to the plant's "resistance" against the clinically important pathogens (15). However, there is a wide disparity between different studies in terms of the types of extracts tested, efficacy against the pathogens, and MIC values. In addition, there is limited standardized antimicrobial susceptibility testing and validation for clinical use. There is a need for further investigations on standardized extract formulation and comparative in vivo studies for establishing the therapeutic applicability (16).

6.4 Antidiabetic Activity

Andrographis paniculata has been shown to have significant antidiabetic properties in in vitro and in vivomodels by several mechanisms of action. The antidiabetic activity of *Andrographis paniculata* has been examined in a few studies. Experimental studies using streptozotocin-induced diabetic rats have shown that at doses ranging from 250-400 mg/kg, the plant extract had a significant reduction in fasting blood glucose level between 25% and 55%. It was also observed that the extract has a highly inhibitory effect on enzymes responsible for carbohydrate digestion, α-glucosidase and α-amylase, which are around 50–80%, respectively. Enzymes could be beneficial for the management of post-prandial hyperglycaemia by inhibiting the degradation of carbohydrates and slowing glucose absorption. In addition to its capability to reduce blood glucose, A. paniculata has been found to possess other beneficial effects, such as insulin sensitivity, increased glucose uptake in peripheral tissues, and alteration of hepatic glucose metabolism, further emphasising its potential applications in diabetes.The major bioactive components, andrographolide, flavonoids and other phenolic compounds contribute to the protection of pancreas β-cells from oxidative damage as well as promote insulin secretion.All of these effects have opened the possibility for the clinical use of A. Paniculata for controlling diabetes mellitus and related metabolic disorders (17).

Experimental research has always been shown to exhibit antihyperglycemic properties, but various experimental set-up, extract composition, dose, and treatment periods have yielded inconsistent results. However,

DOI: https://doi.org/10.66220/4mdpen52 ISSN: 3139-9266

there is a lack of significant clinical evidence and further large-scale randomized clinical trials are required to substantiate the long-term efficacy and safety of standardized preparations of *Andrographis paniculata* in diabetic patients (18).

6.5 Cardioprotective Activity

The analyses revealed that *Andrographis paniculata* is a cardio-protective plant possibly due to its antioxidant, anti-inflammatory and lipid-lowering effects, among which. In experimental studies,A. paniculata extracts have been seen to significantly reduce total cholesterol and triglyceride concentrations by ≈20-50 % and increase the concentration of high-density lipoprotein (HDL) by 10-35 % [19]. Since the lipids are beneficial, atherosclerotic and other cardiovascular diseases are prevented. The plant has also been reported to possess antihypertensive activity with a decrease in systolic blood pressure of 10-20 mmHg, which might be due to its vasodilatory and endothelial function-improving activity. The principal bioactive component, andrographolide, has also been shown to modulate cardiac oxidative stress by limiting lipid peroxidation and highlighting endogenous antioxidant defences. In addition, many experimental models have noted its suppression of inflammatory mediators and improvement in myocardial function, suggesting a potential use for A. paniculatain cardiovascular disease (14,19).

6.6 Neuroprotective Activity

Considerable interest in *Andrographis paniculata* (AP) as a valuable source of neuroprotector is based on the presence of labdane-diterpenoids, particularly andrographolide and other diterpenoid compounds. Studies in animal models for cognitive impairment and neurodegeneration have also shown that these bioactive constituents lead to 25-50% greater cognitive performance and memory functions (20). The extracts have also been demonstrated to decrease the oxidative stress-induced neuronal injury by 30-60% via the production of protective endogenous antioxidant systems and inhibition of lipid peroxidation. Besides the other pharmacological actions, *Andrographis paniculata* has exhibited its protective effect against the neurological changes by its action on the balance of neurotransmitters and anti-neuro-inflammatory effect. The plant shows promise in reducing the synthesis and activity of pro-inflammatory mediators such as tumour necrosis factor alpha (TNF-α) and interleukin-1 beta (IL-1β) that collectively could be responsible for inflammatory-mediated damage to neural tissues. Moreover, A. paniculata has been reported to affect apoptosis and inflammatory pathways, further enhancing neuronal survival. It also has the ability to regulate the signalling pathway of reactive oxygen species (ROS) and inflammation, which further demonstrates its neuroprotective effects and its protective activity in preventing neural degeneration. All these synergistic roles could render it important for preventive and therapeutic purposes against neurodegenerative disorders like Alzheimer's disease and Parkinson's disease (20,21).

6.7 Anticancer Activity

There has been extensive interest in *Andrographis paniculata* (AP) because of its ability to possess anticancer activity, and it has been tested in various cancer cell lines. The cytotoxic effect of the plants has been noted in various studies, and the IC_{50} has been in the range 10-100 µg/mL, varying with the category of extract and with the cancer cell line used. Overall, the plant has exhibited weak-to-moderate antiproliferative activity, which is indicative of its potential to contain compounds with a biological effect in relation to cancer research (22).The plant and andrographolide both inhibited the growth of cancer cells by 40-80% by Multiple Mechanisms. Major mechanisms are cell cycle arrest at the G0/G1 phase and/or G2/M phase, and induction of apoptosis that leads to inhibition of the uncontrolled cellular growth, which these two effects do. Andrographolide is a major bioactive compound that has been studied for a number of anticancer mechanisms. Evidence indicates that it can stimulate the activation of tumour suppressor proteins like p53 and stimulate caspase-mediated apoptosis, causing programmed death of the

DOI: https://doi.org/10.66220/4mdpen52 ISSN: 3139-9266

cancer cells. In addition, andrographolide has been found to block tumour angiogenesis and to inhibit the metastatic progression(17). It also acts on key cellular signalling pathways such as Nuclear Factor Kappa B(NF-κB), PI3K/Akt, andMitogen-Activated Protein Kinase Mitogen-Activated Protein Kinase (MAPK) pathways, which have been shown to play a critical role in the growth, proliferation and survival of cancer cells. By inhibiting these pathways, andrographolide could help to inhibit tumour development and progression. Presence of synergistic effect between diterpenoids, flavonoids and phenolic compounds revealed the anticancer activity of A. paniculata, thus making this herb a source of attractive anticancer agents (22).

While several experimental studies show promising anticancer activity, the efficiency is widely different based on the cancer cell lines, extract preparation and the experimental procedures used. Furthermore, they are yet to be fully translated into clinical oncology use at a routine level due to lack of broad clinical studies. Standardization, pharmacokinetics studies and controlled clinical trials should be subject of future research (23).

6.8 Hepatoprotective Activity

Andrographis paniculata is usually recognised due to its hepatoprotective properties and is widely researched in multiple animal models of liver damage. 'Experimental studies have emphasised the hepatic rescuing properties of Andrographis paniculata. Plant extracts have also been shown to markedly decrease serum liver enzyme markers, such as alanine aminotransferase (ALT), aspartate aminotransferase (AST), and alkaline phosphatase (ALP), which have beneficial effects on liver function and suggest decreased hepatocellular damage during treatment. The antioxidant and anti-inflammatory activity of the main bioactive compound of the plant (andrographolide) largely contributes to these protective effects. A decreased oxidative stress in liver tissue has also been shown with improvement of endogenous antioxidant defence mechanisms. After treatment, increased activities of enzymes like Catalase (CAT), Glutathione Peroxidase (GPx) and Superoxide Dismutase (SOD) were observed. Histopathological examinations, furthermore, have shown a decrease in necrosis and fat accumulation in the liver and minimal infiltration of inflammatory cells, as well as a considerable restoration of the normal liver architecture. Together, these results suggest that A. paniculata is a promising medicinal plant for hepatoprotective activity due to the antioxidant and anti-inflammatory potential that it exhibits (24,25).

