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Medicinal Plant Diversity and Traditional Healthcare Knowledge in the Trans-Himalayan Cold Desert of Ladakh, India

Vaneet Jishtu[1]* and G.S. Goraya[2]

[1]*ICFRE-Himalayan Forest Research Institute, Conifer Campus, Panthaghati, Shimla 171 013, India*

[2]*PCCF and HoFF Himachal Pradesh Forest Department, Talland, Shimla 171 001, India*

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Abstract: The Trans-Himalayan cold desert of Ladakh, situated in the western Indian Himalaya, represents one of the most ecologically extreme yet biologically significant high-altitude landscapes. Characterized by high elevations, low precipitation, intense solar radiation, prolonged winters, and short growing seasons, the region supports a fragile ecosystem where vegetation is sparse but highly specialized. Despite these harsh environmental conditions, Ladakh harbours considerable floristic diversity, with nearly 500 plant taxa reported to be used in traditional healthcare systems, highlighting its importance as a reservoir of ethnomedicinal knowledge and plant genetic resources. Traditional medicinal knowledge, preserved and practiced for centuries by indigenous communities, continues to play a central role in primary healthcare, particularly in remote settlements where modern medical services remain limited. The traditional Sowa Rigpa (Amchi) system of medicine relies extensively on locally available plant resources to treat respiratory ailments, digestive disorders, musculoskeletal problems, altitude-related illnesses, and chronic diseases. Ethnobotanical studies indicate that families such as Asteraceae, Lamiaceae, Ranunculaceae, Fabaceae, and Apiaceae dominate the medicinal flora, with herbaceous species and leaf-based preparations being most common. Several high-value species, including *Aconitum heterophyllum*, *Dactylorhiza hatagirea*, *Podophyllum hexandrum*, *Rheum* spp., *Rhodiola* spp., and *Saussurea costus*, exhibit significant pharmacological potential. However, medicinal plant resources face growing threats from climate change, habitat degradation, overharvesting, and rapid socio-economic transitions. Conservation initiatives led by regional institutions and community participation are promoting documentation, cultivation, and sustainable management of these valuable resources. This review synthesizes historical, ethnobotanical, pharmacological, and conservation studies to provide an integrated understanding of medicinal plant diversity in Ladakh, emphasizing its significance for local healthcare, biodiversity conservation,

***Correspondence**
Vaneet Jishtu
vjishtuv@gmail.com

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and future pharmacological research in the Trans-Himalayan region.

Key words: Ladakh, Trans-Himalaya, cold desert, medicinal plants, ethnobotany, Sowa Rigpa, conservation, traditional knowledge, conservation.

The Trans-Himalayan region of Ladakh was designated as a Union Territory on 5 August 2019 following its separation from the former state of Jammu and Kashmir. The region comprises two districts, Leh and Kargil, covering an area exceeding 78,000 km² and extending between 32°15′50″-35°38′11″ N latitude and 75°36′73″-78°31′11″ E longitude. Elevations range from approximately 2,700 to 7,560 m above mean sea level, with most inhabited areas situated above 4,200 m (Raj, 2013; Dawa *et al*., 2022). Popularly known as the "Land of High Passes," Ladakh represents one of the world's most extreme and ecologically distinctive cold desert landscapes (Fig. 1). Located in the northwesternmost part of the Indian Himalaya, the region accounts for nearly 90% of India's cold desert area (Jishtu and Goraya, 2020).

Ladakh occupies a unique biogeographical position as one of the highest inhabited regions on Earth, with human settlements occurring at elevations of up to 5,500 m (Buth *et al*., 1998). The region is characterized by high altitude, prolonged winters, short growing seasons, intense solar radiation, low precipitation, wide diurnal temperature fluctuations, and rugged mountainous terrain (Juyal, 2014; Gaur *et al*., 2024). These environmental constraints create a harsh and fragile ecosystem in which vegetation remains sparse, highly specialized, and unevenly distributed across the landscape (Stewart, 1916; Kala and Mathur, 2002; Shukla and Srivastava, 2020; Jishtu and Goraya, 2020). Until the late twentieth century, many parts of Ladakh remained relatively inaccessible, resulting in limited floristic exploration (Kachroo *et al*., 1977). Systematic botanical investigations gained momentum only during the twenty-first century (Klimeš and Dickoré, 2005, 2006; Zargar *et al*., 2023; Banoo *et al*., 2025a).

