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Bridging Traditional Knowledge and Modern Research: A Comprehensive Review of Four Medicinal Plants from Uttarakhand, India

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Abstract

Background: *Hypericum perforatum* L. (St. John's Wort), *Verbascum thapsus* L. (Great Mullein), *Stellaria media* (L.) Vill. (Star Chickweed), *and Urtica dioica* L. (Stinging Nettle) are significant plants in their respective families: *Hypericaceae*, *Scrophulariaceae*, *Caryophyllaceae*, and *Urticaceae*. These plants have long been utilised in traditional medicine due to their different bioactive compounds, which have been associated with multiple biological activities. The bioactive compounds present in these medicinal plants have been reported to work as sedatives, antioxidants, antimicrobials, anti-inflammatories, and other pharmacological activities, though several observations remain based on preliminary experimental studies. **Aim:** This review summarises the botanical characteristics, ethnobotanical uses, phytochemical composition and pharmacological properties of four notable plant species: *H. perforatum, V. thapsus, S. media,* and *U. dioica*. By examining these aspects, the review aims to present the ethnobotanical and pharmacological relevance of these plants in natural ecosystems and their potential applications in herbal medicine. **Methods:** The relevant information related to *H. perforatum, V. thapsus, S. media,* and *U. dioica* was obtained from various sources, including PubMed, Google Scholar, the National Institutes of Health (NIH), CABI Digital Library, eFlora of India, India Flora Online, and the India Biodiversity Portal. **Conclusion:** *H. perforatum, V. thapsus, S. media,* and *U. dioica* are significant plants used for culinary and medicinal purposes. Various studies focus on extracting bioactive compounds from these species using different techniques. Additionally, traditional ethnobotanical knowledge enhances the quality and quantity of these compounds, guiding their application in modern medicine and nutrition.

Major Findings: The review highlights the traditional knowledge of folk medicinal plants, identification and significance of bioactive compounds for therapeutic utilisation, and their potential applications in modern research. It further helps in bridging the gap between traditional practices and modern research and validates the efficacy of traditional remedies.

Keywords: Ethnopharmacology, Great Mullein, Star Chickweed, St John's Wort, Stinging Nettle, Traditional Medicine

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1. Introduction

India is recognised as a biologically rich country with considerable ethnic, cultural and floristic diversity. Since ancient times, tribal and rural communities inhabiting forest regions have utilised medicinal plants for food, fodder and various health-related services, resulting in the development of traditional ethnobotanical knowledge[1-2]. India has long been recognised for its medicinal plant diversity and associated traditional medicinal systems. According to the World Health Organisation (WHO) estimates, a substantial proportion of the global population depends on traditional medicine and herbal remedies

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for healthcare practices. Increasing interest in herbal products has also contributed to the expansion of the herbal medicine sector globally and in India[3]. Herbal medicines continue to play an important role in primary medicinal care in several developing countries because of their traditional acceptance, accessibility and comparatively lower economic cost[4]. However, continuous exploitation of medicinal plants and habitat disturbances have contributed to the gradual loss of biodiversity and associated traditional knowledge systems[5]. Ethnobotanical information related to medicinal plants has largely been documented through interactions with traditional healers and local communities[1].

Uttarakhand, located in the North-West Himalayan region of India, is well known for its rich forest cover and medicinal plant diversity. The region is mainly divided into Garhwal and Kumaon geographical zones and supports high floristic diversity associated with traditional medicinal practices[2]. The state possesses more than 5000 vascular plant species, among which a considerable proportion has medicinal importance. The region also supports diverse indigenous medicinal practices associated with local communities[6]. Owing to its diverse climatic and geographical conditions, Uttarakhand serves as a major region that supports medicinal plant resources for ethnomedicinal applications[7].

Review-based investigations on medicinal plants are important for summarising ethnobotanical uses, phytochemical constituents and pharmacological observations associated with traditionally utilised taxa. Such studies may contribute to a better understanding of ethnopharmacological applications and bioactive compounds reported from medicinal plants[8]. The selected medicinal plant species, including *Verbascum thapsus* L., *Stellaria media* (L.) Vill., *Urtica dioica* L., and *Hypericum perforatum* L. have been widely reported from Uttarakhand and adjoining Himalayan regions in previously published floristic and ethnobotanical studies. Information regarding traditional uses of these medicinal plants has been documented in published ethnobotanical literature from Himalayan communities.

Botanical descriptions summarised in the present review are based on previously published taxonomic and floristic accounts. Botanical descriptions summarised in the present review were compiled from previously published taxonomic and floristic references, including *V. thapsus*[9], *U. dioica*[10], *S. media*[11] and *H. perforatum*[12]. *Verbascum thapsus* has traditionally been utilised for respiratory and inflammatory disorders[13-14]. *Urtica dioica* is widely utilised in traditional medicine, food preparations and local medicinal practices in the Himalayan region[15]. *Stellaria media* has been traditionally used for respiratory, digestive and inflammatory conditions[16]. Studies also reported antimicrobial and other biological activities associated with the species[17]. *Hypericum perforatum* is recognised for its ethnomedicinal importance and diverse phytochemical constituents related to antidepressant, antimicrobial and pharmacological applications[18-19].

Although numerous studies have independently reported ethnobotanical and pharmacological properties of these medicinal plants, comparative critical evaluation of phytochemical diversity, levels of pharmacological evidence, and methodological limitations remains comparatively limited, particularly for Himalayan medicinal taxa.

Unlike previous species-specific reports, the present review comparatively integrates ethnobotanical applications, phytochemical diversity and pharmacological evidence associated with four medicinal plants frequently utilised in Uttarakhand and nearby areas.