6.9 Anti-obesity Activity

The active phytochemistry of *Andrographis paniculata* showed considerable potential for application in anti-obesity therapydue to its role in lipid metabolism regulation, adipogenesis inhibition, as well as energy homeostasis improvement. Experimental evidence of the activity of the plant extract to inhibit the activity of pancreatic lipase (PL) suggests values of 45-75%, which in turn would lower fat absorption in the intestine and also caloric intake in vivo (26). In high-fat diet (HFD)-induced obesity models, A. paniculata extracts showed a 15-30% decrease in body weight gain as compared to controls receiving the placebo after 6-8 weeks of oral treatment, and a decrease of 20-40% of total body fat mass and visceral adipose tissue accumulation following treatment. The majority of these benefits are linked to the inhibition of several important elements of lipid metabolism, such as a decrease in the transcription factor involved in fatty acid synthesis (PPAR-γ and C/EBP-α) and induction of fatty oxidation. Other properties of Andrographolide include antioxidant and anti-inflammatory effects that could help to restore metabolic homeostasis and thus reduce the complications of obesity (26,27).

6.10 Anti-ulcer Activity

It has been evaluated in several experimental studies for anti-ulcer effects, and *Andrographis paniculata* has been shown to possess significant gastroprotective effects in these studies. Its Cytoprotective, Antioxidative and antisecretory activities are mainly responsible for these beneficial effects. Gastric ulcer protective effect: In animal

DOI: https://doi.org/10.66220/4mdpen52 ISSN: 3139-9266

models of gastric ulceration, A. paniculata orodispersible tablets showed a strong protective effect at the doses of 250 to 500 mg/kg. A significant improvement in the severity of gastric ulcers was noted in ethanol-induced as well as aspirin- and NSAID-induced ulcer models (50-70% decrease in gastric ulcer index). These results indicated that the plant could be used to maintain the integrity of the gastric mucosal barrier and to decrease the damage to the stomach mucosa due to ulcer (28). The gastroprotective activity is attributed to the presence of andrographolide and its diterpenoids, which activate the mucosal defence mechanisms and decrease the oxidative stress. In addition, *Andrographis paniculata* has reportedly increased gastric mucus secretion by 30–55%, thus fortifying the mucosal barrier to damage caused by gastric acid and pepsin. Additionally, an approximately 20-45% reduction in gastric acid secretions occurred; this decrease resulted in less irritation of the mucosa with subsequent ulcer formation. Moreover, the extract possesses antioxidant properties that have been shown to alleviate gastric tissue damage through decreased lipid peroxidation and inflammatory responses. These results indicate that A. paniculata is a potential natural therapeutic agent for the prevention and treatment of peptic ulcer disease (28, 29).

6.11 Antithrombotic Activity

In addition, *Andrographis paniculata* has also exhibited potent anti-thrombotic (anticoagulant) and antiplatelet effects, which fall under its cardiovascular protective activities. Plant extract and Andrographolide inhibited platelet aggregation at various concentrations (50mg/mL to 150mg/mL), and when stimulated with ADP, Collagen and Thrombin, 30-60% inhibition was observed in vitro(30). Antithrombotic activity is primarily mediated by the mechanism of thromboxane A_2 inhibition, which is important for platelet activation and vasoconstriction. Moreover, Andrographolide can modulate intracellular calcium signalling, thus decreasing platelet activation and aggregation. Experimental studies have also shown prolonged clotting time and fibrin formation inhibition, indicating mild anti-coagulation activity. In addition, the antioxidant and anti-inflammatory effects of the herb could maintain endothelial function and minimise vascular damage, key processes in thrombus formation. Overall, these mechanisms enhance blood flow and may reduce the incidence of thrombosis and other complications associated with cardiovascular effects (30,31).

6.12 Immunomodulatory Activity

It has been proposed in the literature that *Andrographis paniculata* possesses a strong immunomodulatory activity on both the innate and acquired immune systems. These extracts stimulate phagocytosis by macrophages by 25-60%, which helps the body to eliminate microbial pathogens that cause infection. 'It has been reported that *Andrographis paniculata* has a significant immunomodulatory effect because of regulation of the production of cytokines and immune homeostasis. It has been identified through studies that the plant encourages the expression of anti-inflammatory cytokines like IL-10 and inhibits the production of pro-inflammatory mediators like TNF, IL-1β and IL-6. Such a control of cytokine activity may help to diminish excessive inflammatory reaction. Further, A. paniculata extracts have been found to promote lymphocyte proliferation, increasing by 20% to 45%, indicating a strengthening of the adaptive immune response (32). Andrographolide, the main bioactive compound in the plant, is important in playing a role in these effects by regulating key immune signalling pathways, such as Nuclear Factor Kappa B(NF-κB), Mitogen-Activated Protein Kinase (MAPK), and Janus Kinase / Signal Transducer and Activator of Transcription(JAK/STAT). Andrographolide regulates these pathways, which helps to keep the immune system proper and prevents excessive inflammatory situations. Moreover, the plant improves the activity of natural killer (NK) cells and antibody production, thus strengthening host defence mechanisms. These results indicated that A. paniculata has great therapeutic potential in the treatment of infectious, inflammatory and immune diseases (13, 32).

6.13 Anti-aging Activity

DOI: https://doi.org/10.66220/4mdpen52 ISSN: 3139-9266

However, due to its potent antioxidant, anti-inflammatory and cytoprotective effects, *Andrographis paniculata* is becoming increasingly used and popular as an anti-aging agent. Oxidative stress has been reported to play a pivotal role in ageing and A. paniculata significantly hampered up to 30 to 60% oxidative damage was shown by decrease in MDA concentration (a marker of lipid peroxidation) (12). On the contrary, it activates the activity of endogenous antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx), which helps in up-regulating cell resistance by 25-50% against the reactive oxygen species. These effects are important in ensuring the stability (or resistance from oxidising) of important biomolecules such as DNA, proteins and lipids.In addition, it has also been described as inhibiting the formation of AGE, improving mitochondrial function and reducing chronic inflammation associated with delayed cellular senescence (13). Considering the synergistic effect of andrographolide, flavonoids and phenolic compounds, which may play a role in anti-aging and healthy aging interventions, A. paniculata holds great promise (12,14).

While the results of the different preclinical studies are always promising, thanks to their antioxidant and anti-inflammatory activity, the bulk of this evidence has come from experiments using various doses of ethanolic extracts. The findings are difficult to directly translate to clinical practice because of the lack of standard formulations and dose optimization, as well as poorly designed human clinical trials. Single, large clinical trials with long term follow-up and using standardized androgolides rich preparations should be conducted further to confirm the long-term efficacy and safety (14).