Despite its extreme environmental conditions, Ladakh supports a remarkably diverse assemblage of plant species that have evolved distinctive morphological, physiological, and biochemical adaptations enabling survival under high-altitude stress (Thomson, 1852; Stewart, 1916; Kaul, 1997; Murti, 2001; Saxena *et al*., 2018; Hussain *et al*., 2023; Ali and Vyas, 2025). A recent floristic account by Shukla and Srivastava (2020) documented 1,085 flowering plant species belonging to 370 genera and 74 families in Ladakh. Of these, 808 species representing 283 genera and 62 families are dicotyledons, whereas 277 species under 87 genera and 12 families belong to monocotyledons. The flora represents an important transition zone between Himalayan and Central Asian phytogeographical regions and provides essential plant resources that have sustained indigenous healthcare traditions, particularly the Amchi (Sowa-Rigpa) system of medicine practiced by local communities. Herbal remedies derived from locally available plants are commonly used to treat ailments such as fever, respiratory disorders, digestive problems, musculoskeletal pain, skin diseases, and health complications associated with high-altitude living.

The use of medicinal plants in Ladakh dates back to early human habitation, with traditional medical knowledge rooted in cumulative empirical observations of healers and communities and transmitted orally across generations (Tsering, 2008; Jamshidi *et al*., 2018; Nath *et al*., 2023). One of the earliest scientific documentations of Ladakh's medicinal flora was provided by Abrol and Chopra (1962), who highlighted the region's rich biodiversity and its utilization in traditional remedies. Rizvi (1999) further emphasized the historical importance of medicinal plants as trade commodities exchanged along trans-Himalayan trade routes linking Ladakh with Tibet, Central Asia, and the Indian plains. Medicinal and aromatic plants were traded alongside salt, wool, tea, and grains, illustrating the deep integration of botanical knowledge within local economies and survival strategies. Traditional Amchi medicine relied extensively on both locally collected and traded plant materials, although the decline of caravan trade and changing geopolitical boundaries significantly altered their accessibility and distribution networks. Medicinal plants continue to represent a major component of the biological resources of the Trans-Himalaya, with several species being endemic or near endemic (Rawal *et al*., 2013). Estimates suggest that more than half of the regional flora possesses documented medicinal

properties (Singh and Chaurasia, 2000; Kala, 2005; Kumar *et al*., 2011; Thaneshwari and Mehdi, 2021; Jishtu and Goraya, 2020, Jishtu *et al*., 2023; Batool, 2023; Gurmet *et al*., 2025).

Indigenous communities of Ladakh have historically depended on medicinal plants as their primary healthcare resource, particularly in remote settlements where modern medical facilities remain limited or seasonally inaccessible (Jishtu and Goraya, 2020; Hadi *et al*., 2022; Gurmet *et al*., 2025). This knowledge system has evolved through centuries of close interaction with the mountain environment and has been carefully preserved through intergenerational transmission. Medicinal plants are used for treating common ailments, chronic diseases, injuries, and high-altitude-related health problems, including respiratory disorders, digestive disturbances, joint pain, and cold-related illnesses. Species such as *Rhodiola rosea*, *Hippophae rhamnoides*, *Artemisia brevifolia*, and *Ephedra gerardiana* have gained international recognition for their medicinal, nutritional, and industrial significance (Agnihotri, 2025). Navchoo and Buth (1992) documented the extensive experiential knowledge possessed by tribal and rural communities regarding plant properties and applications. Schultes (1960) emphasized the urgent need to document indigenous botanical knowledge before it declines under the pressures of modernization. In response, several Indian research organizations have initiated efforts to document and integrate traditional medicinal knowledge with modern healthcare frameworks while safeguarding community rights and intellectual heritage (Shekhar, 2024).

In recent decades, rapid socio-economic transformations, climate variability, overharvesting, and habitat degradation have emerged as significant threats to both medicinal plant diversity and associated traditional knowledge systems. Consequently, developing a comprehensive understanding of medicinal plant diversity in Ladakh has become essential for conservation planning and sustainable resource management. This chapter therefore provides an integrated overview of the medicinal plant wealth of the Trans-Himalayan cold desert of Ladakh, addressing ecological settings, taxonomic diversity, ethnomedicinal

Fig. 1. The sacred "Gonbo Rangjon" in Lungnak Valley, Zanskar, Ladakh – stands tall in the trans Himalayan landscape, signifying a revered spiritual and cultural site, symbolizing the very close relationship between nature, faith, and local traditions (Photograph by Vaneet Jishtu).

importance, conservation concerns, and emerging challenges. It further identifies future research priorities and highlights the potential of Ladakh's medicinal flora for pharmacological and phytochemical investigations, emphasizing their relevance not only for local healthcare but also for broader scientific and therapeutic applications. Conservation of medicinal plant resources is closely linked with the continuity of the Amchi medical tradition, which currently faces economic constraints and increasing difficulty in accessing essential raw materials.

