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Formulation innovations, pharmacological insights, and recent patent advancements in *Andrographis paniculata*

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ABSTRACT

Andrographis paniculata, popularly known as Kalmegh in the Indian subcontinent, is a multifunctional herb that possesses immense pharmacological properties. It has been used in Ayurvedic and other herbal formulations globally, in particular as a hepatoprotectant, antimalarial, and anti-inflammatory agent. Recent years have witnessed substantial progress in the research initiatives focused on the herb. The present review considers the pharmaceutical dosage forms of the multifarious herb *A. paniculata* along with discussing recent patents on the plant, venturing into the details of its therapeutic uses, methods of preparation of its extracts and their modification along with a brief discussion of various roles of the plant that constitute its pharmacological properties. The analysis was carried out using various web-based sources such as Scopus, PubMed, ScienceDirect, Google Scholar, Google Patents, and other allied databases. The data of patents on *A. paniculata* was extracted from the Google Patents database along with the use of the advanced search option to access the exact data on the plant along with the specific dates of publication, grant date, language, and countries. *A. paniculata* has huge potential as a major pharmaceutical drug on the market as evident from its many pharmacological activities. China dominated this field and had the highest number of patents granted and published. America, Australia, Korea, and Japan also contributed significantly towards new inventions.

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1. Introduction

Andrographis paniculata, widely known as Kalmegh in the Indian subcontinent, is an herb of many uses. It finds mentions in the Siddha, Unani, and the Ayurvedic systems of medicine along with the Iranian and Chinese medicine systems, which gives it an esteemed status. In the Indian subcontinent, it is popularly known as Kalmegh, in China as Chuan-Xin-Lian, and as Nain-e-Havandi in the Iranian folklore. The medicinal plant is commercially important along with being multifaceted in its utility. It is extremely bitter in nature and has immense medicinal value. This is due to the predominance of andrographolide (Figure 1) that belongs to the class of diterpenoid lactones. The other commercially important phytoconstituents include 14-deoxyandrographolide, dehydroandrographolide, neoandrographolide, iosandrographolide, paniculide-A, -B, -C, andrographidine-A, -B, -C, -D, -E, -F, andrographiside, andropanoside, and 5-methyl wogonin. Taking advantage of these, varieties of formulations have been prepared. This plant proclaims its dominance in the herbal industry as hepatoprotectant, antimalarial, antipyretic, and antiviral. Its multifarious therapeutic applications attract the general public to more plant-based healthcare. As the demand for herbal drugs increases drastically globally, so does the market of *A. paniculata.* The herb is used in various formulations in the form of capsules and tablets to treat infections of the upper respiratory tract, fevers of viral origin, liver disease, as anti-inflammatory, and immunity booster [1,2]. The plant, being an important part of the traditional medicine system, owns a wide range of herbal formulations to its credit. Market trends regarding the herb show an increased inclination toward its consumption as a natural medicine with minimal side effects as opposed to modern medicine. The demands for the drugs derived from Kalmegh are on the rise notably after the COVID-19 pandemic due to its antiviral activity against the SARS-CoV-2. Studies have revealed that it considerably inhibits their replication, reduces symptoms, and provides relief against infections that affect the upper respiratory system [3].

The plant has various monographs registered under its name, such as in the Indian Pharmacopoeia Commission and under the WHO. The dosage forms of these marketed formulations serve a variety of purposes. Physicians prescribe various dosage forms according to requirements in many forms such as solid which constitute film-coated, hard and soft capsules, sugar-coated, enteric-coated capsules, and granules. The semi-solid dosage forms include creams, gels, and ointments.

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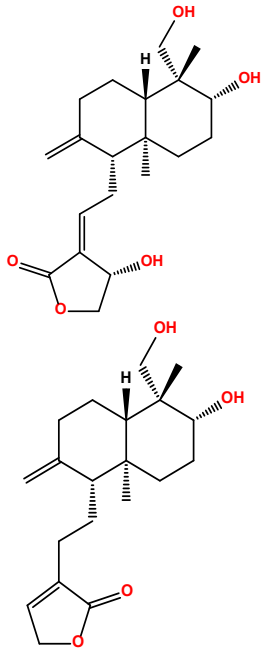

Properties of andrographolide
Chemical formula: $C_{20}H_{30}O_5$
Chemical name:(3*E*,4*S*)-3-[2-[(1*R*,4*aS*,5*R*,6*R*,8*aS*)-6-hydroxy-5-(hydroxymethyl)-5,8*a*-dimethyl-2-methylidene-3,4,4*a*,6,7,8-hexahydro-1*H*-naphthalen-1-yl] ethylidene]-4-hydroxyoxolan-2-one
CAS NO: 5508-58-7
Melting point-229-232℃

Properties of 14-deoxyandrographolide
Chemical formula: $C_{20}H_{30}O_4$
Chemical name: 4-[2-[(1*R*,4*aS*,5*R*,6*R*,8*aS*)-6-hydroxy-5-(hydroxymethyl)-5,8*a*-dimethyl-2-methylidene-3,4,4*a*,6,7,8-hexahydro-1*H*-naphthalen-1-yl] ethyl]-2*H*-furan-5-one
CAS NO: 4176-97-0
Melting point-176-178 ℃

Figure 1. Chemical structure of andrographolide and 14-deoxyandrographolide and some of their chemical properties.

The liquid formulations include syrups, mother tinctures, drops, and injectable formulations. Gaseous dosage forms include aerosols [4]. The *A. paniculata* formulations are sold in the form of these formulations globally focusing mainly on the relief of ailments related to the liver and respiratory tract serving as an immunoprotective agent. Especially after the appearance of coronavirus (COVID-19), the demand for immunoprotectants and respiratory medicaments that have a more natural background has increased [5]. For example, in October 2015, 59 solid dosage form products containing *A. paniculata* were authorized by the Therapeutic Goods Administration (TGA), Australia [4]. Formulations based on *A. paniculata* are herbal formulations, and there is a lack of these in modern medicine due to challenges faced in standardization of these drugs. The market impact of *A. paniculata* is expected to increase to *USD* 92.1 million in 2025 at an impressive CAGR of 5.9 % for the years 2019-2033 [5]. The formulations of *A. paniculata* occur in two types, which are pharmaceutical and herbal formulations [6]. *A. paniculata* is available in various formulations in the market, especially herbal formulations, these offer limited solubility and bioavailability, thus restricting the efficacy of the formulations. Recent innovations in this sector such as liquid dosage forms in the form of injectables, syrups, and tinctures. The liquid dosage forms offer a more effective route to enhance absorption as they are more readily soluble and may also hold an advantage over solid dosage forms through enhanced dissolution in the systemic circulation. Along with the semisolid forms, *viz*. ointments, gels, and creams lead to enhanced effectiveness. The drawback of these dosage forms is the lack of dose standardization and limited toxicity profiles. Recent innovations in formulations with respect to dosage form overcome these limitations and lead to greater bioavailability. Nanoparticle-based drug delivery systems, nanoemulsions, hydrogels, micelles, and liposomes are some of the most advanced superior alternatives to conventional dosage forms that address the limitations of rapid dissolution, quick elimination, and show improved effectiveness in multiple dosing and slow release of the compound [2]. This study provides a comprehensive and critically structured synthesis of phytochemistry, pharmacological evidence, formulation innovations, and recent patent developments related to *A. paniculata*. It bridges traditional medicinal knowledge with modern pharmaceutical and technological advances, providing clarity on the translational potential and existing research gaps. This review highlights innovation trajectories and emerging therapeutic directions. In general, it serves as a valuable reference framework for researchers, formulation scientists, and policy makers working on phytopharmaceutical development.

2. Methodology

A detailed literature review strategy and patent review strategy were implemented in combination for the analysis. Databases including Scopus, PubMed, ScienceDirect, and Google Scholar were searched for pharmacological and formulation-related studies published between 2000 and 2025. The patent data were retrieved from Google Patents and the relevant patent office databases, focusing on the granted patents from 2021-2025. For the patent analysis, the specific keyword was set as '*Andrographis paniculata*' and using the advanced search option additional keywords *viz.* 'andrographolide', 'therapeutic uses', and 'method of extract preparation and its modification' were made. Furthermore, all language and patent office database were taken into consideration, and all the data available globally was utilized for the recent patents and designs query search. The general screening process involved initial keyword-based retrieval, duplicate removal, title and abstract screening, full-text eligibility assessment, and final inclusion based on predefined criteria. Inclusion criteria included original peer-reviewed research articles, reviews, and granted patents focused on *A. paniculata*, studies reporting pharmacological activity, patents addressing therapeutic applications, formu-lation innovations, and extraction modifications. The exclusion criteria involved the removal of duplicate records, publications without accessible abstracts, and patents not related to therapeutic and formulation relevance. This screening of the data set led to 108 data entries, of which 58 belonged to the recent patents category and 50 were from the literature on pharmacology, phytochemistry, and formulation innovations pertaining to *A. paniculata*.