6.14 Anti-anxiety and Sedative Activity

Andrographis paniculata has shown anxiolytic and sedative effects in several experimental models. Studies are usually performed by various behavioural tests in animal models such as the elevated plus maze, open field test and light-dark box test when anxiety-related behaviours were measured after administration of A. paniculata extracts or andrographolide (33), which have been shown to reduce their effect reduce approximately 20-45% on anxiety-related behaviours. Additionally, the plant has been found to increase sleep duration by 20–35% and decrease sleep onset latency, suggesting slight sedative properties. These neuropharmacological effects are thought to be mediated through the modulation of central neurotransmitter systems, especially the γ-aminobutyric acid (GABAergic) pathway, which is responsible for stimulating neuronal inhibition and subsequently relaxing excitatory processes. Additionally, based on experimental findings, andrographolide's action toward serotonergic and dopaminergic signalling coexists in the modulation of mood and reduction of stress. The antioxidant and anti-inflammatory properties of the plant prevent neural tissues from damage and stress, which may additionally contribute to its anxiolytic activity. In experimental studies, A. paniculata showed a more appropriate safety profile than traditional agents of anxiolytic activity, which clearly indicates the viability of A. paniculata as a natural agent for treating anxiety, stress-related disorders and sleep disturbances (33).

The available data are mostly based on animal behavioural studies which handled hydroalcoholic or ethanolic extracts at varying doses. The evidence is still not very strong due to the differences in the experimental protocols used and the limited clinical validation; however, anxiolytic effects were consistently reported. More studies on humans with standardized dosing strategies would allow recommendations to be made from clinical studies (24).

6.15 Anti-atherosclerotic Activity

Andrographis paniculata exerts a significant antioxidant activity against the development of AD through its easy modulation of lipid metabolism, oxidative stress, inflammation and endothelial function. Specifically, the area of atherosclerotic plaque formation has been reduced by approximately 20-50% in hyperlipidemic and atherosclerotic animal models with doses of A. paniculata extracts of 200-400 mg/kg (35). One of the main

DOI: https://doi.org/10.66220/4mdpen52 ISSN: 3139-9266

mechanisms consists of 30-60% inhibition of low-density lipoprotein (LDL) oxidation, foam cell prevention and slowing down of atheromatous plaque development. Moreover, it enhances endothelial function via the increase of nitric oxide (NO) bioavailability and vasodilation (27). The plant is also extremely potent in reducing inflammatory activity through inhibition of VCAM-1, ICAM-1 and pro-inflammatory cytokine TNF-α/IL-6. Therefore, these cellular actions, which actually antagonise the process of adherence and infiltration to vascular walls, prevent the formation of atherosclerotic plaques in the vessel wall. Further, the antioxidant and lipid-lowering properties of A. paniculata promote plaque stabilisation and reduce the risk of plaque rupture, thereby reducing the chances of cardiovascular complications, including myocardial infarction and stroke, as mentioned earlier (35,19).

6.16 Anti-fertility Activity

This is supported by various studies exhibiting a notable antifertility activity for Andrographis paniculata,especially on the male experimental animals. Administration of leaf powder and ethanolic extracts in a prolonged period (subchronic) significantly reduced sperm count, sperm motility, fertility rate, and degeneration of the seminiferous tubules was observed. The authors also associated these effects with disruption of spermatogenesis and alteredbiomolecular patterns in the functions of reproductive tissues (impaired male reproduction) (36). Moreover, andrographolide, a major bioactive diterpenoid of A. paniculata, has been demonstrated to modulate reproductive hormones as well as testicular metabolism, which could play a role in its antifertility activity. Nevertheless, this adverse effect has not been observed in some studies testing standardised extracts (13), indicating that, depending on the dosage/time of treatment and type of extract employed, reproductive effects may differ. Preclinical studies suggest that *Andrographis paniculata* exhibits reversible antifertility effects in experimental animal models. However, sufficient clinical evidence is still lacking, and additional studies are required to establish its safety, efficacy, and mechanism of action in humans (37).

In general, the antifertility effects reported have mostly been found in experimental animals with a large differences in doses, as well as in duration and in preparation of extracts. Importantly, however, there is a dearth of information about reversibility and safety of these effects in human beings. Thus, continued toxicological investigation and clinical trial studies are needed prior to considering potential therapeutic use (36).

6.17 Anti-viral Activity

The in vitro and in vivo data indicate that *Andrographis paniculata* has a broad-spectrum antiviral effect on various viral diseases. The main compound, Andrographolide, has been found to possess anti-viral properties by inhibiting various stages of viral reproduction, including virus entry, viral DNA replication and viral protein synthesis. A paniculata and its diterpenoid components also have anti-influenza, anti-dengue virus activity, anti-herpes simplex virus (HSV), hepatitis viruses, and respiratory viral infections (13). Andrographolide, flavonoids and other phenolic constituents are a source of antiviral activity. The antimicrobial effectiveness of A. paniculata against viral infections is correlated with the ability of these compounds to modulate host immune responses and inhibit propagation steps for viral multiplication. Additionally, the plant has also reported immunomodulatory and antioxidant properties that see them boost host defence mechanisms as well as curtail virus-induced oxidative stress (a possible side effect of viral infections). Therefore, although the preclinical evidence is promising, additional clinical studies are needed to ascertain the therapeutic success, safety and effectiveness of A. paniculata for the management of viral diseases (38).

To date, most antiviral studies have focused on andrographs with high concentrations of andrographolide or on animal models of infection. There is little clinical evidence and comparisons are difficult because of differences in the strain of the virus, composition of virus extracts and different treatment plans.

DOI: https://doi.org/10.66220/4mdpen52 ISSN: 3139-9266

Standardized formulations should be used in future multicenter clinical studies for confirmation of antiviral efficacy in humans (13).

6.18 Anti-osteoporotic Activity

In the present scenario, Andrographis paniculatahas demonstrated considerable potentialthat can promote both bone formation and bone resorption inhibition through the potential herbs. In an experimental model of human marrow-derived MSCs proliferation, differentiation, and mineralisation, andrographolide acts as an activator of osteogenic markers, such as alkaline phosphatase (ALP), osteocalcin and runt-related transcription factor-2 (RUNX2) in vitro. Furthermore, extracts from A. paniculata have been reported to inhibit the differentiation and function of osteoclasts in vitro or in vivo by inhibition of the RANKL-mediated signalling pathway, thereby prompting an anti-bone-resorption effect (39).Upon the treatment of andrographolide-rich extracts in osteoporotic animal models, greater improvements were measured in bone mineral density (BMD), trabecular bone architecture and bone strength. Antioxidant and anti-inflammatory properties of A. paniculata also enhance its bone-protective effects as it lowers oxidative stress and inflammatory mediators in conditions such as osteoporosis progression. The results of these studies indicated that A. paniculata could be a promising natural treatment factor, but more clinical trials were needed to test the safety and efficacy in humans(40).