This study presents a comprehensive review of traditional medicinal plant use in the Trans-Himalayan region, with particular emphasis on Ladakh. Relevant peer-reviewed literature was systematically compiled from major scientific databases and search platforms, including Google Scholar, PubMed, ScienceDirect, and other recognized sources. Published articles, books, reports, and ethnobotanical surveys were critically screened to extract information on medicinal plant diversity, ethnobotanical characteristics, therapeutic applications, conservation status, and major anthropogenic and environmental threats. Special emphasis was placed on plant species used within the Sowa-Rigpa (Amchi) system of medicine, incorporating both historical documentation and contemporary research. Field surveys conducted across Ladakh were integrated to supplement the review with first-hand information obtained from Amchi practitioners and community elders. The compiled data were critically analyzed and synthesized to develop an integrated understanding of traditional knowledge systems, plant-use patterns, and their continuing role in healthcare practices across the Trans-Himalayan region.

*Research history and institutional contributions to medicinal plant studies in Ladakh***:** In Ladakh, local research institutes/organisations such as Regional Research Laboratory (RRL) (earlier DIHAR), National Institute of Sowa-Rigpa (NISR), Ladakh Autonomous Hill Development Council (LAHDC), Himalayan Forest Research Institute (ICFRE-HFRI), Sher-e-Kashmir University of Agricultural Sciences and Technology (SKAUST), and G.B. Pant National Institute of Himalayan Environment (GBPNIHE) are actively emphasizing the documentation, and cataloguing of medicinal plants and their uses. However, despite numerous studies across the Himalayan region, research from Ladakh remains limited and largely fragmentary. Earlier, reviews on medicinal plants from the early and mid-20th century period were of limited nature (Chauhan *et al*., 2020). Bashir *et al*. (2018) conducted a review on the ethnobotanical aspect of medicinal plants of Kargil district, revealing that some less known medicinal plants have been used by indigenous communities. However, towards the end of the century and the beginning of the 21st century a number of regional studies across Ladakh were conducted that included the works of Buth and Navchoo (1988); Navchoo and Buth (1989, 1990; 1992), Bhattacharyya (1991), Singh *et al*., 1996; Kaul (1997), Uniyal (1981); Srivastava *et al*. (1981); Sharma and Kachroo (1981); Singh and Chaurasia (2000); Kala (2000, 2005, 2006); Ballabh and Chaurasia (2007, 2009, 2011); Ballabh *et al*. (2008); Chaurasia *et al*. (2008), Kumar *et al*. (2009); Chaurasia and Ballabh (2011); Angmo *et al*. (2012, 2019, 2022); Gairola *et al*. (2014); Namtak and Sharma (2018); Rigzin *et al*. (2019); Jishtu and Goraya (2020); Chauhan *et al*. (2020); Haq *et al*. (2021); Jishtu *et al*. (2021, 2022, 2023a and b, 2025); Dawa *et al*. (2022); Batool *et al*. (2023); Batool and Gairola (2025) and Gurmet *et al*. (1998, 2025). Namtak and Sharma (2018) carried out a comprehensive review of ethnomedicinal research conducted in Ladakh over the past four decades. Their critical evaluation offers valuable insights into the continuity and reliability of traditional knowledge systems. In contrast, only a few reviews of a more limited scope have been reported (Bashir *et al*., 2018 and Chauhan *et al*., 2020).

Medicinal plants traditional knowledge: Although the Ladakh landscape may appear inhospitable, the region hosts a surprisingly diverse range of plant species. A critical review of studies conducted in Ladakh over the past few decades reveals that indigenous communities have recorded approximately 502 medicinal taxa belonging to 74 families and 261 genera used for medicinal purposes (Goraya and Ved, 2017; Batool *et al*., 2023). This is corroborated by recent Sowa Rigpa research reporting that, among nearly 1,100 plant species occurring in Ladakh, about 525 possess medicinal value (Anonymous[1]). Most ethnobotanical investigations have been concentrated in the Leh and Nubra valleys,

where the population is predominantly Buddhist and follows a traditional medical system practiced for centuries. Comparatively fewer ethnobotanical studies are available from the Kargil and remote Zanskar regions (Uniyal, 1981; Kumar, 2012; Rinchen and Pant, 2014; Bashir *et al*., 2018; Angmo *et al*., 2019; Jishtu *et al*., 2025). Nevertheless, available reviews indicate substantial consensus among Ladakhi communities regarding plant uses and associated traditional knowledge. Collectively, these studies demonstrate that traditional medicinal knowledge among Ladakhi communities remains remarkably rich.