2. Literature Survey and Methodology

The present review was conducted to compile and critically evaluate published information related to the ethnobotanical uses, phytochemical constituents, and pharmacological properties of *H. perforatum*, *V. thapsus*, *S. media* and *U. dioica* reported from Uttarakhand and adjoining Himalayan regions. Relevant information was collected from published scientific databases and online repositories, including PubMed, Google Scholar, NIH repository, ScienceDirect, CABI Digital Library, eFlora of India, India Flora Online and India Biodiversity Portal. Initially, approximately 200 records were identified through database searching and manual screening. Subsequently, articles published between 2000 and 2025 were selectively screened on the basis of title, abstract and relevance to ethnobotanical, phytochemical and

pharmacological aspects of the selected medicinal plants. Additional relevant publications were also reconsidered through backward searching of cited literature to avoid exclusion of important information sources. Duplicate, unrelated and incomplete reports were excluded during successive stages of screening. Finally, 65 relevant studies comprising ethnobotanical, phytochemical, pharmacological, botanical and review-based literature were included for comparative evaluation in the present review (Figure 1). Particular attention was given to distinguish information derived from traditional reports, *in-vitro* studies, experimental investigations and available clinical observations. Keywords related to phytochemistry, ethnomedicine, traditional uses, pharmacological activities and medicinal applications of the selected species were used during the literature search. Only English-language articles associated with medicinal, phytochemical, ethnobotanical and pharmacological aspects of the selected taxa were considered, whereas duplicate records, incomplete reports and unrelated studies were excluded from the analysis. Information obtained from the selected literature was comparatively evaluated to examine ethnobotanical applications, phytochemical diversity, pharmacological evidence and methodological limitations associated with the selected medicinal plants[20]. Particular attention was given to distinguish evidence derived from *in-vitro* assays, *in vivo* investigations and available clinical observations.

The plant names used in this study, [*Verbascum thapsus* L., *Stellaria media* (L.) Vill., *Urtica dioica* L., and *Hypericum perforatum* L.] have been verified using the "World Flora Online" database (accessed on January 26, 2025 and 17 November 2025, at www.worldfloraonline.org) to ensure accuracy.

3. Geographical Distribution and Botanical Description

3.1 Geographic Distribution

The plant species studied were distributed across different regions of the world. In India, *H. perforatum* is found in Jammu and Kashmir, the western Himalayan region, Himachal Pradesh, and Uttar Pradesh. *Verbascum thapsus* can be found in Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Haryana, Ooty, and Tamil Nadu. *Stellaria media* occurs in the Himalayan region, as well as in Himachal Pradesh, Uttarakhand, Uttar Pradesh, Maharashtra, Karnataka, Kerala, Tamil Nadu, Arunachal Pradesh, Assam, Bihar, Punjab, Sikkim, and West Bengal. *Urtica dioica* is present in Jammu and Kashmir, Himachal Pradesh, Uttarakhand, and West Bengal.

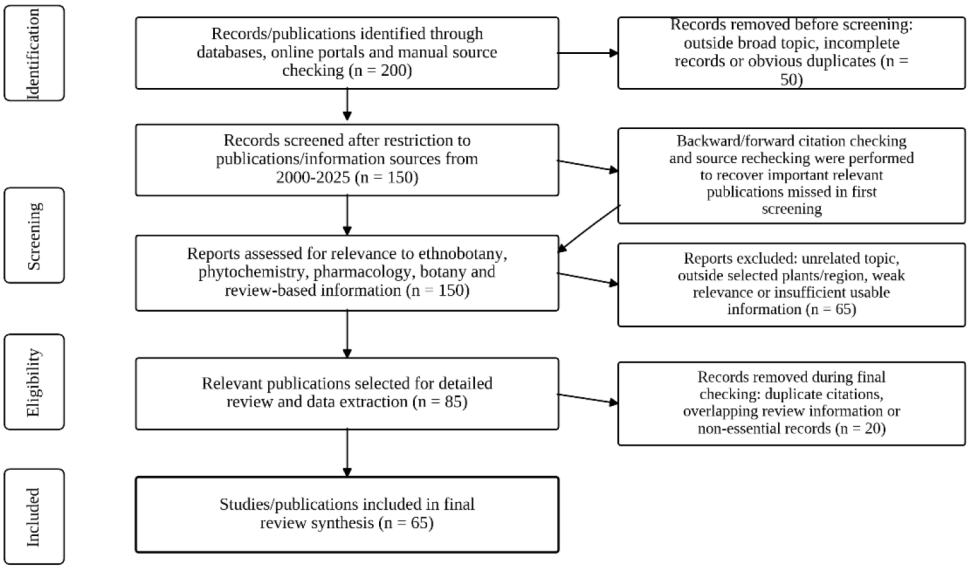


Figure 1. PRISMA flow diagram for selection of literature.

Common mullein is found in fields, grasslands, and along roads[21]. It also grows in rocky areas, woods, and barren lands[13-14]. This plant is native to central and western Asia, Europe, and northern Africa, but it has also been introduced as a medicinal herb in North America and Australia. *Urtica dioica* is distributed worldwide, except in certain regions of Antarctica. *Stellaria media* thrives best in damp areas, pasturelands, and lawns. *Stellaria* species inhabit regions of North America, Asia, Europe, and Africa [11], even at altitudes of up to 4,300 meters in the Himalayas 16. St. John's wort is found in various locations, including North Africa, Europe, Madeira, West Asia, the Azores, Australia, and North America. The species has been reported from habitats including roadside margins, grasslands, sparse forests, burnt areas and open landscapes[18-19].

3.2 Botanical and Ecological Description

The morphological characteristics and traditional information related to the selected plant species were compiled from published floristic literature and available ethnobotanical reports (Table 1 and Figure 2).

Verbascum thapsus (Great mullein) is a biennial herb characterised by an erect habit and woolly appearance[22-23]. During the first year of growth, the species commonly exhibits a basal rosette habit with bluish-green to greyish foliage, whereas flowering shoots developing during the second year may attain heights of up to 3m[22]. Yellow flowers are produced from June to September in dense terminal spikes[23-24]. The leaves are broad, oblong to oblanceolate and densely pubescent, while the fruit is represented by a capsule containing brown seeds[13-14].