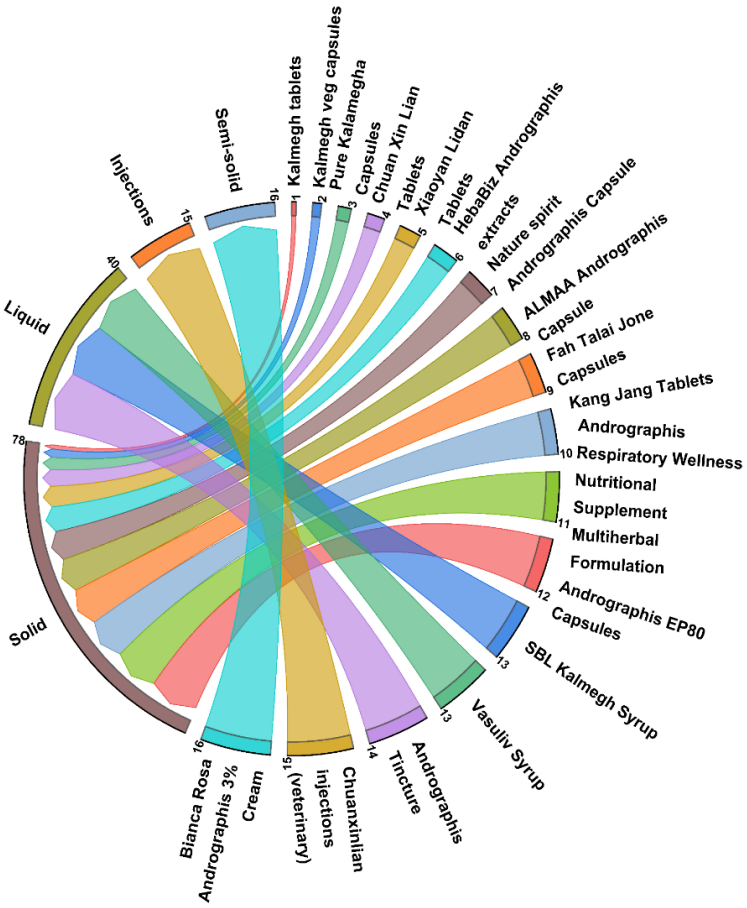

Figure 2. Cord diagram of dosage forms and corresponding herbal formulations of *A. paniculata* in the market.

3. Phytochemistry

The diversity and abundance of secondary metabolites present in the chemical composition of the plant are represented by a variety of different classes, among which the diterpenoid lactones are the most characteristic and the most therapeutically significant [7]. These phytochemical compounds are found in different quantitative and qualitative amounts depending on the specific plant part, the amount of plant growth, and the environmental conditions under which the plant grows. Regardless of these factors, the leaf is generally the part of the plant with the highest concentration of bioactive compounds. The characteristic chemicals of *A. paniculata* consist primarily of labdane-type diterpenoid lactones. Andrographolide is the main chemical compound found in this species and serves as the primary chemical marker for quality control and the standardization of herbal medications derived from *A. paniculata* [8]. The most common diterpenoid chemicals derived from *A. paniculata* include neoandrographolide, 14-deoxyandrographolide, 14-deoxy-11,12-didehydroandrographolide, and andrograpanin [7,9]. All of these compounds contribute to an extensive array of pharmacological activities attributed to *A. paniculata*, including anti-inflammatory, liver-protective, immunomodulatory, antidiabetic, antiviral, and anticancer activities [8]. Flavonoids, another class of phytochemicals, have also been isolated from *A. paniculata*, predominantly from the aerial parts of the plant. Some examples of flavonoids found in *A. paniculata* include apigenin, luteolin, quercetin, kaempferol, and andrographidine derivatives [9]. Flavonoids possess powerful antioxidant and anti-inflammatory properties and have been reported to work together with diterpenoid lactones to enhance their biological effects [2,4]. The phenolic fraction of *A. paniculata* further enhances its therapeutic potential. Several phenolic acids have been identified such as caffeic acid, ferulic acid, chlorogenic acid, gallic acid, and p-coumaric acid and are associated with free radical scavenging and redox regulation activities [4]. Furthermore, a few sterols, *viz*. sitosterol, stigmasterol and campesterol, along with triterpenoids, saponins, tannins, glycosides, reducing sugars, and amino acids, have been recognized. Thus, collectively, these constituents support the multifunctional pharmacological profile of plants [7,9]. In summary, the phytochemical profile of *A. paniculata* is dominated by labdane-type diterpenoid lactones, supported by flavonoids, phenolics, and other minor constituents. This complex and synergistic chemical composition provides a strong scientific basis for its extensive traditional use and its growing importance in modern phytopharmaceutical research and herbal drug development. Andrographolide, the major diterpenoid lactone, is particularly notable as the most promising candidate for microencapsulation, nanoparticle delivery systems, and controlled release formulations because of its low solubility in water and limited bioavailability. Compounds such as 14-deoxyandrographolide and neoandrographolide are often found in formulations and known to have hepatoprotective and immunomodulatory benefits, with special reference to polyherbal combinations to improve liver and respiratory health. Flavonoids such as apigenin and luteolin have anti-inflammatory and antioxidant properties, making them ideal ingredients for dermatological and anti-aging formulations. Furthermore, other minor sterols and phenolic acids can also contribute to the synergistic effect, providing a basis for the development of formulations containing standardized extracts as opposed to individual compounds

[2,7-10]. Currently, more than 30 formulations are marketed globally to target and provide relief from various types of ailments (Figure 2) [11-25].

4. Patents

In recent years there has been a significant increase in the number of patents related to *A. paniculata* that highlight the importance of the herb in multiple fields (Table 1 [26-35]), giving an impetus to its increased production and sale in the market and Table 1 includes the recent patent in the year 2025 on *A. paniculata* highlighting their application area and the key ingredients involved. These patents highlight its therapeutic uses tabulated in Table 2 up to the year 2021 [36-65] and aim to improve the quality of secondary metabolites (Table 3 [66-83]) obtained from the herb and Table 3 summarizes the patents on the extract preparation and modification of *A. paniculata* upto the year 2021.

4.1. Development of microencapsulated formulation based on Andrographolide and Method of Preparation (556149) granted-2024-12-18

This patent is based on andrographolide as a constituent of a microencapsulated formulation aimed at increasing the bioavailability of the drug formed from Kalmegh through its release, so that it is stable, thus improving its pharmaceutical efficacy. The andrographolide encapsulated in the formulation is used to relieve diabetes and infection of the liver, *viz.* jaundices, skin diseases and also acts as an antipyretic [26].

4.2. PAR-1 inhibitor, chiral synthesis method thereof, preparation method and application of salt crystal form thereof (CN117362279B) granted-2024-03-12

This invention utilizes andrographolide as a starting material for the preparation of PAR-1 inhibitor, the detailed method of its chiral synthesis, preparation, and finally the use of their crystal salt forms. The proposed use of the PAR-1 inhibitor is in the treatment of thrombotic diseases [27].

4.3. A kind of andrographolide diterpenoid lactone compound and its extraction method and application (CN117645589B) granted-2024-10-15

The innovation deals with the methods of preparation of the extract of *A. paniculata* and its subsequent separation through detailed techniques that yield andrographolide, which has been proposed to be of superior quality. It also has anti-inflammatory activity against Interleukin-6 (IL-6), nitric oxide, and tumor necrosis factor-alpha (TNF-α) [28].

4.4. Herbal fumigation moxibustion for strengthening spleen and clearing lung and preparation method thereof (CN118806860B) granted-2024-12-24

The present invention claims a spleen strengthening and lung-clearing formulation for moxibustion and herbal fumigation along with the specification of the method of preparation. Constituents such as *A. paniculata*, *Euryale ferox*, *Eriobotrya japonica* leaf, *Citrus reticulata* peel, *Platycoodon grandiflorum*, *Momordica grosvenorii*, eume, *Lilium*, *Poria cocos*, *Polygonatum odoratum*, *Dioscorea polystachya*, *Alpinia oxyphylla*, *Coix* seed, *Houttuynia cordata*, *Aucklandia lappa*, *Frirllaria cirrhosa*, *Codonopsis pilosula*, *Ginkgo biloba*, *Trichosanthes* root, *Gynostemma pentaphyllum*, *Atractylodes macrocephala, Syzigium aromaticum*, gyspum, *Ophipogon japonicus*, and *Chelidonium majus*. The herbal fumigation and moxibustion developed by this invention is used externally on the body surface, improving the effects of the drug and the acupuncture point by increasing the absorption of the prescribed medication when it touches the acupuncture point skin. It also claims to reduce symptoms such as shortness of breath, sputum, and cough [29].