6.19 Anti-melanogenic/Skin Whitening Activity

In this context, the effect of *Andrographis paniculata* on melanin synthesis inhibition and key melanogenic pathways is of importance. Activity of melanin-producing cells and of the rate-limiting melanogenesis pathway enzyme, tyrosinase, has been reported to be inhibited by the activity of bioactive compounds such as andrographolides and their inhibition of the size of melanin-producing cells (41). Furthermore, A. paniculata has been demonstrated to decrease the production of some melanin synthesis-related proteins like microphthalmia-associated transcription factor (MITF), tyrosinase and tyrosinase-related proteins (TRP-1 & TRP-2), which leads to lesser skin pigmentation and darkening. Moreover, types of flavonoids and diterpenoids found in plants also demonstrate antioxidant properties,which entails that they are able to increase their depigmenting effect, demonstrating down-regulation of melanogenesis in an oxidative stress manner.For all the aforementioned properties, A. paniculata has been of special concern as a natural source for use in cosmetic/dermatological formulations for hyperpigmentation skin problems, skin tone and skin whitening activity. However, its long-term effectiveness and safety in humans have not yet been confirmed by further clinical studies (42).

6.20 Anti-photoaging Activity

Andrographis paniculata has a potent anti-photoaging activity, both on UV-induced oxidative stress and on extracellular matrix degradation. It has been found that andrographolide can inhibit the matrix metalloproteinases (MMPs), which are known to downregulate MMP-1 and MMP-3 that are responsible for the degradation of collagen and causing wrinkle formation in photoaged skin (43). In addition, A. paniculata extracts treatment was also reported as increasing the production of collagen production and reducing the levels of Reactive Oxygen Species (ROS) in UVR-stimulated skin cells. The plant also shows the ability to inhibit different mediators of inflammation, such as IL-6, TNF-α and COX-2, all of which are closely associated with the skin inflammatory reactions and ageing upon photo-irritation. A. paniculata possesses antioxidant, anti-inflammatory and collagen preservation properties which help to prevent wrinkle formation in vitro and retards the occurrence of photoaging. The data shown here may indicate it can be used as a natural ingredient in cosmetics and cosmeceutics in dermatological and anti-ageing applications, but additional clinical trials are still needed in humans (42).

6.21 Anti-asthmatic Activity

DOI: https://doi.org/10.66220/4mdpen52 ISSN: 3139-9266

One uniqueness that was observed was the anti-asthmatic property of Andrographis paniculata, which could be explained by its bronchodilatory, anti-inflammatory and immunomodulatory activity. In experimental studies, andrographolide has been shown to reduce eosinophil infiltration and airways levels of pro-inflammatory cytokines, particularly the close cousins of allergic asthma; IL-4, IL-5 and IL-13. In addition, A. paniculata inhibits the activation of Nuclear Factor Kappa B(NF-κB) and other inflammatory signalling pathways, which results in a decrease in airway hyperresponsiveness and mucus production (44). Another study includes bronchodilatory activity by influencing histamine-mediated stimulation and suppressing leukotriene-induced bronchoconstriction of the lung, resulting in better respiratory function. Also, due to its antioxidant activity, it protects lung tissues from oxidative damage that is associated with chronic airway inflammation. Since these combined pharmacological actions put forward that A. Paniculata might provide potential therapeutic application as a natural drug for the control of asthma or other inflammatory respiratory diseases, additional clinical trials are required to establish the efficacy and human safety (13).

6.22 Anti-allergic Activity

Andrographis paniculatapossesses strong anti-allergic activity via immunoregulation and inhibition of allergic mediator release. Studies have shown that mast cell degranulation is inhibited by andrographolide, and histamine and inflammatory mediators associated with immediate hypersensitivity processes (IHP) are released. Moreover, A. paniculataantagonises the production of immunoglobulin E (IgE) and Th2-type cytokines, such as interleukin-4 (IL-4), interleukin-5 (IL-5) and interleukin-13 (IL-13), which inhibit allergic inflammatory reactions and hypersensitivity reactions (45). Furthermore, the plant contains flavonoids and diterpenoid lactones, which have been shown to block allergen-induced signalling pathways that control allergen-induced infiltration of inflammatory cells into tissues. Furthermore, the antioxidant and immunomodulatory potential of A. paniculatarelates to the alleviation of allergic symptoms and the tissue damage caused by allergies. The pharmacological activities that follow also substantiate the use in the treatment of allergic diseases, such as Allergic Rhinitis (AR), dermatitis and bronchial asthma and suggest conducting clinical trials to establish its therapeutic activity in humans(13).

6.23 Nephroprotective Activity

The antioxidant, anti-inflammatory and cytoprotective properties of A. paniculata have a nephroprotective activity to preserve the kidney against drug and chemical-induced renal damage. The influence of andrographolide and A. paniculata extracts has been reported to significantly ameliorate the serum creatinine, blood urea nitrogen (BUN), and other biochemical parameters of renal dysfunction in nephrotoxicity models via cisplatin- or gentamicin-induced toxicity as observed through experimental studies. This anti-diabetic activity has been associated with its ability to reduce malondialdehyde (MDA) markers and lipid peroxidation and augment the antioxidant enzymes level in the body (like super oxide dismutase (SOD), catalase and glutathione peroxidase (GPx)) (46). In addition, A. paniculata is also able to inhibit inflammatory mediators and prevent the apoptosis of renal tubular cells and further protect kidney structure as well as kidney functions. Histopathological evaluation showed significantly less tubular necrosis and glomerular injury in treated rats, and when administered with high-dose andrographolide-rich extracts, rats showed physiological kidney morphology. These findings indicate that A. paniculata may be a potential natural preventive and therapeutic agent for nephrotoxicity; however, clinical studies are needed to further confirm the effects of A. paniculata on preventing nephrotoxicity in humans (47).

Nephroprotection has been observed in a number of experimental studies through antioxidant and anti-inflammatory mechanisms, but there is considerable variability in the type of extract, doses used and the experimental designs. Therefore further pharmacokinetic studies and under controlled clinical trials conditions are required before the routine clinical use of the product can be recommended (46).

DOI: https://doi.org/10.66220/4mdpen52 ISSN: 3139-9266

6.24 Anti-mutagenic/Genoprotective Activity

Andrographis paniculata has also exhibited an extremely remarkable anti-mutagenic and genoprotective effect against oxidative and chemically induced cell DNA damage. 'Andrographolide and related diterpenoid compounds have been shown to significantly decrease DNA strand breaks, chromosomal aberrations, as well as micronucleus formation in response to genetically damaging agents, leading researchers to suggest potential use of these compounds for maintenance of genomic stability. The antioxidant activity of A. paniculata, with its ability to eliminate reactive oxygen species (ROS) and inhibit oxidative stress-induced damage to DNA, was acknowledged as the main mechanism responsible for its genoprotective activity in the majority of the studies (48). Further, the plant has been observed to activate internal antioxidants and DNA repair systems, indicating a decrease in genetic mutations build-up. Experimental Studies have further suggested that A. paniculata reduces mutagen-induced genotoxicity and universal cytoprotection of normal cells against free radical-mediated injury without a major risk of genetic toxicity. Either way, these results may indicate the important potential role of A. Paniculata in preventing mutagenesis, carcinogenesis and other disorders related to genomic instability conditions, but more studies on its molecular mechanisms involved are certainly needed, together with clinical relevance (21).

7. Clinical Studies and Evidence on Andrographis paniculata

While a significant number of preclinical studies have demonstrated the therapeutic potential of Andrographis paniculata, the clinical studies have been more extensively carried out on respiratory tract infections, common cold, inflammatory and immune-related disorders. Some randomised controlled trial studies involving 300-1200 mg/day for 5-14 days of treatment have been performed, where standardised extracts of A. paniculata were compared to placebo or resulted in a significant reduction in the severity and duration of the common cold and other upper respiratory tract infections such as pharyngotonsillitis (49,50). Clinical improvement with benefit respiratory infections in fever, sore throat, cough, fatigue and total symptom score has also been demonstrated in clinical trials (50).