Urtica dioica (stinging nettle) is a perennial herb bearing opposite, dark green leaves with serrated margins and abundant stinging trichomes on both surfaces. The stem is erect, fibrous and covered with hairs. The species possesses small unisexual flowers arranged in racemose inflorescences arising from upper leaf axils. Staminate and pistillate flowers differ morphologically, with female flowers containing a superior ovary[25].

Stellaria media (star chickweed) is an annual herb characterised by slender, weak stems and ovate leaves. The flowers are small, white and deeply lobed, while flowering generally occurs between May and October, and the species may attain a height of approximately 40cm under favourable conditions[11].

Hypericum perforatum (St. John's Wort) is characterised by erect, branched stems which are reddish near the base and attain heights of 40–100 cm[18-19]. Leaves are opposite, sessile and bear translucent glandular dots. Yellow flowers are borne in branched cymes and contain numerous stamens arranged in bundles[18].

Flowering generally occurs from June to September, followed by the formation of capsular fruits.

Ecological characteristics, habitat preferences and distributional features of the studied medicinal plants are comparatively summarised in Table 2.

4. Traditional Pharmacological Uses

The pharmacological activities discussed in the present review are based on previously published *in-vitro* investigations, animal-model studies and limited clinical observations. Several reported biological activities remain



Figure 2. Floral and vegetative morphology of different ethnobotanical plants collected from Uttarakhand, India.

Table 1. Comparative taxonomic, morphological and phytochemical characteristics of selected medicinal plants

Characters	*Verbascum thapsus*	*Urtica dioica*	*Stellaria media*	*Hypericum perforatum*
Family	*Scrophulariaceae*	*Urticaceae*	*Caryophyllaceae*	*Hypericaceae*
Habit	Biennial herb	Perennial herb	Annual herb	Perennial herb
Stem characters	Erect, woolly stem	Erect stem with stinging hairs	Slender, weak stem	Branched stem with glandular dots
Leaf characters	Alternate, broad, velvety leaves	Opposite, serrate leaves	Opposite ovate leaves	Sessile leaves with translucent glands
Flower characters	Yellow flowers in terminal spikes	Small greenish flowers	White bifid petals	Bright yellow flowers
Major phytochemicals	Verbascoside, aucubin, hesperidin, saponins	Flavonoids, tannins, sterols, lignans	Apigenin, gypsogenin, phenolics	Hypericin, hyperforin, quercetin, rutin
Diagnostic markers	Woolly leaves and dense inflorescence	Presence of stinging trichomes	Small white star-shaped flowers	Black glandular dots on petals and leaves

preliminary and therefore should not be interpreted as clinically established therapeutic applications. Comparative pharmacological observations and evidence levels associated with the selected medicinal plants are summarised in Table 3.

4.1 *Verbascum thapsus*

Verbascum thapsus has been investigated for different pharmacological properties using extracts prepared from flowers, leaves and roots. These plant parts have also been reported in capsule form in some studies[13,14,26]. The presence of bioactive compounds such as hesperidin and coumarin has been associated with reported biological activities[26]. Previous investigations have reported antioxidant, antimicrobial, anti-inflammatory and antiviral observations associated with *V. thapsus* extracts; however, most findings were derived from laboratory-based or preliminary experimental studies[24,26-30]. Studies have also suggested possible wound-healing potential associated with the plant extracts[13,14]. Some additional activities, including fungicidal, depressant, pesticide, estrogenic and sedative effects, have also been reported[24,31]. Nevertheless, controlled clinical validation for several traditional applications remains limited[26,32].

4.2 *Urtica dioica*

Urtica dioica has been investigated for various biological activities using roots, stems and leaves. Investigations have reported antioxidant, anti-inflammatory and antimicrobial activities associated with *U. dioica* extracts, although several observations remain preliminary[25,33,34]. Root extracts have been examined for possible activity related to prostatic hyperplasia, while leaf extracts have been studied for anti-inflammatory responses associated with rheumatoid arthritis. Cancer-related experimental observations associated with plant extracts have also been documented[35]. Pharmacological investigations associated with *U. dioica* include both *in-vitro* and *in-vivo* studies; however, only limited clinical evidence is presently available for several traditionally reported medicinal applications[25,36].

4.3 *Stellaria media*

Experimental investigations conducted on animal models suggested possible effects of *S. media* on glucose metabolism, oxidative stress and associated cardiac dysfunction[37,38]. Leaves contain SmAMP3 peptide, which has been associated with antifungal and antibacterial properties[39]. Possible anti-obesity observations associated with the whole plant have also been reported from animal-model studies[40]. In addition to its astringent and cooling effects[41], *S. media* has also been investigated for hepatoprotective activity[42]. Several biological activities reported for *S. media* were primarily supported through laboratory-based or animal-model investigations, whereas clinical validation remains insufficient[17,38].

Table 2. Comparative ecological characteristics of the studied plant species

Ecological Parameters	*Verbascum thapsus*	*Urtica dioica*	*Stellaria media*	*Hypericum perforatum*
Habitat	Roadsides, grasslands and rocky slopes	Moist nitrogen-rich soils	Damp gardens and cultivated lands	Open grasslands and disturbed habitats
Distribution	Europe, Asia and North Africa	Cosmopolitan	Temperate regions worldwide	Europe and temperate Asia
Altitudinal range	Up to ~3200 m	Lowland to montane regions	Up to ~4300 m	~800–2100 m
Soil preference	Well-drained rocky soils	Moist fertile soils	Nutrient-rich moist soils	Mesic to moderately dry soils
Light preference	Open sunlight	Partial shade	Shade tolerant	Open light conditions
Ecological role	Pioneer species	Nutrient cycling species	Ground cover species	Pollinator-supporting species

4.4 *Hypericum perforatum*

Hypericum perforatum has been investigated for pharmacological activities related to psychological disorders, wound healing, inflammation and antimicrobial responses. Some traditional and experimental reports have discussed possible applications of *H. perforatum* in severe pathological conditions; however, strong clinical validation remains limited for several therapeutic claims[18,19]. Compared with the other reviewed taxa, *H. perforatum* possesses comparatively stronger clinical documentation, particularly regarding antidepressant applications; however, additional standardised investigations are still required for several other therapeutic claims[43].