4.5. Compositions and methods for immune health (US11931390B1) granted-2024-03-19

The formulation comprises *A. paniculata* extract at approximately 20% to 30% by weight of the total formulation, *Moringa oleifera* extract at approximately 24% to 36% by weight of the total formulation; *Withania somnifera* extract at around 16% to 24% by weight of the total formulation and *Ocimum sanctum* extract at roughly 20% to 30% by weight of the total formulation. This method proposes relief from symptoms of the upper respiratory tract by the administration of the formulation to enhance the immunity along with its maintenance and support along with decrease in the concentration of C-reactive protein in the mammal's blood, or an increase in the concentration of immunoglobulin G in the mammal's blood. The mammals include primates, and enhanced immunity may target a virus or an infection of the upper respiratory tract. This formulation may be presented in the form of a capsule, pill, or tablet [30].

4.6. Application of Chinese and western compound medicine in preparation of leukaemia treatment medicine (CN116270787 B) granted-2024-03-08

This invention presents a novel application of a hybrid Chinese and Western medicinal formulation for the treatment of leukemia. The formulation is composed of raw materials including *Lonicera*, common *Andrographis* herb, *Radix isatidis*, *Taraxacum*, acetaminophen, amantadine hydrochloride, and chlorpheniramine maleate. This hybrid medicinal preparation demonstrates efficacy in treating leukemia by inhibiting leukemia cell proliferation and enhancing the immune function of patients. The types of leukemia addressed include acute myelogenous human leukemia, acute lymphoblastic leukemia, chronic myelogenous leukemia, and chronic lymphoblastic leukemia [31].

4.7. Anti-dandruff composition and preparation method and application thereof (CN117482015B) granted-2025-02-07

The anti-dandruff composition production process and usage are stated in this application. 1% to 5% of *Sophora flavescens* root, 0.5% to 5% of *Saposhnikovia* root, 0.5% to 2% of *Magnolia officinalis* bark, 0.3% to 2% of *Glycyrrhiza* root, 0.1% to 1% of *A. paniculata* leaf, and the remaining solvent make up the proposed anti-dandruff composition. A green, safe and non-irritating formulation can be achieved by the components working together to effectively inhibit *Malassezia furfur* production, oil secretion, free radical DPPH scavenging, improving the barrier function of the scalp, and reducing dry, itchy, and dandruffy scalps [32].

4.8. A hair dye for preventing hair breakage, hypoallergenic and repairing (CN119074574B) granted-2025-04-01

The current invention pertains to the domain of hair colouring products, specifically focusing on a hair dye designed to prevent hair breakage, facilitate repair, and hypo-allergenicity. This hair dye incorporates active ingredients such as propylene glycol, polyquaternium salt, *Camellia* oil, caprylic/capric triglyceride, trehalose, glycerine, hydrolyzed wheat protein, *Panax ginseng* extract, *Hippophae rhamnoides* leaf extract and *A. paniculata* extract, along with *Garcinia mangostana* bark extract, all of which possess moisturizing, anti-inflammatory and restorative properties.

Table 1. Summary of recent patents highlighting their application area and the key ingredients involved.

No	Patent no.	Title	Key ingredients	Application area	Classification system	Assignee	Grant date	Ref.
1	556149	Development of a microencapsulation formulation based on andrographolide and method of preparation thereof	Andrographolide	Diabetes, hepatoprotection, antipyretic, skin	A61K	Gajbhiye NA, Kumar J	2024-12-18	[26]
2	CN117362279B	PAR-1 inhibitor, chiral synthesis method thereof, preparation method and application of salt crystal form thereof	Andrographolide	Thrombotic diseases	A61K31/443; A61P7/02; A61P9/10; C07D405/06	Shandong University Shandong Qidu Pharmaceutical Co Ltd.	2024-03-12	[27]
3	CN117645589B	A kind of andrographolide diterpenoid lactone compound and its extraction method and application	Andrographolide	Anti-inflammatory (IL-6, TNF-a)	C07D307/58; A61P29/00; C07H1/08; C07H15/18	Anhui University of Traditional Chinese Medicine AHUTCM	2024-10-15	[28]
4	CN118806860B	Herbal fumigation moxibustion for strengthening spleen and clearing lung and preparation method thereof	*A. paniculata* and multi-herbs	Respiratory issues, cough, breathlessness	A61H39/06; A61K33/06; A61K36/9062; A61P1/14, A61P11/00; A61P11/14	Taihaole Biotechnology Co Ltd.	2024-12-24	[29]
5	US11931390B1	Compositions and methods for immune health	*A. paniculata*, *Moringa*, *O. sanctum*	Respiratory infection	A61K31/365; A61K31/56; A61K31/585; A61K31/7048; A61K36/185; A61K36/19, A61K36/53; A61K36/81; A61K45/06; A61K9/00; A61P11/00	Karallief Inc.	2024-03-19	[30]
6	CN116270787B	Application of Chinese and western compound medicine in preparation of leukaemia treatment medicine	*Lonicera*, common *Andrographis* herb, *R. isatidis*, *Taraxacum*, acetaminophen, amantadine hydrochloride, chlorpheniramine maleate	Leukaemia (various types)	A61K31/13; A61K31/167; A61K31/4402; A61K36/355; A61P35/02	Key Laboratory of Natural Product Chemistry of the Guizhou Academy of Sciences	2024-03-08	[31]
7	CN117482015B	Anti-dandruff composition and preparation method and application thereof	*Sophora flavescens* root, *Saposhnikovia* root, *M. officinalis* bark, *Glycyrrhiza* root, *A. paniculata* leaf	Dandruff, scalp barrier enhancement	A61K8/9789; A61P17/14, A61Q5/00; A61Q5/02; A61Q5/12	Guangzhou Baiaishen Biotechnology Co Ltd.	2025-02-07	[32]
8	CN119074574B	A hair dye for preventing hair breakage, hypoallergenic and repairing	Propylene glycol, polyquaternium salt, *Camellia* oil, caprylic/capric triglyceride, trehalose, glycerine, hydrolysed *Triticum aestivum* protein, *Panax ginseng* extract, *Hippophae rhamnoides* leaf extract, *A. paniculata* extract, *Garcinia mangostana* bark extract	Hair care, hypoallergenic colouring	A61K8/34; A61K8/37; A61K8/60; A61K8/64; A61K8/81; A61K8/92; A61K8/9789; A61P29/00; A61Q19/00; A61Q5/10	Guangzhou Yangyitang Pharmaceutical Technology Co Ltd.	2025-04-01	[33]
9	US12280082B2	Formulation for inhibiting virus replication	*A. paniculata*, PVP K30, acrylic polymer	Antiviral (Coronaviridae, including SARS-CoV-2)	A61K31/40; A61K36/19; A61K36/23; A61K36/81; A61K36/00	Ganju Shibban Krishen	2025-04-22	[34]
10	CN115887243B	A kind of hydrogel beauty liquid and preparation method thereof	*Gardenia*, *Lonicera*, *Taraxcum*, *A. paniculata*, *Magnolia* bark, *Poria cocos*, *Polyporus umbellatus*, *Alisma* rhizome, *Musa* seeds, *Phaseolus vulgaris*, *Prunus persica* kernels, *L. chuanxiong*	Dermatology, acne treatment	A61K8/04; A61K8/34; A61K8/73; A61K8/86; A61K8/9728; A61K8/9789; A61K8/9794; A61P17/10; A61Q17/00; A61Q19/00	Suzhou Chunghwa Chemical & Pharmaceutical Industrial Co Ltd.	2025-01-28	[35]

Table 2. Patents related to the therapeutic potential of *A. paniculata*.