Furthermore, A. paniculata has been demonstrated to have beneficial effects for humans not only in the respiratory system, but also in the anti-inflammatory and immune system regulation. There is support for its traditional application in inflammatory conditions from supplementation studies with standardised extracts, which have shown marked reductions in a number of clinically relevant measures of inflammation and enhanced immune function. Moreover, there is preliminary clinical evidence that it may be beneficial in metabolic disorders due to improvements in glycemic control and lipid profiles, although large-scale clinical trials are still required to validate these results (51,52).

Safety: Therapeutic doses of A. paniculata are generally safe. Clinical studies have only shown mild side-effects such as gastrointestinal upset, headache, nausea and rare allergic reactions without evidence of substance toxicity during short-term treatment. But as an immunomodulatory agent (shows an enhancing effect on host immunity), use should be avoided in pregnant women and in those patients receiving immunosuppressive therapy (52).

However, there are still some limitations despite the promising clinical results. However, most studies reported were limited by small sample sizes and short treatment durations, which represented the inability to assess long-established efficiency or safety. Moreover, variations in extract standardisation, andrographolide content, dosage regimens and study design also preclude a direct comparison between studies. Hence, standardised formulations of A. paniculata need to be compared in large-scale, multicenter randomised controlled trials for the definitive clinical efficacy and safety profiles, pharmacokinetic characteristics, and therapeutic indications tested (Figure 3).

The findings from the current clinical studies suggest that *Andrographis paniculata* could have therapeutic potential, but there are limitations in the study design, short duration of follow-up, and heterogeneity of the studies. Standardized preparations should be used in future multicenter, randomized controlled trials to provide firm recommendations for treatment (13).

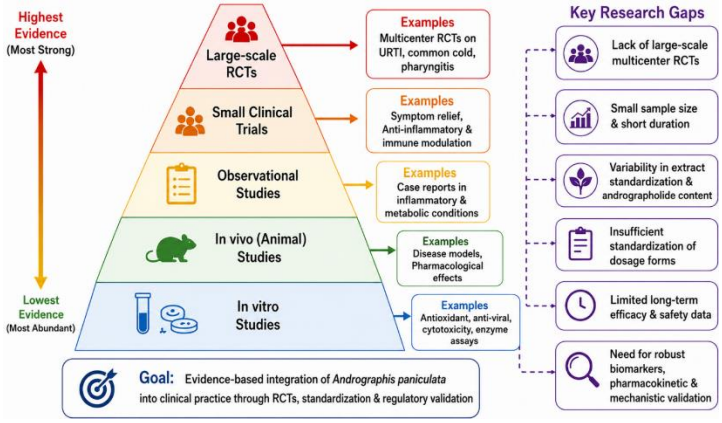


Figure 3. Translational Evidence Hierarchy, Clinical Evidence, and Key Research Gaps in *Andrographis paniculata* Studies

8. Challenges and Limitations of Andrographis paniculata

Despite the extensive pharmacological profile of Andrographis paniculata, in clinical practice translation, it faces several obstacles. Differences in geographical origin, climatic conditions, harvesting season/cultivating practices and plant parts used have even led to significant variation in phytochemical composition, especially andrographolide content. These variations can play a very important role in the biological activity and therapeutic efficacy of herbal preparations (53). In addition, the lack of uniform extraction protocols and dosage preparations frequently leads to variable concentrations of bioactive constituents that hinder both the replicability and comparability of studies (4).

The other major drawback is the limited clinical validation of A. paniculata. Human clinical studies, on the other hand, have been relatively less extensive and are often limited by small sample sizes and short treatment duration. Therefore, there is still a shortage of long-term safety and effectiveness data and dosage regimens (49). Additionally, andrographolide, having low aqueous solubility and only poorly absorbed from the intestine,causes, among other things, a low oral bioavailability, which is an important issue regarding therapeutic application. Moreover, challenges relating to quality control and standardisation of A. paniculata-based products alongside the absence of harmonised regulatory frameworks for herbal medicines amongst nations complicate their regulatory approval (54).

The rate of publication bias is another major one, in that studies with favorable drug responses are more likely to be published as they are more likely to show positive results. This could lead to inconsistent accuracy in assessing the therapeutic potential of Andrographis paniculata. In addition, large methodological differences exist between published studies in their extraction procedures, in their standardization of the phytochemicals, in their dose regimen, in their experimental models, and in the methods used to assess its outcome, making imperative direct comparison difficult (53).

A number of clinical studies have proven promising therapeutic results but most are single centrifuge with small numbers of patients and short follow-up times. Enormous multicenter randomized controlled trials with

DOI: https://doi.org/10.66220/4mdpen52 ISSN: 3139-9266

standardized protocols are still not available. Additionally, some preparations of *Andrographis paniculata* contain significantly lower amounts of andrographolide, differing extractions, varying standard or quality of manufacture, and also differ markedly from one plant to another; this makes it hard to translate existing evidence into adherence to a standard protocol, or to obtain reproducible products or manufacturing standards (49).

9. Comparative Perspective with Other Medicinal Plants

Andrographis paniculata shares several pharmacological properties with several medicinal plants such as Curcuma longa (turmeric), Withania somnifera (ashwagandha), Tinospora cordifolia (giloy) and Panax ginseng that include anti-inflammatory, antioxidant, immunomodulatory and anticancer actions. A. paniculata, however, possesses a rich source of diterpenoid lactones, particularly andrographolide, which has extensively been studied to inherit molecular mechanisms that involve NF-κB, MAPK and JAK/STAT signaling pathways. Curcumin is the major bioactive component of C. longa, whereas, withanolides and ginsenosides are the best known bioactive compounds in W. somnifera and P. ginseng, respectively. All of these plants have been identified as therapeutic plants with therapeutic potential, but there is lack of direct comparative clinical studies. Standardized head to head clinical trials and comparative pharmacological studies are recommended for future studies in order to establish the comparative efficacy, safety and clinical utility of these herbal medicines (55,56).

10. Future Perspectives

High-quality clinical evidence on *Andrographis paniculata* should be established by adequately poweredRandomized Controlled Trials RCTs with long follow-up periods. Despite the inspirational therapeutic promise shown by several preclinical and small clinical studies, it remains to be demonstrated whether these benefits can be reproduced long-term or be considered with respect to safety, efficacy and their very condition-specific optimal dosage regimens. Moreover, insights in the form of standardised extracts containing well-defined concentrations of andrographolide and other bioactive diterpenoids will add to batch-to-batch consistency and reproducibility of therapeutic outcomes (49,57).

Another future research direction is the integration of A. paniculata with drug discovery and advanced development techniques. Current methods, including molecular docking, network pharmacology, metabolomics and artificial intelligence-assisted drug design, may allow the identification of new molecular targets and action mechanisms. In addition, nanoformulation-based delivery systems such as nanoparticles, liposomes, nanoemulsions and solid lipid nanoparticles might considerably increase the solubility, bioavailability, stability, and targeting-specific nature of andrographolide(58, 59).