5. Ethnobotanical Uses

Ethnobotanical knowledge associated with medicinal plants has traditionally been preserved through local communities, oral transmission and indigenous medicinal practices in both Indian and European regions[44,45]. In Uttarakhand, rural communities continue to utilise medicinal plants for health, food, fodder and cultural practices. The ethnobotanical uses of the selected species are summarised below.

5.1 *Verbascum thapsus*

In traditional practices, *V. thapsus* has been used for cultural, household and medicinal purposes. Historically, the Romans and Greeks utilised this plant as a candle during funerals and sacred ceremonies. In Ireland and Rome, it has been known as "lungwort" due to its traditional use in lung-related ailments in humans and livestock. Fresh mullein leaves have been used traditionally for headaches, ear pressure, earache and burns. Leaves have also been used for piles, tumours, and ulcers, while tea prepared from the plant has been used for coughs, diarrhoea and chest or abdominal discomfort. Mullein has also been used as a herbal substitute for tobacco. The plant juice has been used for rough warts, and dried root powder has been used for toothaches and cramps[46]. Flower extract mixed with hot water has been used as a natural dye, while leaves have been used traditionally for insulating shoes. The aerial parts, including leaves and flowers, have also been used in folk practices for inflammatory skin conditions and wound care. In antiquity, mullein served as a home remedy for migraines, pneumonia, congestion, fevers, allergies, throat ailments, catarrh, tonsillitis, colic and skin disorders[21].

5.2 *Stellaria media*

Ethnopharmacologically, *S. media* has been utilised for different household and folk medicinal applications. The plant has been commonly employed for coughs, throat infections, fevers, colds, gastrointestinal infections and diarrhoea. The whole plant has been used as a plaster for broken bones and swellings. Porridge prepared from its leaves has been used traditionally for respiratory and gastrointestinal disorders. Dried leaves have been processed into pills or powders for traditional use. Use of the species for arthritis and bronchitis has also been documented[47]. The porridge prepared from leaves has also been applied to wounds

Table 3. Comparative phytochemical constituents and reported pharmacological observations of selected medicinal plants

Species	Major Phytochemicals	Reported Pharmacological Observations	Evidence Level
Verbascum thapsus	Verbascoside, aucubin, hesperidin, coumarins, saponins	Antioxidant, antimicrobial and anti-inflammatory observations	Mainly *in vitro* and experimental studies
Urtica dioica	Flavonoids, sterols, tannins, phenolics, lignans	Antioxidant, antihyperglycaemic and anti-inflammatory observations	Experimental and limited clinical evidence
Stellaria media	Apigenin, gypsogenin, flavonoids, phenolics	Hepatoprotective, antimicrobial and anti-obesity observations	Preliminary experimental studies
Hypericum perforatum	Hypericin, hyperforin, quercetin, rutin	Antidepressant, antimicrobial and wound healing observations	Experimental and clinical studies

and used to reduce bleeding. Leaves, stems, and roots have been used in plasters for swelling and bone-related conditions. Decoction of *S. media* has been used for menstrual pain and skin itching[48]. Juice prepared from *S. media* has traditionally been used for liver and gallbladder-related complaints[49]. During winter, *S. media* accumulates carbohydrates such as stellariose, raffinose and lychnose, which may contribute to its seasonal physiological properties[50].

5.3 *Hypericum perforatum*

Hypericum perforatum has been widely used in folk medicine for psychological and inflammatory conditions, particularly mild to moderate depression[51]. Traditionally, it has been taken orally for neuralgia, anxiety, excitability, fibrositis, dermatological problems and sciatica. Oil extracted from the plant has been commonly used for minor burns and injuries, while dried extracts have been used in capsules and tablets. The raw plant material has also been prepared as tea. In traditional Chinese medicine, *H. perforatum* has been used for hemoptysis, metrorrhagia, traumatic haemorrhages, hematemesis, jaundice, urinary tract infections, acute mastitis, irregular menstruation, eye pain, sore throat, painful furuncles and rheumatic arthritis. Ancient Greek physicians used the plant for menstrual cramping, snake or reptile bites, gastrointestinal distress, superficial wounds, sciatica and ulcers. Its utilisation in depression and nervous disorders is also documented[52]. In Islamic traditional medicine, *H. perforatum* has been used for menstrual regulation, gout-related complaints, fever, haemorrhoids, urinary stones, polydipsia, jaundice and swelling[43,53].

5.4 *Urtica dioica*

Urtica dioica has been used both as a food plant and as a traditional household medicinal resource. It is commonly prepared as soup, curry or vegetable in different communities. Traditionally, it has been used for sciatica, dandruff, haemorrhoids, diabetes, coughs, fevers, diarrhoea, asthma, prostate-related complaints, eczema, gout, snake bites, nosebleeds, tuberculosis, scurvy and anaemia. In traditional practices, nettle has also been used for post-calving care in livestock, neck soreness, sprains, fractures, yolk sores and hematuria[25]. Leaves have been used traditionally for external and internal bleeding and vaginal discharge, and in several Balkan countries, they have been incorporated into folk remedies. Nettle tea has been used during fevers, and fresh nettle juice has been used traditionally to control bleeding from internal organs, including lungs and nose. Alcoholic extracts of *U. dioica* have been used in traditional practices for cholecystitis, chronic hepatitis, habitual constipation and cholangitis. The plant is also consumed as a vegetable, supporting its culinary and ethnobotanical importance[33]. Comparative ethnobotanical applications and traditional preparations associated with the selected medicinal plants are presented in Table 4.