No	Patent no	Title	Key ingredients	Application area	Classification system	Assignee	Grant date	Ref.
1	CN117441841B	Enzymolysis phagostimulant for promoting fish growth and the preparation method thereof	*Cinnamomi japonici*, *Scutellaria Radix*, taurine, anisodamine, brown algae oligosaccharide, polyporus, *Andrographis*, *Radix Acanthopanacis senticos*	Fish growth promoter	A23K10/14; A23K10/30; A23K20/105; A23K20/111; A23K20/142; A23K20/163; A23K40/00; A23K50/80	Foshan Shunde Wanghai Forage Industrial Co Ltd.	2024-10-11	[36]
2	KR102713383B1	Composition to improve the immunity of animals other than humans	*A. paniculata*, *Emblica officinalis*, *Punica granatum*	Immunomodulator	A23K10/20; A23K10/30; A23K20/142; A23K50/10; A23K50/20; A23K50/30; A23K50/75	Kim, H. J.; Lee, H.; H.; Kim, S. G	2024-10-04	[37]
3	CN116570664B	A Chinese medicine composition for treating chicken leg arthritis and its application	*Lonicera*, *Forsythia*, *Hottuynia cordata*, *A. paniculata*, *Viola yedonesis*, white moss peel, *Scutellaria baicalensis*	Arthritis	A61K36/86; A61K47/10; A61K47/26; A61K9/06; A61P19/02; A61P31/04; A61P31/14	Yangzhou Boxingnong Biotechnology Co Ltd.	2025-04-04	[38]
4	CN116211923B	Traditional Chinese medicine medicated bath preparation for treating *Tinea* and preparation method and application thereof	Lucid *Ganoderma*, *Lithospermum*, *Coptis chinensis*, *Lonicera*, *Artemisia scoparia*, *Taraxacum*, *Andrographis* herb, *Scutellaria baicalensis* root, *Bupleurum*, *Dictamnus dasycarpus*	Psoriasis, onychomycosis, other skin tinea diseases	A61K36/75; A61P17/00; A61P17/06; A61P31/10	Sun, Z.	2024-09-06	[39]
5	CN116211933B	Anticoccidial traditional Chinese medicine composition and application thereof	*Artemisia annua*, *Melia azedarach* bark, *Sanguisorba officinalis*, *Fraxinus excelsior*, *Hypericum perforatum*, *Fructus quisqualis*, *Andrographis* herb, *Rehmannia* root, *Astragalus mongholicus*	Anticoccidial, antiparasitic, detoxification, antidysenteric	A61K36/804; A61P33/02	Yulin Normal University	2024-03-29	[40]
6	CN116370369B	Natural plant extract composition with the effects of relieving, repairing, and resisting allergy and application thereof	*Cynanchum atratum* extract, *Sophora flavescens* root extract, *A. paniculata* extract, *Bletilla* root extract, *Stephania tetrandra* root extract, *Citrus* fruit extract	Anti allergic	A61K8/9789; A61K8/9794; A61P17/04; A61P37/08; A61Q19/00; A61Q19/02	Qingyuan Wangsha Biotechnology Co Ltd.	2024-02-27	[41]
7	CN117204503B	Pomegranate rind extract composite additive and preparation method and application thereof	*Punica granatum* rind extract, *Phellodendron amurense* bark, *Rheum officinale*, *Andrographis* herb, *C. chinensis*	Feed additive	A23K10/20; A23K10/22; A23K10/30; A23K10/37; A23K20/158; A23K20/174; A23K20/20; A23K20/26; A23K20/28; A23K50/80; A61K36/756; A61P21/00; A61P37/04; A61P39/00; A61P39/06	Guangdong Nutriera Biotechnology Co ltd Guangdong Liankun Group Co Ltd.	2024-06-18	[42]
8	CN118987062B	Composition for preventing and controlling PEDV infection in piglets and its application	*A. paniculata*, *Clostridium butyricum*	Preventing PEDV infection in piglets	A23K10/12; A23K10/16; A23K10/30; A23K20/00; A23K50/30; A61K35/742; A61K36/19; A61P1/00; A61P1/12; A61P29/00; A61P31/14; A61P37/04; C12P1/04; C12R1/07	Jilin Agricultural University	2025-01-24	[43]

Table 2. Continued.

No	Patent no	Title	Key ingredients	Application area	Classification system	Assignee	Grant date	Ref.
9	CN113812547B	Feed for promoting growth of bee colony and preparation method thereof	Hydrolyzed *Glycine max* powder, emulsion, wild *Rosa* pollen, sugar powder, yeast tablets, nutrient reinforcing agents, *A. paniculata* herb	Feed for promoting bee colony growth	A23K10/14; A23K10/18; A23K10/20; A23K10/30; A23K20/147; A23K20/158; A23K20/163; A23K20/168; A23K40/00; A23K50/90	Research Institute of Silkworms Mulberries and Bees Yunnan Academy of Agricultural Sciences	2024-02-23	[44]
10	CN114636764B	Screening method for anti-inflammatory and antiviral active ingredients of *A. paniculata*	*A. paniculata* with cyclooxygenase-2, interleukin-6, angiotensin converting enzyme 2	Anti-inflammatory, antiviral screening	A23K10/14; A23K10/18; A23K10/20; A23K10/30; A23K20/147; A23K20/158; A23K20/163; A23K20/168; A23K40/00; A23K50/90	Wuhan Botanical Garden of CAS	2024-01-26	[45]
11	KR102689489B1	A cosmetic composition comprising *Chamaecyparis obtuse* leaf extracts, *A. paniculata* extract, astaxanthin as active ingredients	*Chamaecyparis obtuse* leaf extracts, *A. paniculata* extract, astaxanthin	Skin barrier strengthening, skin regeneration	A61K8/14; A61K8/35; A61K8/9761; A61K8/9789; A61Q19/00; A61Q19/08	Hwang, E. K.	2024-07-26	[46]
12	CN115845004B	Traditional Chinese medicine microcapsule for treating pig diarrhoea and preparation method thereof	*Pulsatilla chinensis*, *Syzygium cumini*, *Fraxinus excelsior*, *Lonicera*, *Pueraria lobata* root, dried *Citrus* peel, common *Andrographis* herb, white *Hyacinthus* bean, *Saussurea costus*, *Atractylodes macrocephala* rhizome, *Coix* seed, *Raphanus sativus* seed, *Poria cocos*	Treating pig diarrhoea	A61K8/14; A61K8/35; A61K8/9761; A61K8/9789; A61Q19/00; A61Q19/08	Henan Dahua Biotechnology Co Ltd.	2024-04-19	[47]
13	CN116616316B	Attractant for tea tree pests and preparation method and application thereof	*A. paniculate, Medicago sativa* extracts	Improving the attraction effect on tea garden pests.	A01N65/08; A01N65/20; A01N65/24; A01P19/00	Shandong Liuyuan Ecological Agriculture Co Ltd.	2023-09-15	[48]
14	TWI826254B	Whitening composition and use thereof	*Sarcandra glabra*, an extract of *A. paniculate,* extract of *Rosmarinus officinalis*	Skin whitening composition	A61K36/185; A61K36/19; A61K36/53; A61K8/9789; A61P17/00; A61Q19/00	Wu, Y.; Lin, Z.	2023-12-11	[49]
15	CN115006496B	Chinese herbal medicine composition for treating pneumonia of foxes, raccoon dogs and martens	*A. paniculata*, *Trichosanthes trichosanthes*, *Phragmites* root, *Houttuynia cordata*, *Codonopsis pilosula*, *Solidago, Glycyrrhiza glabra*	Treating pneumonia of foxes, raccoon dogs, martens	A61K36/899; A61P11/00; A61P31/04	Hebei Xuhong Animal Pharmaceutical Co Ltd.	2023-09-08	[50]
16	CN114903944B	Composition and preparation to improve cervical HPV infection symptoms and preparation method	*A. paniculata*, *Polygonum cuspidatum*, *Bupleurum*, *Scutellaria baicalensis*, *Pericarpium granati* extracts, *Panax ginseng*, *Paeonia* root extract, hydrolyzed ginsenoside, *Radix scrophulariae* extract	Improving cervical HPV infection symptoms	A61K35/744; A61K36/808; A61K47/32; A61K9/06; A61P15/00; A61P31/20	Feng Xun	2023-09-22	[51]
17	LU501512B1	Stress-resistant preparation for transport of juvenile crabs of *Eriocheir sinensis* and the preparation method thereof	*Gastrodia elata* Blume, *Mentha* leaf, *Nardostachyos*, *Schisandra chinensis*, *A. paniculata, Trigonella foenum-graecum*, *Taraxacum, Nephrolepis,* water	Stress-resisting preparation for transport of juvenile crabs	A23K20/10; A23K50/80; A23L33/105	Chang, Y.; Song, S.; Su, G.; Xu, M.; Wang, F.; Yu, H.; Li, Y.; Tang, J.; Li, Z.; Cao, P.; XuBo, L	2022-08-19	[52]

Table 2. Continued.