Identification of andrographolide derivatives & structural analogues with improved pharmacokinetic & pharmacodynamic properties remains an important area for study. The ability to modify the parent molecule has already shown promise in enhancing drug efficacy while ameliorating toxicity and limiting the concerns posed by poor aqueous solubility. Further medicinal chemistry efforts could yield new lead candidate compounds amenable to clinical translation (60).

In addition, pharmacogenomics and precision medicine progress have the potential to tailor A. paniculata-based therapies according to an individual's genetic and metabolic profile. Considering its multitarget pharmacodynamic profile, future systems biology approaches may support the optimisation of patient-oriented therapeutic strategies and enhance treatment success. Interdisciplinary research of this kind will play a key role in converting the traditional medicinal values of A. paniculata into evidence-based applications to modern medicine (5,58).

DOI: https://doi.org/10.66220/4mdpen52 ISSN: 3139-9266

There is a high potential for the future therapeutic use of *Andrographis paniculata* with emerging technologies that are expected to significantly contribute to the improvement of the further development of A.paniculata as a therapeutic product. The drug delivery enhancements with the use of nanotechnology such as drug nanocarriers like nanoparticles, liposomes and nanoemulsions may cause an improvement in the bioavailability, stability, and targeted delivery of andrographolide and other bioactive phytochemicals. Moreover, omics technologies like genomics, transcriptomics, proteomics and metabolomics are valuable tools to gain deeper insight into the molecular mechanisms, pharmacologic targets, and biomarker identification of Andrographis paniculata. Moreover, intelligent drug discovery, molecular docking, network pharmacology, and machine learning techniques could expedite the screening of new targets in cases of drug discovery and precision in herbal medicine development. The synergy between these cutting-edge technologies and traditional pharmacological studies could reduce the gap between preclinical findings and clinical applications of Andrographis paniculata-derived therapeutics, enhancing their global acceptance and potential.The combination of these advanced technologies with traditional pharmacological research holds the promise of making considerable strides toward clinical translation and global acceptance of Andrographis paniculatea-derived therapeutic products (59, 60).

11. Research Gaps and Future Priorities

Although there are ample anecdotal pharmacological evidences found on Andrographis paniculata, there are some important research gaps. Although numerous studies are published, most of them deal with in vitro experiments and animal studies, with the quality multicenter randomized clinical trials still insufficient. Moreover, considerable differences in phytochemical compositions, extraction parameters, dosing schemes and formulation prevent the reproducibility and comparability of various studies. Future investigations should focus on standardized extract development, all pharmacokinetic and toxicological investigations, multicenter clinical studies, and incorporation of advanced technologies like nanotechnology, omics-based approach, and artificial intelligence(aI) for drug discovering for evidence-based clinical applications (55).

12. Conclusion

Andrographis paniculata (Burm. f.) Nees represents a valuable medicinal plant that connects traditional therapeutic knowledge with modern pharmacological research. Extensive investigations have identified andrographolide and related diterpenoids as key bioactive constituents responsible for several biological activities, including antioxidant, anti-inflammatory, antimicrobial, antidiabetic, immunomodulatory, anticancer, and cardioprotective effects. Current evidence supports the therapeutic relevance of A. paniculata; however, the available findings are primarily based on preclinical studies, and further well-designed clinical investigations are required to establish its efficacy and safety for specific disease conditions. Despite its promising pharmacological potential, several challenges limit its clinical translation, including variations in phytochemical composition, lack of standardized formulations, differences in extraction and preparation methods, limited bioavailability of active compounds, and insufficient large-scale multicenter clinical trials. Addressing these limitations through advanced phytochemical standardization, innovative drug delivery systems, omics-based approaches, and integrative clinical research will be essential for improving the reliability and therapeutic application of A. paniculata-derived products. Future research should focus on bridging the gap between experimental evidence and clinical practice by developing standardized, evidence-based formulations and evaluating their long-term safety and efficacy. Such efforts will enhance the potential of A. paniculata as a scientifically validated natural therapeutic resource and support its integration into modern healthcare systems.

Conflict of interest

The authors have no conflict of interest to declare.

Authors contribution

Study conception and design: AKP, DK; data collection: NP, PRS; draft manuscript: NP, NS, AKP; reviewing and editing: DK, LPS. All authors reviewed the results and approved the final version of the manuscript.

Funding

The authors have not received any financial support for this study

References

1. Kim JK, Kim KH, Shin YC, Jang BH, Ko SG. Utilization of traditional medicine in primary health care in low- and middle-income countries: a systematic review. Health Policy Plan. 2020;35(8):1070–1083. doi: 10.1093/heapol/czaa022.
2. Tiwari SS, Honmane SM, Sarda RR, Gattani SG, Mahaparale PR, Hoque ME. Economic benefits of natural products in modern drug discovery in the twenty-first century. In Traditional Resources and Tools for Modern Drug Discovery: Ethnomedicine and Pharmacology 2024 Sep 28 (pp. 641-662). Singapore: Springer Nature Singapore. doi: 10.1007/978-981-97-4600-2_25.
3. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. doi: 10.1136/bmj.n71.
4. Newman DJ, Cragg GM. Natural Products as Sources of New Drugs over Nearly Four Decades. J Nat Prod. 2020;83(3):770–803. doi: 10.1021/acs.jnatprod.9b01285.
5. Venkata RB, Prasanth DS, Pasala PK, Panda SP, Tatipamula VB, Mulukuri S, Kota RK, Rudrapal M, Khan J, Aldosari S, Alshehri B. Utilizing *Andrographis paniculata* leaves and roots by effective usage of the bioactive andrographolide and its nanodelivery: investigation of antikindling and antioxidant activities through in silico and in vivo studies. Frontiers in Nutrition. 2023 May 31;10:1185236. doi: 10.3389/fnut.2023.1185236.
6. Duche-Pérez A, Gutiérrez Aguilar OA, Valero Quispe JL, Serruto Castillo A, Mamani Daza LJ. Systematic review of ethnomedicinal knowledge: Documentation, evaluation, and conservation of medicinal plants and their therapeutic applications. F1000Research. 2025 Dec 22;13:1324. doi: 10.12688/f1000research.157960.2.
7. Fatima, B., Mishra, U. and Singh, A., 2026. Medicinal and Nutritional Importance of *Andrographis paniculata* in Human Health. In *Medicinal Plants and their Bioactive Compounds in Human Health: Volume 2* (pp. 531-547). Springer Nature Singapore. doi: 10.1007/978-981-95-3620-7_24.
8. Liu S, Liu J, Wang Y, Deng F, Deng Z. Oxidative stress: signaling pathways, biological functions, and disease. MedComm. 2025 Jul;6(7):e70268. doi: 10.1002/mco2.70268.
9. Paré G, Kitsiou S. Chapter 9 Methods for Literature Reviews. In: Lau F, Kuziemsky C, editors. Handbook of eHealth Evaluation: An Evidence-based Approach [Internet]. Victoria (BC): University of Victoria; 2017 Feb 27.
10. Erol A. Basics of Writing Review Articles. Noro Psikiyatr Ars. 2022 Jan 13;59(1):1-2. doi: 10.29399/npa.28093.
11. WHO. WHO Monographs on Selected Medicinal Plants. Geneva: World Health Organization; 2007.
12. Akowuah, G.A., Zhari, I., Norhayati, I., Sadikun, A., & Khamsah, S.M. (2006). Antioxidant activity and phenolic content of Andrographis paniculata extracts. Food Chemistry, 104(3), 1020–1026. doi: 10.55003/cast.2024.261033.
13. Jayakumar T., Hsieh C.Y., Lee J.J., Sheu J.R. (2013). Experimental and clinical pharmacology of Andrographis paniculata and its major bioactive phytoconstituent andrographolide. Evidence-Based Complementary and Alternative Medicine, 2013, 846740. doi: 10.1155/2013/846740.