The pioneering work of Abrol and Chopra (1962) laid the foundation for subsequent ethnobotanical research in Ladakh. Their study systematically documented medicinal plants of the region, highlighting Ladakh's rich herbal diversity and describing therapeutic applications for ailments such as fever, inflammation, and digestive disorders. This early documentation introduced Ladakhi medicinal flora into scientific discourse and emphasized their importance within the traditional Sowa-Rigpa (Tibetan medicine) system, a conclusion consistently supported by later studies. Among the earliest ethnobotanical investigations, Buth and Navchoo (1988) documented 40 medicinal herbs, providing one of the first systematic accounts of plants used in the traditional Amchi medical system.

At the beginning of the 21st century, Ballabh and Chaurasia (2002, 2007, 2008, 2009, 2011) from DRDO conducted pioneering field surveys and, aided by logistical access and mobility in the region, documented medicinal applications associated with specific health conditions, thereby strengthening empirical ethnomedicinal documentation. Jishtu and Goraya (2020) examined members of the family Leguminosae (nom. alt. Fabaceae) in Ladakh by synthesizing information from previously published floristic and ethnobotanical studies, complemented by primary observations and data accumulated over two decades of extensive field investigations. This integrative long-term approach significantly strengthened and updated the ethnobotanical records of the region. Recent studies (Haq *et al*., 2021; Hadi *et al*., 2022; Batool *et al*., 2023; Angmo *et al*., 2024; Jishtu *et al*., 2025) have focused on medicinal plant resource utilization among different ethnic groups of Ladakh, including Amchis, Abas, shepherds, Dards, Brokpas, Baltis, Purkies, and herbal practitioners. Numerous investigations show that species belonging to the family Asteraceae are the most widely represented among medicinal plants used by indigenous communities, followed by Lamiaceae, Ranunculaceae, Fabaceae, Rosaceae, and Apiaceae. Most plants employed in traditional ethnomedicine are herbaceous, with leaves constituting the most frequently used plant part, followed by flowers, roots, seeds, and the whole plant. These studies have generated baseline inventories of plant species, vernacular names, parts used, and preparation methods, forming the foundation for subsequent quantitative and conservation-oriented research documenting hundreds of medicinal species used in Ladakh's traditional healthcare systems.

Medicinal plant knowledge has traditionally been transmitted orally from one generation to the next. This traditional knowledge has been documented across Ladakh by several researchers. Dorjey (2015), Namgial *et al*. (2025), and Jigmet *et al*. (2025) recorded plant-based traditional medicinal knowledge from the Sham region of Leh. Namtak and Sharma (2018) investigated medicinal plant resources and their traditional uses in the Skuru watershed of the Karakoram Wildlife Sanctuary. Dawa *et al*. (2022) conducted ethnobotanical studies on 54 rare and endangered medicinal plants from Chang-La, Tanglang-La, and surrounding villages (Meru, Lato, Gya, Sasoma, and Rumtse). Kumar *et al*. (2011) documented traditional medicinal knowledge relating to 65 plant species from the Nubra Valley. Paul *et al*. (2021) recorded 95 medicinal plants used around the Changthang Plateau, primarily for gastrointestinal and respiratory ailments. Hayder (2021) documented 50 plant species used for medicinal and nutritional purposes by villagers from remote Turtuk (Baltistan area of Nubra Valley) for treating various diseases. Haq *et al*. (2021) reported 105 ethnobotanically important plant species used by the Balti, Brokpa, and Beda ethnic groups in the Kargil region. Banoo *et al*. (2025b) documented 121 plant species from Drass. Angmo *et al*. (2022) recorded traditional knowledge of wild edible plants in Leh district, while Angmo *et al*. (2024) provided additional contributions from western

Ladakh. Gurmet *et al*. (2025) investigated ethnomedicinal plants of the Sapi Valley and their applications within the Sowa-Rigpa system of medicine, whereas Gurmet *et al*. (2025) documented 126 plant taxa from the same valley. Bashir *et al*. (2018) reviewed medicinal plant ethnobotany of Kargil district. Uniyal (1981), Dhar and Siddique (1992), Rinchen and Pant (2014), Kumar (2012), Angmo *et al*. (2019), Razia and Bilques (2025), and Jishtu *et al*. (2025) surveyed the relatively less-explored Suru and Zanskar regions. A substantial number of high-altitude medicinal plants from Ladakh hold particular importance because of their frequent use and well-documented therapeutic properties, forming the backbone of traditional herbal healthcare while increasingly attracting interest for modern pharmacological research (Kumar *et al*., 2011).