No	Patent no	Title	Key ingredients	Application area	Classification system	Assignee	Grant date	Ref.
18	CN114224992B	Traditional Chinese medicine composition for treating intestinal adhesion and adhesive intestinal obstruction and preparation method thereof	*Panax notoginseng, Carthamus tinctorius, Citrus aurantium, Magnolia officinalis, Prunella vulgaris, Curcuma zedoaria, Astragalus membranaceus, Cordyceps sinensis, Andrographis paniculata, Cucumis sativus seeds, Aucklandia lappa*	Treating intestinal adhesion, obstructions	A61K36/9066; A61K9/14; A61K9/48; A61P1/00	Beijing Jishi Huakang Institute of Traditional Chinese Medicine	2023-03-10	[53]
19	RU2781828C1	Pharmaceutical composition with adaptogenic activity	*A. paniculata*, *Pterocarpus marsupium*, sodium salt of o-carboxybenzoyl ferrocene, *Glycyrrhiza glabra*	Adaptogenic activity	A61K9/48; (IPC1-7): A61K35/78; A61K9/48	National Pharmaceutical University.	2022-10-18	[54]
20	AU2021106876A4	Formulations comprising botanical extracts	*A. paniculata, Reynoutria japonica, Eriobotrya japonica*	Antiviral, antibacterial	A61K31/05; A61K31/19; A61K31/365; A61K31/7034; A61K36/19; A61K36/704; A61K36/73; A61K9/20; A61K9/48; A61P31/04; A61P31/12; A61K36/28; A61K9/00	Apex Biotech Res Pty Ltd.	2021-11-25	[55]
21	AU2021106596A4	A Poly-Herbal Drug Composition and a Method for a Formulation of the Poly-Herbal Drug for the Treatment of a chronic fatigue syndrome	*A. paniculata*, roots of *Asparagus recemosus*, *Fumaria indica*, fruits of *Phyllanthus emblica* L., *Morus alba*, *Terminalia chebula* Retz., *Benincasa hispida*	Treating chronic fatigue syndrome	A61K36/185; A61K36/19; A61K36/42; A61K36/50; A61K36/605; A61K36/8965; A61P25/00	Nirupam, D.; Debapriya, G.; Dinesh, K. P.; Anshul, S.; Naveen S.; Gireesh, K. S.; Ravi, B. S.; Shashi, K. S	2021-12-16	[56]
22	CN113429452B	Acylated mogroside derivatives as anti-inflammatory agents and anti-inflammatory compositions	*Houttuynia cordata* extract, anthocyanin, *A. paniculata* extract	Anti-inflammatory	A61K31/352; A61K31/58; A61K36/19; A61K36/78; A61P29/00; C07J71/00	Li, W.; Huang, H.; He, J.; Huang, J.; Song, G.; Jiang, X.	2022-03-01	[57]
23	AU2021103471A4	A method of preparing ethno-herbal farm produce sanitizer	*O. sanctum*, *Terminalia chebula*, *A. paniculata*, *Indigofera tinctora*, *Azaridachta indica, Aloe barbadensis*, *Curcurma longa*, *Murraya koeniga*	Herbal produce sanitizer	A01N65/48; A23B7/153; A23L3/3472; A01N25/22; A01N65/08; A01N65/20; A01N65/22; A01N65/24; A01N65/26; A01N65/28; A01N65/36; A01N65/42; A01N65/44; A01N65/00	Pravda, C.; Jerrine, J; Aruni, W.; Santhosh K.; Preethi, S.	2022-03-31	[58]
24	KR102482196B1	A composition for preventing or improving circadian rhythm disorders comprising *A. paniculata* plant extracts or andrographolide	*A. paniculata*	Treatment / improvement of circadian rhythm disorders	A23L33/105; A61K31/365; A61K36/19; A61K8/49; A61K8/9789; A61K9/00; A61P43/00; A61Q19/00	Yeom, M. J.; Lee, H.S.; Jeong, E.S.; Park, D. H.	2022-12-29	[59]
25	CN112451589B	A kind of medicinal composition for treating pullorum and the preparation method thereof	*C. chinensis*, *Pulsatilla*, cortex *Phellodendri*, *Astragalus*, *Rhubarb*, *Rehmannia glutinosa*, *Artemisia annua*, *Scutellaria baicalensis*, *A. paniculata*, *Glycyrrhiza glabra*	Treating pulluorum in polutry	A61K36/804; A61P1/12; A61P31/04	Henan University of Science and Technology	2022-05-27	[60]

Table 2. Continued.

No	Patent no	Title	Key ingredients	Application area	Classification system	Assignee	Grant date	Ref.
26	CN112294889B	Medicine for preventing and treating eel edwardsiellosis and preparation method thereof	*Galla japonica*, *Angelica*, *Portulaca oleracea*, *Reynoutria japonica*, *A. paniculata*, *Scutellaria*, *Houttuynia cordata*, *Hedyotis diffusa*, *Stellaria media*, *Glycyrrhiza glabra*	Treating edwardsiellosis in eels	A61K35/64; A61K36/78; A61P31/04	Jimei University	2021-12-14	[61]
27	CN113144039B	Plant anti-allergy relieving composition and preparation method and application thereof	*Oldenlandia diffusa, A. paniculata*	Anti-allergic	A61K36/28; A61K36/748; A61K36/804; A61P17/00; A61P17/04; A61P29/00; A61P37/08; (IPC1-7): 61K009/107; A61K009/12; A61K036/06; A61K036/19; A61K036/74; A61K036/804; A61K125/00; A61K127/00; A61K36/28; A61K36/748; A61K36/804; A61P029/00; A61P037/08; A61P17/00; A61P17/04; A61P29/00; A61P37/08	Shanghai Neijianhui Biotechnology Co Ltd.	2023-02-07	[62]
28	KR102308756B1	Cosmetic composition containing mixture extracts of *Citrus unshiu* Peel Extract and *A. paniculate* as active Ingredient	*A. paniculate, Citrus unshiu*	Skin protection, improvement	A61K8/9789; A61Q19/00; A61Q19/0	Lee, C. H.; Park, H. W; Lee, G. S.; Gu, G. C.	2021-10-06	[63]
29	CN113321631B	Biandrographolide G, preparation method and application thereof in medicines	*A. paniculata*	Anti-inflammatory	A61K31/365; A61P35/00; C07D307/60	Yunnan Biobiaopha Technology Co Ltd.	2022-02-01	[64]
30	CN111685036B	Method for mutagenizing *A. paniculata* by ethyl methanesulfonate	*A. paniculata*	Enhanced cultivation for pharmaceutical use	A01C1/00; A01H1/06	CROP Research Institute of the Guangdong Academy of Agricultural Sciences	2021-07-23	[65]

The formulation of this hair dye shows remarkable efficacy in soothing the skin, hydrating it, and improving hair quality [33].

4.9. Formulation for inhibiting virus replication (US12280082B2) granted-2025-04-22

The current invention pertains to an innovative formulation that includes drug substances, which can be combined with additional active pharmaceutical components, designed to inhibit the replication of viruses within the Coronaviridae family. This formulation specifically incorporates *A. paniculata*, PVP K30, and an acrylic polymer. Furthermore, the invention includes various pharmaceutical formulations that utilize distinct methods of application [34].

4.10. A kind of hydrogel beauty liquid and preparation method thereof (CN115887243B) granted-2025-01-28

The present invention pertains to the domain of dermatological care and is designed to introduce a hydrogel beauty liquid along with its preparation method. This hydrogel beauty liquid incorporates a composition derived from traditional Chinese medicine, which consists of the following raw materials in specified weight proportions: 8-12 parts of *Gardenia*, 8-12 parts of *Lonicera*, 16-24 parts of *Taraxacum*, 8-12 parts of *A. paniculata*, 8-12 parts of *Magnolia* bark, 8-12 parts of *Peltandra*, 8-12 parts of *Polyporus umbellatus*, 8-12 parts of *Alisma* rhizome, 8-12 parts of *Musa* seeds, 8-12 parts of *Phaseolus vulgaris*, 8-12 parts of *Prunus persica* kernels and 8-12 parts of *Ligusticum chuanxiong*. These ingredients are known for their properties in alleviating heat and detoxifying, cooling the blood, and removing dampness, which collectively contribute to a marked improvement in acne-prone skin and the suppression of *Propionibacterium* acnes. Furthermore, research indicates that *Gardenia* and *Magnolia* bark exhibit a synergistic effect within the formulation, greatly improving the efficacy of acne treatment [35].

5. Antimicrobial potential

5.1. Antibacterial and antifungal potential

The plant shows great potential demonstrating antimicrobial and antifungal abilities. It is known for its ability to suppress the ability of *Bacillus subtilis*, *Escherichia coli*, *Pseudomonas aeruginosa,* and *Candida albicans* to flourish [84]. The methanolic extracts of the leaves have also been shown to hinder the populations of *Staphylococcus aureus*, *Enterococcus faecalis*, *Pseudomonas aeruginosa*, *P. vulgaris,* and *Mycobacterium tuberculosis* [85]. Also, against the fungi that infect the dermis of the skin such as *Trichophyton rubrum,*

Table 3. Extract preparation and its modification.