14. Dai Y., Chen S.R., Chai L., Zhao J., Wang Y., Wang Y. (2019). Overview of pharmacological activities of andrographolide and its derivatives. Mini-Reviews in Medicinal Chemistry, 19(1), 17–29. doi: 10.1080/10408398.2018.1501657.
15. Mishra PK, Singh RK, Gupta A, Chaturvedi A, Pandey R, Tiwari SP, et al. Antibacterial activity of Andrographis paniculata (Burm. f.) Wall ex Nees leaves against clinical pathogens. Journal of Pharmacy Research. 2013;7(5):45962. doi: 10.1016/j.jopr.2013.05.009.
16. Singha, P.K., Roy, S., & Dey, S. (2003). Antimicrobial activity of Andrographis paniculata. Fitoterapia, 74(7–8), 692–694. doi: 10.1016/S0367-326X(03)00159-X.
17. Zhang X.F., Tan B.K.H. (2000). Antidiabetic property of ethanolic extract of Andrographis paniculata in streptozotocin-diabetic rats. Acta Pharmacologica Sinica, 21(12), 1157–1164.
18. Subramanian R., Asmawi M.Z., Sadikun A. (2008). In vitro α-glucosidase and α-amylase enzyme inhibitory effects of Andrographis paniculata and andrographolide. Journal of Ethnopharmacology, 117(3), 515–520. Doi: 10.18388/abp.2008_3087.
19. Ojha S.K., Bharti S., Joshi S., Kumari S., Arya D.S. (2012). Cardioprotective effects of Andrographis paniculata and andrographolide against myocardial injury. Indian Journal of Pharmacology, 44(2), 226–232.
20. Serrano F.G., Tapia-Rojas C., Carvajal F.J., Hancke J., Cerpa W., Inestrosa N.C. (2014). Andrographolide reduces cognitive impairment in animal models of Alzheimer's disease. Frontiers in Cellular Neuroscience, 8, 404. doi: 10.1186/1750-1326-9-61.
21. Jarukamjorn K, Nemoto N. Pharmacological Aspects of Andrographis paniculata on Health and Its Major Diterpenoid Constituent Andrographolide. Journal of Health Science. 2008;54:37081. doi: 10.1248/jhs.54.370.
22. Banerjee M, Chattopadhyay S, Choudhuri T, Bera R, Kumar S, Chakraborty B, et al. Cytotoxicity and cell cycle arrest induced by andrographolide lead to programmed cell death of MDA-MB-231 breast cancer cell line. Journal of Biomedical Science. 2016;23(1):40. doi: 10.1186/s12929-016-0257-0.
23. Kumar R.A., Sridevi K., Kumar, N.V., Nanduri, S., & Rajagopal, S. (2004). Anticancer and immunostimulatory compounds from Andrographis paniculata. Journal of Ethnopharmacology, 92(2–3), 291–295. doi: 10.1016/j.jep.2004.03.004.
24. Trivedi N.P., & Rawal U.M. (2001). Hepatoprotective and toxicological evaluation of Andrographis paniculata on liver damage models. Indian Journal of Pharmacology, 33(4), 288–293.
25. Handa, S. S., A. Sharma, and K. K. Chakraborti. Natural products and plants as liver protecting drugs. Fitoterapia (1986): 307-351.
26. Ding L., Wang L., Wang Z., Jiang H. (2014). Anti-obesity effects of andrographolide and Andrographis paniculata through regulation of adipogenesis and lipid metabolism. Phytotherapy Research, 28(6), 889–895. doi: 10.1124/jpet.114.217968.
27. Burgos RA, Alarcón P, Quiroga J, Manosalva C, Hancke J. Andrographolide, an Anti-Inflammatory Multitarget Drug: All Roads Lead to Cellular Metabolism. Molecules. 2020;26(1). Doi: 10.3390/molecules26010005
28. Wasman SQ, Mahmood AA, Chua LS, Alshawsh MA, Hamdan S. Antioxidant and gastroprotective activities of Andrographis paniculata (Hempedu Bumi) in Sprague Dawley rats. Indian J Exp Biol. 2011;49(10):76772. Doi:
29. Thakur AK, Soni UK, Rai G, Chatterjee SS, Kumar V. Protective effects of Andrographis paniculata extract and pure andrographolide against chronic stress-triggered pathologies in rats. Cell Mol Neurobiol. 2014 Nov;34(8):1111-21. doi: 10.1007/s10571-014-0086-1.
30. Thisoda P., Rangkadilok N., Pholphana N., Worasuttayangkurn L., Ruchirawat M., Satayavivad J. (2006). Inhibitory effect of andrographolide on platelet aggregation and thrombus formation. Eur J Pharmacol. 2006 Dec 28;553(1-3):39-45. doi: 10.1016/j.ejphar.2006.09.052.