6. Phytochemical Compositions

Medicinal plants contain diverse phytochemical constituents associated with different biological activities and traditional medicinal applications. The selected medicinal plant species, including *V. thapsus*, *S. media*, *U. dioica* and *H. perforatum*, possess various

bioactive compounds distributed in different plant parts such as roots, stems, leaves, flowers and bark (Figure 3 and Tables 1 and 3). Previously published studies have reported flavonoids, phenolic acids, glycosides, alkaloids, tannins, terpenoids and other phytochemical constituents associated with these species[17,25,26,53,54]. Ursolic acid and related triterpenoid compounds reported from these medicinal plants have been associated with different pharmacological observations, including anticancer-related activities investigated under experimental conditions[55]. Differences in phytochemical composition among the selected taxa may contribute to variation in their reported biological activities. Quercetin reported from the selected medicinal plants has been associated with antioxidant, antimicrobial and cardioprotective activities in previous experimental investigations[56-58]. ß-sitosterol identified in some of the selected medicinal plants has been worked out for different pharmacological activities, although additional studies related to toxicity, clinical validation and therapeutic standardisation are still required[59,60].

The bioactive constituents derived from *H. perforatum* include a diverse array of compounds associated with reported biological activities. Among these, flavonoids and tannins stand out for their antioxidant qualities, while anthracene-quinone derivatives, specifically naphthodianthrones, are noted for their distinctive chemical structure and reported biological effects. The plant also contains prenylated phloroglucinols and volatile oils that may contribute to reported pharmacological observations. Notably, the tetraketone compounds present in *H. perforatum* have demonstrated antibacterial properties. One of the most researched compounds is hyperforin, associated with antidepressant activity[18]. Other important bioactive compounds include adhyperforin, rutin, chlorogenic acid, quercitrin hydrate, quercetin, hyperoside, and quercitrin[19]. Among these, hypericin (Figure 4) and hyperforin have been specifically shown to exhibit antibacterial properties, further emphasising the importance of *H. perforatum* in biological activities[61].

Verbascum thapsus (mullein) contains various bioactive compounds that contribute to its medicinal properties[62]. Among these are saponins, which are known for their potential health benefits. The plant contains essential carbohydrates and several flavonoids, including methylguercitin, hesperidin, and verbascoside (Figures 5 and 6), which are known for their anti-inflammatory and antioxidant effects. Additionally, *V. thapsus* is a source of phenolic acids and phenylethanoid glycosides that may play a role in various biological activities[31]. Coumarin, a compound with anticoagulant effects, is also present, along with carotenoids that provide antioxidant properties. It is also rich in proteins, phenylpropanoid glycosides, and a unique tetra glycoside. The plant also contains a significant amount of vitamin C, which has significant nutritional relevance. The presence of lignins and tannins contributes to its structural integrity and potential health benefits, while saponins offer additional therapeutic properties. Moreover, the plant is known to contain iridoids, including iridoid glycosides such as harpagoside, harpagide, and aucubin, particularly concentrated in its leaves[31]. The presence of bioactive compounds, including minerals, terpenes, triterpenes, and sesquiterpenes, indicates the phytochemical diversity in *V. thapsus*, and their use in herbal medicine and traditional therapies[13,14,26].

Table 4. Comparative ethnobotanical applications and traditional medicinal uses of selected medicinal plants

Species	Plant Parts Used	Traditional Uses	Traditional Preparation	Evidence Level
Verbascum thapsus	Leaves, flowers, roots	Asthma, cough, burns, wounds, arthritis	Herbal tea, ointment, decoction	Mainly traditional and preliminary experimental studies
Urtica dioica	Leaves, roots, stems	Rheumatism, diabetes, anaemia, hypertension, arthritis	Soup, decoction, extracts	Experimental studies with limited clinical evidence
Stellaria media	Whole plant, leaves	Wounds, obesity, cough, swelling, and respiratory disorders	Paste, decoction, porridge	Mostly preliminary experimental studies
Hypericum perforatum	Flowers, aerial parts, oil	Depression, burns, wounds, anxiety, inflammation	Herbal tea, oil, capsules	Experimental and limited clinical evidence

Urtica dioica contains various bioactive compounds that have been reported for essential biological activities. Among these are phytosterols, flavonoids, amino acids, saponins, tannins, phenolic compounds, alkaloids, lignans, sterols, fatty acids, terpenoids, triterpenes, ceramides, and coumarins[25,33]. Notably, the interaction with *U. dioica* can lead to skin inflammation, which is primarily triggered by biochemical compounds such as acetylcholine and histamine present in the plant[25].

The extract from *S. media* similarly contains various bioactive compounds. It boasts flavonoids noted for their wound healing and antioxidant properties, primarily attributed to the presence of vincenin-2 and apigenin[63]. Additionally, triterpenoids found in the plant, particularly the triterpenoid saponin known as gypsogenin, are recognised for their antioxidant and hepatoprotective effects. The plant is also a source of various phenolic acids, including caffeic acid, vanillic acid, chlorogenic acid, and ferulic acid, which have been reported for health benefits[17]. High Performance Thin Layer Chromatography (HPTLC)-based phytochemical characterisation has also been reported for *S. media* extracts[64]. Additionally, bioactive compounds present in *S. media* include gamma-linolenic acid, beta carotene, flavonoids, phenols, triterpenoids, and beneficial lipids, supporting its ethnopharmacological importance.

Comparative evaluation of the selected medicinal plants indicated considerable variation in ethnobotanical utilisation, phytochemical diversity and pharmacological evidence among the studied taxa. *Hypericum perforatum* and *U. dioica* showed comparatively broader pharmacological documentation, including limited clinical investigations, whereas *V. thapsus* and *S. media* were mainly represented through ethnobotanical records and preliminary experimental studies. The reviewed species also differed in dominant phytochemical constituents, including flavonoids, phenolic acids, terpenoids, glycosides, tannins and antimicrobial peptides, which may contribute to differences in their reported biological activities. Such comparative observations suggest that integration of ethnobotanical knowledge with phytochemical and pharmacological investigations may improve understanding regarding the therapeutic significance of Himalayan medicinal plants.