No	Patent no	Title	Classification system	Assignee	Grant date	Ref.
1	CN118221617B	Method for removing other lactones in andrographolide	C07D307/60	Chengdu Tongde Pharmaceutical Co Ltd.	2024-07-23	[66]
2	CN218774333U	Andrographolide production extraction element	B01D11/02	Guangdong Ocean University	2023-03-31	[67]
3	CN218793918U	Andrographolide purification distillation retort	B01D3/00	Xi'an Arisun Chempharm Co ltd	2023-04-07	[68]
4	CN217313567U	Dried *A. paniculata* leaf crushing device	B02C18/14; B02C21/00; B02C4/02; B02C4/30; B02C4/42	Guangxi Jiajin Pharmaceutical Co Ltd.	2022-08-30	[69]
5	CN217330557U	*A. paniculata* drying device	B08B3/10; F26B11/18; F26B21/00; F26B25/0	Guangxi Jiajin Pharmaceutical Co Ltd.	2022-08-30	[70]
6	CN217313844U	A reducing mechanism for *A. paniculata* processing production	B02C23/02	Guangxi Jiajin Pharmaceutical Co Ltd.	2022-08-30	[71]
7	AU2021107020A4	A method for studying phytochemical, antioxidant, and antimicrobial activities and hptlc analysis for *A. paniculata* and *C. rosea*	A61K31/352; A61K31/365; A61K31/475; A61K31/575; A61K31/7048; A61K33/38; A61K36/19; A61K36/24; A61K9/51; A61P31/04; A61P31/10; A61P39/06; G01N30/90	Mausami, D.; Anil, K.; Shweta, P.; Ekta, S	2021-12-23	[72]
8	AU2021106073A4	A process for hptlc-based quantification of andrographolide in *A. paniculata*	G01N30/90; C07D307/60	Anil, K.; Rajeshwari, P. L.; Lutfun, N.; Nidhi, S.	2021-12-09	[73]
9	CN215558949U	A measurement filling device for *A. paniculata* lactone	B67C3/02; B67C3/22; B67C3/28	Sichuan Wenlong Pharmaceutical Co Ltd.	2022-01-18	[74]
10	CN215541656U	A reducing mechanism for *A. paniculata* processing production	B02C23/02	Sichuan Wenlong Pharmaceutical Co Ltd.	2022-01-18	[75]
11	CN113063883B	Method for simultaneously identifying 7 effective components in three-flavor *Bistorta* rhizome oral liquid	G01N30/06; G01N30/74	Wei, X.; Zhang, C.; Zhang, Z.; Li, Y.; Zheng, H.; Yang, Z.; Guo, T.; Ji, C.	2022-12-23	[76]
12	CN214047018U	A kind of vegetable soilless cultivation device of *A. paniculata*	A01G31/02; A01G31/06	Shanxi Agricultural University	2021-08-27	[77]
13	CN214597692U	A drug concentration device for *A. paniculata* injection production	B01D29/31; B01D29/64; B01D36/00; B65B3/12; B65B3/26	Luoyang Luoshen Pharmaceutical Co Ltd.	2021-11-05	[78]
14	CN214020595U	A kind of dissolving tank lid for producing andrographolide	B01F1/00; B01F15/00	Sichuan Wenlong Pharmaceutical Co Ltd.	2021-08-24	[79]
15	CN214051224U	A kind of stirring and mixing device for andrographolide production	B01F15/00; B01F15/02; B01F15/04; B01F7/04	Sichuan Wenlong Pharmaceutical Co Ltd.	2021-08-27	[80]
16	CN110896858B	Tissue culture method of *A. paniculata*	A01H4/00	Spaceflight (beijing) Food Technology Research Institute	2021-07-16	[81]
17	CN110896837B	High-quality and high-yield planting method for *A. paniculata*	A01G2/10; A01G31/00; A01G7/04; A01G7/06	Spaceflight (beijing) Food Technology Research Institute	2022-03-04	[82]
18	CN110585138B	*A. paniculata* granules and the preparation method thereof	A61K36/19; A61K47/26; A61K47/36; A61K9/16	Heilongjiang University of Chinese Medicine	2021-08-03	[83]

Candida albicans, Microsporum canis, and *Candida tropicalis*. Most of the available evidence comes from *in vitro* studies showing inhibition of bacteria and fungi, and limited clinical confirmation [86].

5.2. Antimalarial potential

A. paniculata has a long-standing history of traditional use in India for the treatment of malaria and has shown antimalarial properties in both *in vitro* and *in vivo* research. The primary active ingredient, andro-grapholide, has shown significant antiplasmodial effects, which encompass both blood schizonticidal and gametocytocidal activities against *Plasmodium berghei* with an IC_{50} value of > 32 µg/mL. As well as against *Plasmodium falciparum* by the xanthones obtained from the roots of the plant *in vitro* with an IC_{50} value of 4 µg/ml [87]. The extracts of the plant were seen to act in a manner that deterred the formation of haemozoin, countermanded the pore opening of mitochondria and re-instated its normal functioning along with the phospholipids of its membrane and enzyme dependent ATP-hydrolysis in the resistant *P. berghei* infected mice [88,89].

5.3. Anti-viral potential

Although there have been only a few specific researches on *A. paniculata* anti-HIV effectiveness, its immunomodulatory qualities point to possible advantages in HIV treatment. The medicinal ingredients in the plant may improve immunological responses, which is important for those living with HIV. *A. paniculata* can help the immune system fight viral infections by enhancing lymphocyte activity and regulating cytokine production [90]. HIV-1 and HIV-1 (UCD123) infection of H9 cells was prevented by dehydroandrographolide at 1.6 mg/mL and 50 mg/mL, respectively. HIV-1 infection of human lymphocytes was also inhibited at 50 mg/mL [91]. In cocultures of uninfected and HIV-1 infected MOLT cells, a methanolic extract of the leaves of *A. paniculata*, the bark of *Swietenia mahagon*, the stems and branches of *Loranthus parasiticus*, the fruit of *Helicteres isora*, the rhizomes of *Cucurma aeruginosa,* and the fruits of *Sindora sumatrana* inhibited the development of syncytia [median effective dose [ED_{50}] (70 mg/mL) [92]. Andrographolide is also known to deter the expression of HSV and Epstein-Barr virus (EBV). Preclinical evidence exists for the antiviral action. However, there have been no large, controlled, randomized studies [93,94].

6. Antidiabetic potential

Diabetes is a major disorder that is on the rise around the world. *A. paniculata* has long been used by the Ayurvedic and other systems of medicine for the treatment of madhumeh or diabetes. The plant showed considerable efficacy in curbing the disorder through increased sensitivity to insulin and decreasing glucose levels in the blood. The key bioactive compound Androgra-pholide has been noted to elevate the levels of GLUT-4 and NF-Kappa β expression that is responsible

for improving sensitivity to insulin. Another mechanism by which it operates is the stimulation of pancreatic cells for the release of insulin and the downregulation of the glucose metabolism enzymes such as alpha glucosidase and alpha amylase, which may decrease the rate of sugar absorption in hyperglycaemia-induced type 2 DM rats. The majority of evidence regarding its effect on the glucose transporter 4 (GLUT-4), nuclear factor kappa B (NF-Kappa β), mitogen-activated protein kinase (MAPK) and Janus kinase/ signal transducer and activator of transcription (JAK/STAT) pathways has been generated from preclinical mechanistic studies [95].

7. Hepatoprotective potential

The plant has been used since ancient times in herbal medications to relieve liver-related disorders. This activity is exhibited due to 14-deoxyandrographolide, neoandrographolide along with andrographolide. This has been scientifically validated by its ability to prevent liver diseases. Extracts of *A. paniculata* showed a protective effect in Sprague-Dawley rats against acetaminophen-induced hepatotoxicity by activating glutathione, catalase, and superoxide dismutase and acting against mitochondrial oxidative stress in a dose-dependent manner of 5 and 10 mg/kg [96]. Also, by the diminution of certain serum marker enzymes such as GPT (Glutamic-Pyruvic Transaminase), GOT (Glutamic-Oxaloacetic Transaminase), ALP (Alkaline Phosphatase), bilirubin, and restoration of the distorted hepatic tissue architecture, they showed protective effect against paracetamol induced liver toxicity in doses of 100 and 200 mg/kg [97]. The presence of the predominant diterpene lactones has exhibited antihepatotoxic activity against tertiary butyl hyperoxide and CCL_4–induced toxicity of the liver at concentrations of 25 and 50 mg/kg. *In vivo* animal studies have shown modulation of oxidative stress signalling pathways (Nrf2 (Nuclear factor erythroid 2-related factor 2), JNK (Jun N-terminal kinase), TNF-alpha). There are still not enough human data available to translate this into clinical studies [98].