31. Amroyan E, Gabrielian E, Panossian A, Wikman G, Wagner H. Inhibitory effect of andrographolide from Andrographis paniculata on PAF-induced platelet aggregation. Phytomedicine. 1999 Mar;6(1):27-31. doi: 10.1016/S0944-7113(99)80031-2.
32. Panossian A, Davtyan T, Gukassyan N, Gukasova G, Mamikonyan G, Gabrielian E, Wikman G. Effect of andrographolide and Kan Jang--fixed combination of extract SHA-10 and extract SHE-3--on proliferation of human lymphocytes, production of cytokines and immune activation markers in the whole blood cells culture. Phytomedicine. 2002 Oct;9(7):598-605. doi: 10.1078/094471102321616409.
33. Thakur, A.K., Chatterjee, S.S., Kumar, V., & Bharati, S. (2013). Adaptogenic and anxiolytic-like effects of Andrographis paniculata and andrographolide in experimental models. Phytotherapy Research, 27(5), 699–705. doi: 10.1016/j.jtcme.2014.10.002.
34. Bosco F, Ruga S, Citraro R, Leo A, Guarnieri L, Maiuolo J, et al. The Effects of Andrographis paniculata (Burm.F.) Wall. Ex Nees and Andrographolide on Neuroinflammation in the Treatment of Neurodegenerative Diseases. Nutrients. 2023;15:3428. doi: 10.3390/nu15153428.
35. Wu T, Peng Y, Yan S, Li N, Chen Y, Lan T. Andrographolide Ameliorates Atherosclerosis by Suppressing Pro-Inflammation and ROS Generation-Mediated Foam Cell Formation. Inflammation. 2018 Oct;41(5):1681-1689. doi: 10.1007/s10753-018-0812-9.
36. Akbarsha MA, Manivannan B. Antifertility effect of Andrographis paniculata (Nees) in male albino rats. Indian Journal of Experimental Biology. 1990;28(5):421–426.
37. Allan JJ, Pore MP, Deepak M, et al. Reproductive and fertility effects of a standardized extract of Andrographis paniculata in male Wistar rats. International Journal of Toxicology. 2009;28(4):308–317. doi: 10.1177/1091581809339631.
38. Gupta S, Mishra KP, Ganju L. Broad-spectrum antiviral properties of andrographolide. Archives of Virology. 2017;162(3):611–623. doi: 10.1007/s00705-016-3166-3.
39. Yongyun C, Jingwei Z, Zhiqing L, Wenxiang C, Huiwu L. Andrographolide stimulates osteoblastogenesis and bone formation by inhibiting nuclear factor kappa-B signaling both in vivo and in vitro. J Orthop Translat. 2019 Mar 2;19:47-57. doi: 10.1016/j.jot.2019.02.001.
40. Zhai ZJ, Li HW, Liu GW, Qu XH, Tian B, Yan W, Lin Z, Tang TT, Qin A, Dai KR. Andrographolide suppresses RANKL-induced osteoclastogenesis in vitro and prevents inflammatory bone loss in vivo. Br J Pharmacol. 2014 Feb;171(3):663-75. doi: 10.1111/bph.12463.
41. Zhu P-Y, Yin W-H, Wang M-R, Dang Y-Y, Ye X-Y. Andrographolide suppresses melanin synthesis through Akt/GSK3β/β-catenin signal pathway. Journal of Dermatological Science. 2015;79(1):7483. doi: 10.1016/j.jdermsci.2015.03.013.
42. Dai Y, Chen SR, Chai L, Zhao J, Wang Y, Wang Y. Overview of pharmacological activities of Andrographis paniculata and its potential applications in dermatology and cosmetic science. Journal of Ethnopharmacology. 2019;236:243–256. doi: 10.1080/10408398.2018.1501657.
43. Chao WW, Lin BF. Isolation and identification of bioactive compounds in Andrographis paniculata and their protective effects against UV-induced oxidative damage and matrix metalloproteinase expression in skin cells. Journal of Ethnopharmacology. 2010;128(1):79–84. doi: 10.1186/1749-8546-5-17.
44. Bao Z, Guan S, Cheng C, Wu S, Wong SH, Kemeny DM, Leung BP, Wong WS. A novel antiinflammatory role for andrographolide in asthma via inhibition of the nuclear factor-kappaB pathway. Am J Respir Crit Care Med. 2009 Apr 15;179(8):657-65. doi: 10.1164/rccm.200809-1516OC.
45. Lu, Z. F., Min, J., Wu, X. C., Dong, B. H., Ye, J. M., Liu, X. B., … Gao, Z. J. (2020). Andrographolide inhibits secretagogue-induced pseudo-allergic reaction. Journal of Asian Natural Products Research, 22(11), 1065–1077. doi: 10.1080/10286020.2019.1681408.
46. Zhang Y, Zhang P, Yu P, Shang X, Fu Y, Lu Y, et al. Protective effects of andrographolide on lead-induced kidney injury through inhibiting inflammatory and oxidative responses in common carp. Aquaculture Reports. 2020;17:100395. doi: 10.1016/j.aqrep.2020.100395.

47. Singh P, Srivastava MM, Khemani LD. Renoprotective effects of Andrographis paniculata (Burm. f.) Nees in rats. Ups J Med Sci. 2009;114(3):136-9. doi: 10.1080/03009730903174321.
48. Mussard E, Cesaro A, Lespessailles E, Legrain B, Berteina-Raboin S, Toumi H. Andrographolide, a Natural Antioxidant: An Update. Antioxidants (Basel). 2019 Nov 20;8(12):571. doi: 10.3390/antiox8120571.
49. Coon JT, Ernst E. Andrographis paniculata in the treatment of upper respiratory tract infections: a systematic review of safety and efficacy. Planta Medica. 2004;70(4):293–298. doi: 10.1055/s-2004-818938.
50. Saxena RC, Singh R, Kumar P, et al. A randomized double-blind placebo-controlled clinical evaluation of Andrographis paniculata extract in upper respiratory tract infections. Phytomedicine. 2010;17(3–4):178–185. doi: 10.1016/j.phymed.2009.12.001.
51. Poolsup N, Suthisisang C, Prathanturarug S, Asawamekin A, Chanchareon U. Andrographis paniculata in symptomatic treatment of uncomplicated upper respiratory tract infection: systematic review of randomized controlled trials. Journal of Clinical Pharmacy and Therapeutics. 2004;29(1):37–45. doi: 10.1046/j.1365-2710.2003.00534.x.
52. Hu XY, Wu RH, Logue M, et al. Andrographis paniculata (Chuān Xīn Lián) for symptomatic relief of acute respiratory tract infections in adults and children: a systematic review and meta-analysis. PLoS One. 2017;12(8):e0181780. doi: 10.1371/journal.pone.0181780.
53. Sareer O, Ahmad S, Umar S. Andrographis paniculata: A critical appraisal of extraction, isolation and quantification of andrographolide and other active constituents. Nat Prod Res. 2014;28(23):2081–2101. doi: 10.1080/14786419.2014.924004.
54. Kunle OF, Egharevba HO, Ahmadu PO. Standardization of herbal medicines – A review. International Journal of Biodiversity and Conservation. 2012;4(3):101–112. doi: 10.5897/IJBC11.163.
55. Okhuarobo A, Falodun JE, Erharuyi O, Imieje V, Falodun A, Langer P. Harnessing the medicinal properties of Andrographis paniculata for diseases and beyond: a review of its phytochemistry and pharmacology. Asian Pac J Trop Dis. 2014 Jun;4(3):213–22. doi: 10.1016/S2222-1808(14)60509-0. doi: 10.1016/S2222-1808(14)60509-0.
56. Intharuksa A, Arunotayanun W, Yooin W, Sirisa-ard P. A Comprehensive Review of Andrographis paniculata (Burm. f.) Nees and Its Constituents as Potential Lead Compounds for COVID-19 Drug Discovery. Molecules. 2022; 27(14):4479. doi: 10.3390/molecules27144479.
57. Sahoo N, Manchikanti P, Dey S. Herbal drugs: Standards and regulation. Fitoterapia. 2010;81(6):462–471. doi: 10.1016/j.fitote.2010.02.001.
58. Dai Y, Chen SR, Chai L, Zhao J, Wang Y, Wang Y. Overview of pharmacological activities of Andrographis paniculata and its major compound andrographolide. Critical Reviews in Food Science and Nutrition. 2019;59(sup1):S17–S29. doi: 10.1080/10408398.2018.1501657.
59. Songvut P, Boonyarattanasoonthorn T, Nuengchamnong N, Junsai T, Kongratanapasert T, Supannapan K, Khemawoot P. Enhancing oral bioavailability of andrographolide using solubilizing agents and bioenhancer: comparative pharmacokinetics of Andrographis paniculata formulations in beagle dogs. Pharm Biol. 2024 Dec;62(1):183-194. doi: 10.1080/13880209.2024.2311201.
60. Lim JCW, Chan TK, Ng DS, et al. Andrographolide and its analogues: A review of their pharmacological activities and medicinal chemistry. European Journal of Medicinal Chemistry. 2012;51:145–156. doi: 10.1111/j.1440-1681.2011.05633.x.