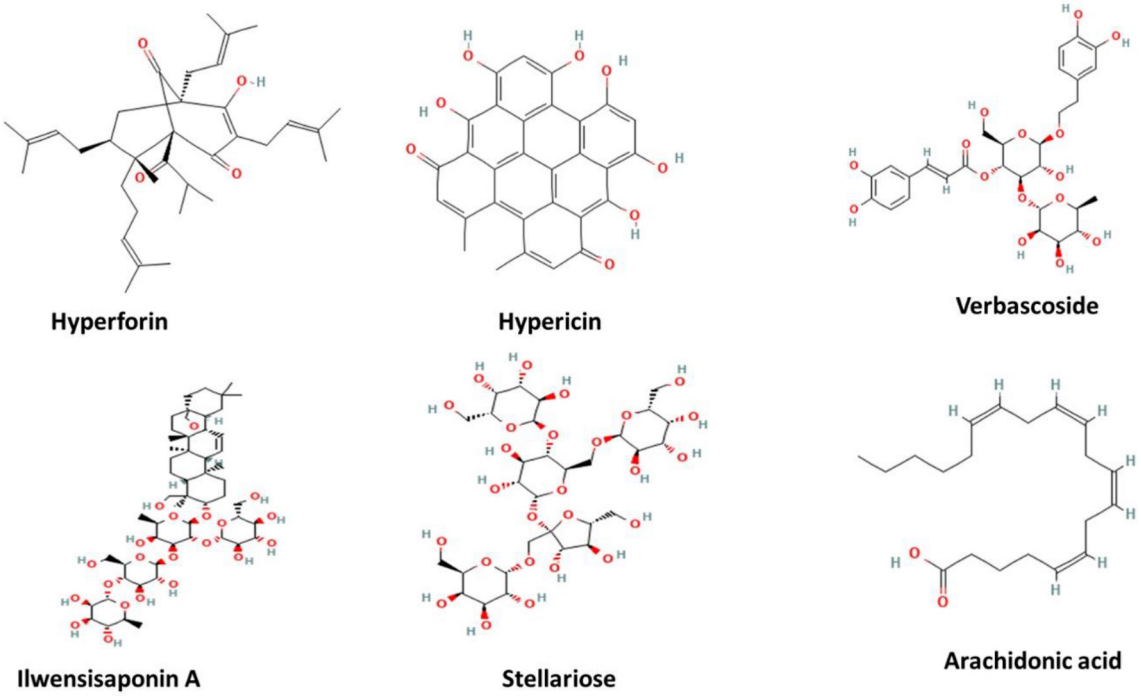


Figure 3. Molecular structure of marker compounds in different plant species: *Hypericum perforatum, Stellaria media, Urtica dioica,* and *Verbascum thapsus*.