8. Mechanism of hepatoprotective action

The primary bioactive component of *A. paniculata* has been studied in great detail for its role in protecting the liver from acetaminophen-induced damage. Chen *et al*., 2008 observed that acetamiophen (APAP) when administered to Sprague-Dawley rats at high doses of 640 mg/kg caused their liver cytochromes, primarily CYP2E1 and minutely CYP1A2 and CYP3A4, to metabolize excess of it into *N*-acetyl-*p*-benzoquinoneimine (NAPQI), which is a highly reactive intermediate and causes oxidative stress in hepatocytes s [99]. It leads to generation of reactive oxygen species (ROS) and reactive nitrogen species (RNS) which activates the stress related pathways such as p53 (Tumor protein), Nrf-2, FGF-2 (Fibroblast growth factor-2) and JNK signalling pathway [100]. Ye *et al*., 2011 studied the action of ROS on the TNF-α, which showed a prominent increase in mitochondria as a result of CCL_4-induced liver toxicity. Further analysis indicated TNF-α to increase JNK concentrations [101]. The JNK signalling pathway, in turn, causes the ROS in mitochondria to increase again activating the JNK pathway forming a never-ending loop. It also activates the Bax (BCL-2 associated X protein) protein which opens the MPT (Mitochondrial permeability transition) pore which causes the potential drop in the membrane which acts in 2 ways, firstly it causes the ATP concentration to decrease which brings about necrosis of the cell [102]. Secondly, it effectuates the translocation of certain mitochondrial proteins such as AIF (Apoptosis inducing factor) and Endo-G (Endonuclease-G) to the nucleus causing the fragmentation of DNA eventually leading to necrosis [103]. NAPQI also influences mitochondrial ETC complexes I and II. This leads to the release of electrons toward molecular oxygen causing the formation of superoxide radicals that combine with cellular NO (nitric oxide) and form RNS. The superoxide free radical is converted to hydrogen peroxide and molecular oxygen by the action of manganese superoxide dismutase (MnSOD). Now, the function of neutralizing these detrimental species lies with enzymes such as GSH (glutathione), CAT (catalase) and SOD. If GSH depletes, then RNS will get converted into a nitro-tyrosinase protein adduct and cause mitochondrial damage and ultimately necrosis. Mondal *et al*., 2022 reported that the APAP overdose induced toxicity of liver in Sprague Dawley rats was relieved by Andrographolide through hepatoprotective mechanism. He further studied the diminution of GSH levels due to the oxidative stress along with other stress enzymes such as SOD and CAT and Andrographolide at concentrations of 5 and 10 mg/kg has been found to be effective in forestalling necrosis [96]. The action was said to occur in three ways, firstly by neutralizing harmful free radicals, second through the activation of the antioxidant enzymes in the mitochondria, and finally by inhibiting pro-oxidant enzymes. Therefore, it inhibits hydrogen peroxide, ROS and RNS, which in turn is unable to activate JNK thereby breaking the loop of cyclic ROS production and, lastly, restocks GSH, CAT, and SOD concentrations that play a crucial role in the inhibition of necrosis due to DNA fragmentation (Figure 3) that is caused by stress in the endoplasmic reticulum [84].

9. Antioxidant potential

The plant is known to possess antioxidant properties due to the predominance of andrographolide (diterpenoid lactone) a major bioactive compound of the plant. This antioxidant potential of the plant has been investigated in many studies using 2,2-diphenyl-1-picrylhydrazyl (DPPH) scavenging activity, FRAP (Ferric Reducing Antioxidant Power) assay, lipid peroxidation assay, hydrogen peroxide (H_2O_2) and nitric oxide scavenging assay. The methanolic extracts of the plant have been shown to possess substantially higher antioxidant potential through the DPPH and H_2O_2 scavenging activities of 71.42±1.14% and 45.6±1.02%, respectively. The IC_{50} values of the *in vitro* antioxidant assays of DPPH, NO_2 scavenging, ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)), and lipid peroxidation assays were at 3.10±0.19, 214±2.08, 0.79±0.04, 74.33±2.85, respectively. The antioxidant activity of *A. paniculata* has been shown mainly *in vitro* through the use of chemical assays such as DPPH, ABTS, FRAP, nitric oxide scavenging, hydrogen peroxide scavenging, and inhibition of lipid peroxidation. Fewer studies have shown antioxidant enzyme modulation *viz*. SOD, CAT, GSH through *in vivo* animal models. However, evidence for clinical use in humans is sparse [98].

10. Anticancer potential

A. paniculata, especially its active component andrographolide, has shown anticancer properties in numerous studies. It triggers apoptosis, suppresses cell growth, and can affect lipid-dependent cancer pathways. Research has indicated that andrographolide is effective against various types of cancer cell. Extracts of *A. paniculata*, particularly andrographolide, possess the ability to suppress the proliferation of multiple cancer cell lines, such as those found in lung, leukemia, and colorectal cancers. This effect is associated with the promotion of apoptosis (programmed cell death) within cancer cells. The findings demonstrate that *A. paniculata* directly targets cancer cells to have anticancer effects, preventing the progression of cancer *via* modifying immune responses in the studies on LPS-stimulated RAW 264.7 cells, HepG2 cells, C57BL/6 mice carcinogen-induced oesophageal tumorigenesis. By preventing the synthesis of cytokines, growth factors,

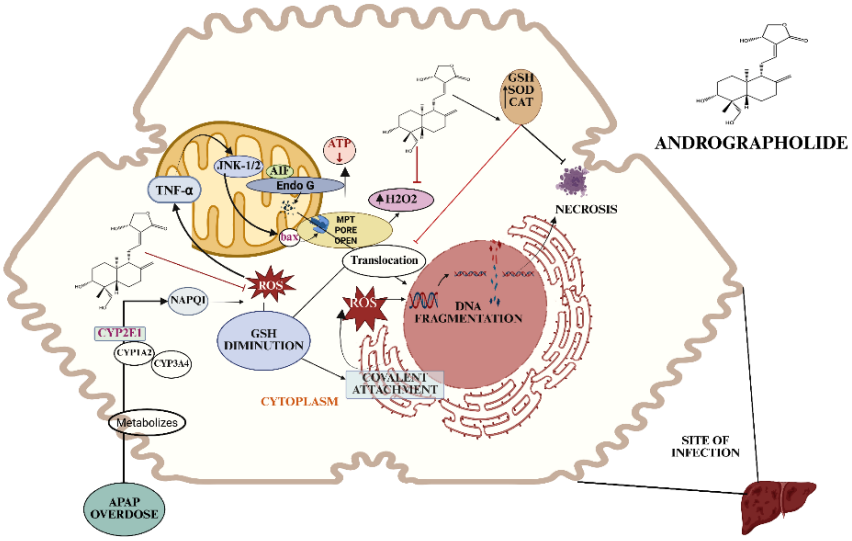

Figure 3. Hepatoprotective mechanism of action of Andrographolide (derived from *A. paniculata*) against acetaminophen induced toxicity of liver (Created in BioRender. Science, P. (2026) https://BioRender.com/36gdj5w).

and chemokines through the nuclear factor-kappa B (NF-θB), mitogen-activated protein kinase (MAPK), and Janus kinase (JAK)/signal transducer and activator of transcription (STAT) signalling pathways, *A. paniculata* has anticancer effects. Furthermore, by controlling inflammation as a result of interactions between cancer cells, immune cells, and stromal cells in the tumor microenvironment. Studies support the anticancer effects of *A. paniculata* with primarily andrographolide through the use of cancer cell lines (HepG2, RAW 264.7, leukemia, colorectal, and lung cancer). These anticancer effects have been repeated in many *in vivo* animal models by analysis of inhibition of tumor growth and induction of apoptosis. However, the number of well-designed clinical trials in cancer patients is very limited, with the majority of evidence being preclinical [104].

11. Anti-inflammatory potential

A. paniculata's anti-inflammatory properties are ascribed to its ability to suppress the expression of inflammatory markers, including E-selectin and intercellular adhesion molecule-1 (ICAM-1). In a rat model of lipopolysaccharide-induced sepsis, the extract of the plant significantly reduced these markers, emphasizing its protective effect against lung injury in a dose-dependent manner showing favorable results at 500 mg/kg [105]. The mechanism is the inhibition of pro-inflammatory mediators and cytokines, which are essential for the inflammatory response. The results of the experiment revealed that higher doses of the extract resulted in a notable decrease in inflammation, indicating a dose-dependent efficacy, underscoring the potential of *A. paniculata* as a therapeutic agent in the management of inflammatory conditions. It was shown that *A. paniculata* reduced the incidence of restenosis after experimental angioplasty and alleviated atherosclerotic artery stenosis caused by deendothelialisation and a high-cholesterol diet. Most studies on anti-inflammatory activity have used *in vitro* tests of cytokine suppression and modulation of the NF-κB pathway. Many *in vivo* animal models, *viz.* LPS-induced inflammation, sepsis, and atherosclerosis have demonstrated dose-dependent anti-inflammatory activity. While there is some clinical evidence, it is relatively limited and is associated with respiratory infections rather than chronic inflammatory conditions [106].