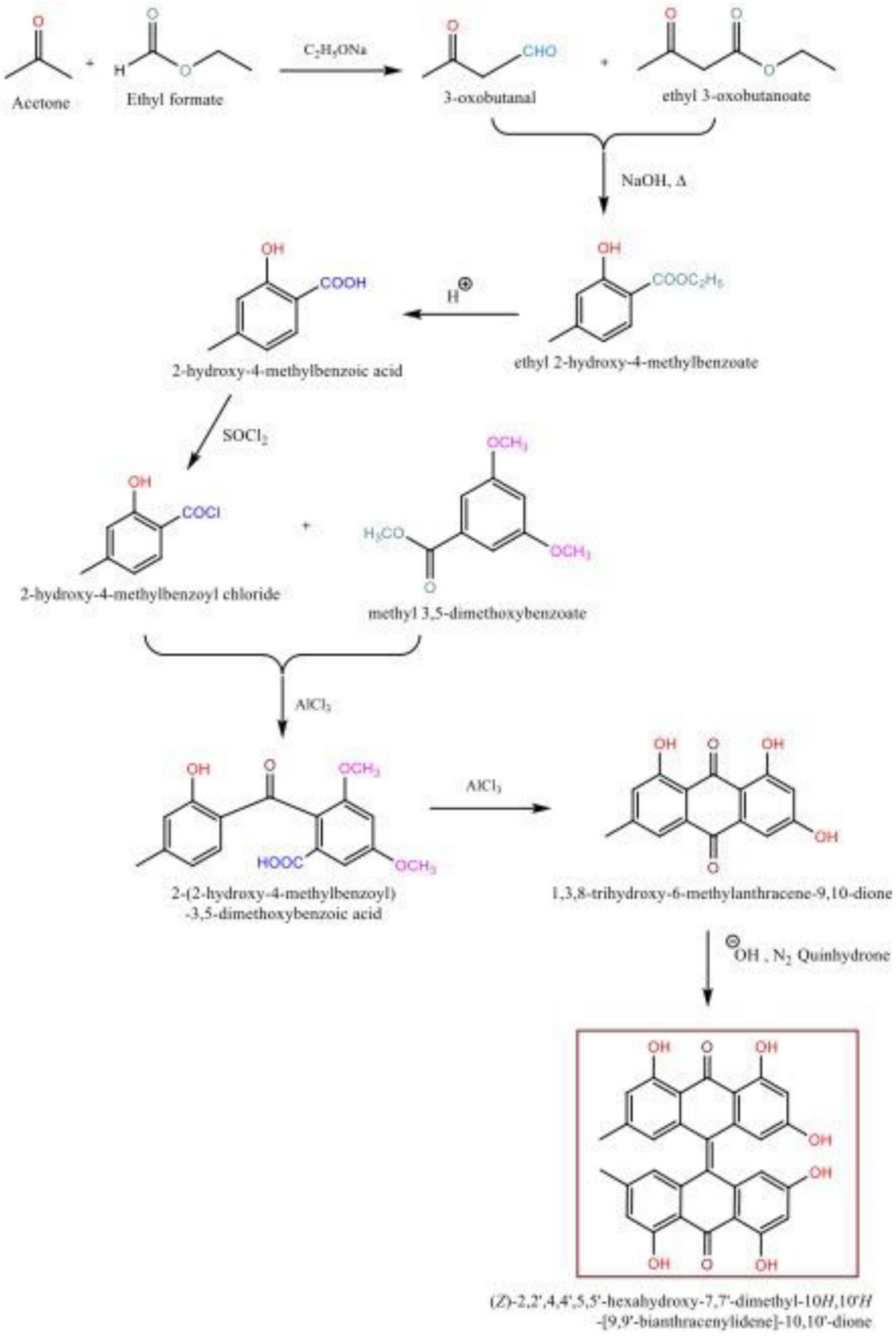


Figure 4. Proposed synthetic route map of marker compound: Hypericin.

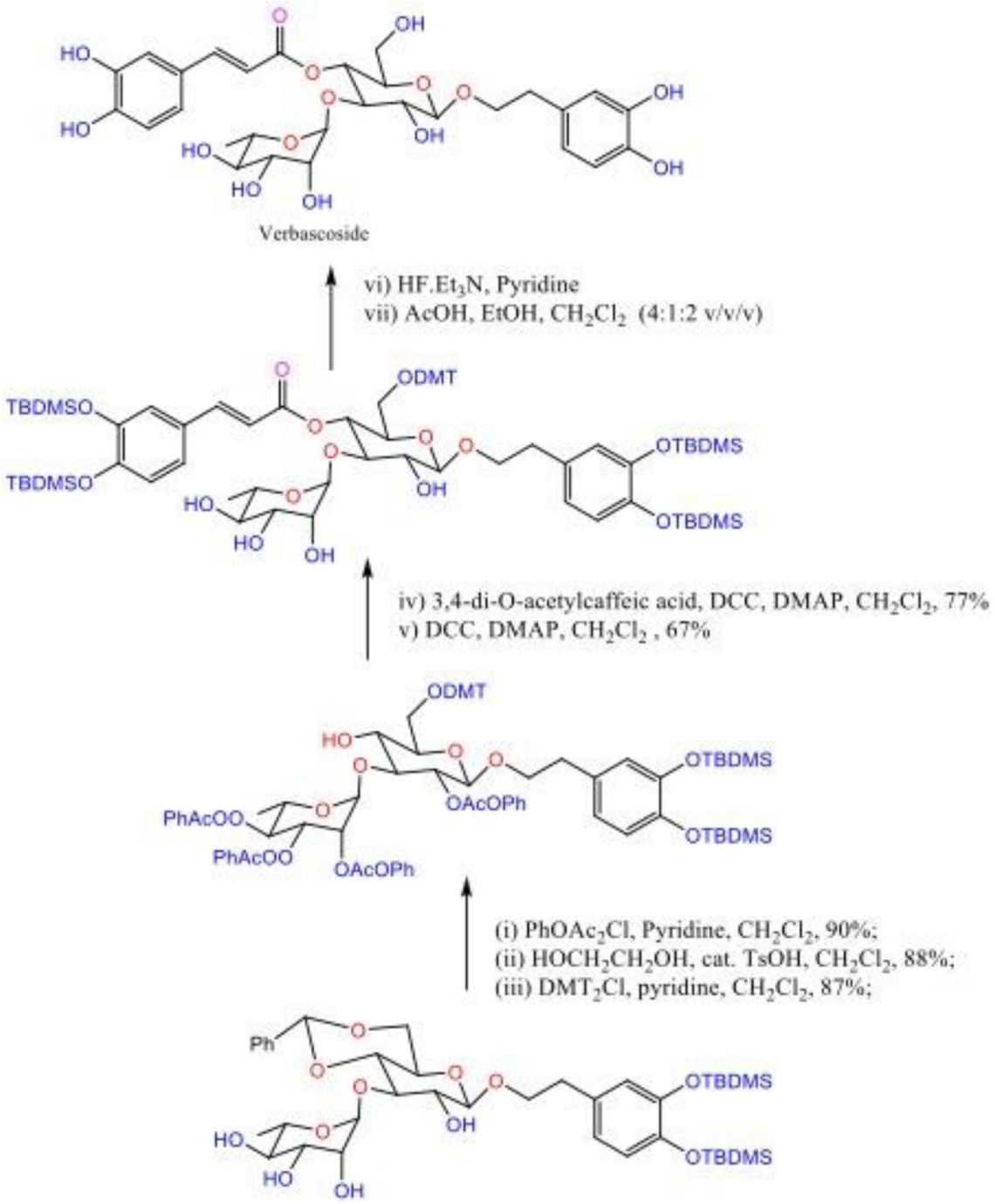


Figure 5. Proposed synthetic route map of marker compound: Verbascoside.

7. Critical Evaluation of Pharmacological Evidence, Limitations and Research Gaps

The present review revealed considerable variation in the level of pharmacological evidence available for the selected medicinal plants. Regardless of the ethnobotanical and pharmacological information known for these plants, the strength of evidence remains uneven among different taxa and biological activities. Most pharmacological observations reported in the literature were derived from *in-vitro* assays or preliminary experimental studies, whereas controlled clinical validation remains

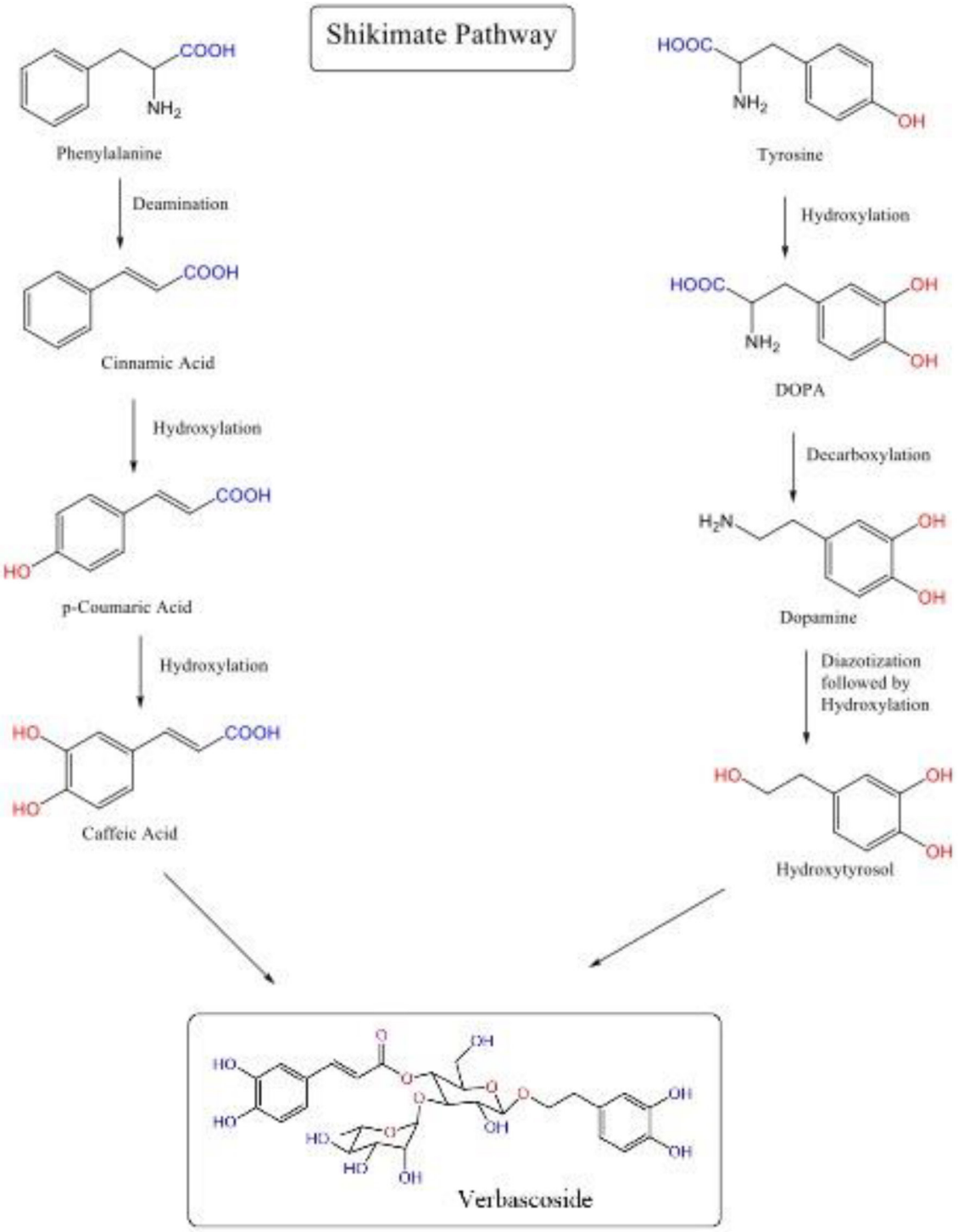


Figure 6. Biosynthetic pathway of verbascoside via the shikimate-derived phenylpropanoid and tyrosine pathways.

comparatively limited for several traditional therapeutic claims. Considerable variation was observed among pharmacological investigations because of differences in extraction procedures, plant parts utilised, phytochemical composition, experimental models and analytical methods. Such methodological differences make direct comparison among studies difficult and indicate the necessity for standardised pharmacological and phytochemical investigations. In several reports, biological

activities observed under laboratory or experimental conditions were not supported through adequate clinical validation, indicating the need for cautious interpretation of certain traditional therapeutic claims. Traditional ethnomedicinal applications associated with wound healing, respiratory disorders, rheumatism and gastrointestinal ailments have repeatedly been documented from Himalayan communities; however, several traditional claims still require controlled pharmacological and clinical validation. Future investigations should therefore focus on standardised extraction procedures, comparative phytochemical profiling, dose-dependent pharmacological validation, toxicity assessment and multicentric clinical studies. Integration of traditional ethnobotanical knowledge with experimental pharmacology may substantially improve the scientific utilisation and conservation of Himalayan medicinal plants. Additionally, studies related to seed germination, cultivation practices and propagation strategies are also required for the sustainable utilisation and conservation of medicinal plant resources[65].

8. Conclusion

Systematic cultivation and conservation strategies are necessary for the sustainable management of medicinal plant diversity in Uttarakhand. Traditional ethnomedicinal knowledge associated with these plants has largely been transmitted orally through local communities and traditional healers, and therefore remains vulnerable to gradual loss. At the same time, excessive and unregulated extraction of medicinal plant resources has contributed to the depletion of natural populations and associated biodiversity. Increasing national and international demand for herbal products has enhanced the economic importance of medicinal plant cultivation. In this context, scientific cultivation, sustainable harvesting practices and proper marketing strategies may support livelihood opportunities for local communities. Improved awareness regarding cultivation methods, market requirements and utilisation of herbal products may further support rural economic development. Although substantial ethnobotanical and pharmacological information is available for these medicinal plants, several traditional claims still require experimental validation. Additional research is also necessary for the standardisation and improvement of cultivation practices aimed at enhancing both biomass production and bioactive constituent yield. Integration of traditional ethnobotanical knowledge with scientific strategies may contribute to long-term conservation and sustainable utilisation of medicinal plant resources in the Himalayan region.

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Author Contribution

Poonam Kumari: Writing – original draft. Santosh Joshi: Supervision, Prabhjot Kaur: Conceptualisation and Validation. Ranjit Singh: Software (Designing synthetic pathway route maps). All authors have read and agreed to the published version of the manuscript.