12. Immunomodulatory potential

A. paniculata possesses immunomodulatory properties that work with the immune system and enhance body immunity. Studies have shown that andrographolide, neoandrographolide, and dehydroandrographolide downregulate the cyclooxygenase (COX) enzyme. Other phytoconstituents of *A. paniculata*, such as skullcapflavone-1, 7-O-methylwoogonin, andrographolide, and neoandrographolide, also had immunomodulatory effects shown by a marked decrease in Prostaglandin E2 (PGE2) and T Box transcription factor 2 (TBX2) (inflammatory mediators) in promyleotic leukaemia cells. In addition, in LPS-stimulated macrophages, they caused the down-regulation of inflammatory cytokines such as NO, IL-6, and IL-1β [107]. Another study has shown andrographolides to be capable of regulating the generation of antibodies and the production of splenocytes that are specific to particular antigens, thus influencing the innate immune response, as well as having the ability to activate both the classical and alternative pathways for macrophage production. Its immunomodulatory activity has helped in the treatment of many autoimmune diseases, one of them being encephalomyelitis. The evidence for immune-modulation is derived mainly from laboratory studies looking at cells involved with the immune response, as well as studies on animals that evaluate the production of antibodies and the activation of different pathways in their immune systems. Although some clinical trials indicate an immunomodulatory effect, particularly in patients with upper respiratory tract infections, there have been few clinical trials that examined how this process works from a mechanistic point of view [108].

12. Conclusions

Andrographis paniculata is a notable herb that has a strong history in ancient medicine that has led to numerous herbal formulations in its name around the world. It has an established role as a hepatoprotectant, anti-inflammatory, and immune-modulator. Innovative patents have improved its extraction and formulation processes and led to improved medicaments. In addition to benefiting humans, it is also effective in treating animals as immunoprotectants and providing respiratory relief. It plays numerous roles as antiviral, antimalarial, antidiabetic, anticancer, anti-HIV, antioxidant, and many more. The ongoing

research and patent activity suggest that there are many unexplored avenues for *A. paniculata*, particularly in hybrid medicinal approaches and its incorporation into modern therapeutic practices. A synthesis of patent evaluations led to the identification of distinct themes and regions in relation to the innovation landscape of *A. paniculata*. Therapeutic focus is predominantly on applications for vaccine development (antiviral, anti-inflammatory, and dermatological), with an accelerated growth in vaccine-oriented formulations and immune supporters since the arrival of COVID-19. Applications in veterinary medicine (livestock-supporting immunities, aquaculture formulations, and poultry therapeutics) are also growing. In terms of technological advancement, continued growth in the various aspects of *A. paniculata* related to microencapsulation and controlled release matrices, hydrogel systems, and polymer-assisted delivery is seen as efforts to mitigate the inherent limitations of bioavailability associated with andrographolide. In addition, advances in extraction purification technologies and improvements in cultivation methods further demonstrate the international collaborative efforts toward standardization and increased yield. Most patent activity has been in China, followed by the United States, Korea, and Australia, indicating concentrated investment in research and development and intellectual property in these locations. Together, these trends indicate a progressive shift from the use of traditional crude extract forms of *A. paniculata* to the development of commercially driven and technologically advanced phyto-pharmaceuticals that are specific to specific applications. Although the density of patents reflects the momentum of innovation, this does not correlate with the presence of clinical proof of concept and the potential for superior therapeutic benefits, indicating a continuing need for alignment between research conducted in academic settings and clinical research. Some of the research that compared similar biological effects showed similarities and differences in outcomes. An array of studies, both *in vitro* and *in vivo*, examining the anti-inflammatory capabilities of extracts consistently suppress pro-inflammatory mediators, *viz.* TNF-α, IL-6, COX-2, and NF-κB signalling. However, there was variability in response between studies based on the type of extract and amount of extract administered, as well as the type of experimental model. The antioxidant capacity of the extracts was again evaluated by free radical scavenging assays, i.e. DPPH, ABTS, and FRAP and reported consistently, although IC_{50} values still showed marked variability based on solvent type used to obtain the extract and the concentration of the phytochemicals. In anticancer studies, while cell line studies confirm apoptosis induction by the extracts and cell-cycle arrest, the signalling mechanisms involved differ such as MAPK, JAK/STAT, PI3K/Akt, depending on the model used for the cancer under assessment. There were similar patterns of cytokine modulation in the immune-modulatory studies, yet variability in the immunological studies through the use of several immune cell types and varying doses administered limits the comparability of the studies. Together, these findings support the reproducible pharmacodynamic potential of extracts. However, they also necessitate the need for standardized extract preparations, harmonized method-logies, and well-designed comparative clinical trials [98,104,106,108]. There are many pharmacological applications of *A. paniculata* and there is much preclinical evidence supporting these applications, as well as an increasing number of patents for this herb. The continued advancement of the herb into a more therapeutic practice is based on the translation of existing scientific knowledge into clinical research. Future research efforts that focus on the development of standardized extracts, the measurement of the pharmacokinetics of the extracts and the conduct of properly designed and well-designed clinical trials create the basis for the successful integration of evidence-based *A. paniculata* into therapeutic regimens.

13. Present and future advances

The world is shifting towards a more herbal outlook that has minimum side effects and is as equally effective as modern medicine. *A. paniculata* resonates with this natural system of medicine. The current advances in *A. paniculata* focus on the research and development activities in recent years. There has been a great focus on exploiting the traditional application of the herb in a more scientific setting and putting it to better use for the human population as well as for livestock, as illustrated by patents on herbal formulations for alleviating ailments of the spleen and lungs [29]. Another one of its long-established uses is as a hepatoprotectant which is visible from the marketed formulations as a liver protectant [2]. Its conventional use as a reliever of respiratory infections has been put to use against SARS-CoV-2 and has led to its popularity after the COVID-19 pandemic [3]. Its use as an immunoprotectant along with its other benefits has led to more than 30 herbal formulations commercialized worldwide [15,30]. The technical advance-ments in crude extract that have occurred over the years have provided us with patents on the refined methods that increase the quality, quantity, and yield of *A. paniculata* with improved tissue culture methods and provide enhanced separation of bioactives such as andrographolide from other diterpene lactones and improved devices for crushing, drying, and purifying the plant. More fine-tuned methods that improve its bioavailability, such as microencapsulation, aim at improving the delivery of the drug through controlled release. Along with being useful to humans, various patents have refined its diversified use for vetenary purposes such as immunity enhancers, anticoccidial compositions, for flourishing bee colonies through feed, in treating arthritis in chickens, and as a pest attractant [26-83]. The market impact of *A. paniculata* is expected to increase to USD 92.1 million in 2025 at an impressive CAGR of 5.9 % for the years 2019-2033 [5]. As far as future perspectives are concerned, the recent patents published point toward ongoing research on various aspects of this herb, which may lead to improved formulations in the market in the near future. The current patents granted open new avenues in ideas such as microencapsulation in formulations, hybrid medicinal approaches in treating cancer, and a more focused approach towards its therapeutic use as a hepatoprotectant and immune protectant and their incorporation in modern medicine. Some patents in the field of skin care and dermatology, such as its use as a hydrogel and antidandruff shampoo that works well against *Malassezia furfur*, also highlight the potential of the plant in the field of dermatology [2,32,35]. Along with the improved methods brought forth by patents on extract preparation and cultivation, far-effective formulations will be introduced to the market that increase the impact of *A. paniculata* in all spheres. Therefore, emerging areas include nanoformulation strategies, hybrid medicinal systems that combine traditional and modern pharmacology, precision cultivation methods, and veterinary development [2,37,50,65, 77]. Innovation must therefore be accompanied by scientific validation to ensure safe and effective translation.

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Conceptualization: Ashun Chaudhary, Vipasha Sharma; Methodology: Ashun Chaudhary, Vipasha Sharma; Software: Ashun Chaudhary, Vipasha Sharma;

Validation: Vipasha Sharma; Formal Analysis: Vipasha Sharma; Investigation: Vipasha Sharma; Resources: Ashun Chaudhary, Vipasha Sharma; Data Curation: Vipasha Sharma; Writing - Original Draft: Vipasha Sharma; Writing - Review and Editing: Ruchika Kumari, Palak Thakur; Visualization: Vipasha Sharma, Ashun Chaudhary; Supervision: Ashun Chaudhary; Project Administration: Ashun Chaudhary.

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