Potential medicinal taxa: Several medicinal plant species from Ladakh have demonstrated promising pharmacological properties, including anti-inflammatory, antioxidant, antimicrobial, hepatoprotective, and anticancer activities. These medicinal plants not only play a vital role in traditional healthcare but also represent valuable resources for future drug discovery and development. Earlier studies from Ladakh have identified *Ephedra gerardiana* and *E. intermedia* as important medicinal plants used for the treatment of fever (Abrol and Chopra, 1962; Haq *et al*., 2021). *Nepeta glutinosa* has been reported to be effective against diarrhoea (Hussain *et al*., 2023). *Rhodiola rosea*, *Inula racemosa*, and *Dactylorhiza hatagirea* are integral to traditional Ladakhi medicine, addressing health concerns ranging from menstrual disorders to general well-being (Gurmet and Stobgais, 2016; Gurmet *et al*., 2025; Chauhan *et al*., 2020; Jishtu *et al*., 2023). *Physochlaina praealta* (Decne.) Miers (Langthang) and the introduced species *Hyoscyamus niger* L. (Gya-Lhathang) are regarded as valuable sources of solanaceous alkaloids (Abrol and Chopra, 1962; Jishtu *et al*., 2025). *Elsholtzia densa* Benth. (leaves) and *Pedicularis cheilanthifolia* Schrenk (whole plant) are commonly used for the treatment of menorrhagia (Stanzin and Sharma, 2018). *Lactuca tatarica* (L.) C.A. Mey., a common agricultural weed, has multiple uses in the treatment of various ailments (Angmo *et al*., 2022; Shukurlu, 2022). *Oxytropis microphylla* (Pall.) DC. (stag-sha) has attracted considerable attention for its potential health benefits and ecological significance, particularly for its antioxidant, antimicrobial, and anti-inflammatory properties (Ahmad *et al*., 2008; Zomba *et al*., 2025). *Thymus linearis* Benth., followed by *Aconitum heterophyllum* Wall., are among the most widely utilized plant species based on the highest use reports (Batool *et al*., 2023). Chaurasia *et al*. (2012) reviewed *Podophyllum hexandrum* Royle and highlighted its significant anticancer potential, particularly due to bioactive compounds such as podophyllotoxin. Collectively, these findings provide a foundation for future ethnomedicinal and pharmacological research in the Ladakh region. Joshi *et al*. (2006) documented the biodiversity of Nubra Valley with emphasis on plant resource conservation and bioprospecting, identifying several medicinally and economically important plant species and stressing the need for sustainable management and conservation of plant genetic resources.

Kaul (1997) enumerated six modern drugs derived from traditional plants of Kashmir and Ladakh, namely *Artemisia annua*, *Atropa belladonna*, *Colchicum luteum*, *Digitalis lanata*, *Ephedra gerardiana*, and *Hyoscyamus niger*, along with their therapeutic claims. Other medicinal plants from the region reviewed for therapeutic applications include *Achyranthes aspera*, *Aconitum heterophyllum*, *Ephedra gerardiana*, *Juniperus communis*, and *Rheum emodi*. Investigations into secondary metabolites of Ladakh plants have revealed a broad spectrum of therapeutic properties, generating considerable interest in understanding their chemical composition, biosynthetic pathways, and pharmacological activities (Zomba *et al*., 2025). Shabir *et al*. (2023) conducted a detailed ethnopharmacological review of three of the most utilized medicinal plants—*Mentha longifolia* (Phuloling), *Peganum harmala* (Sepan), and *Podophyllum hexandrum* (Danmokusho).

Notable medicinal plants from Ladakh with diverse therapeutic potential include *Acantholimon lycopodioides*, *Achillea millefolium*, *Aconitum heterophyllum*, *A. violaceum*, *Aconogonum tortuosum*, *Alkekengi officinarum*, *Arnebia euchroma*, *Artemisia macrocephala*, *Capparis spinosa*, *Carum carvi*, *Corydalis govaniana*, *Cicer microphyllum*, *Codonopsis ovata*, *Dactylorhiza hatagirea*, *Delphinium brunonianum*, *Dolomiaea costus*, *Dracocephalum heterophyllum*,

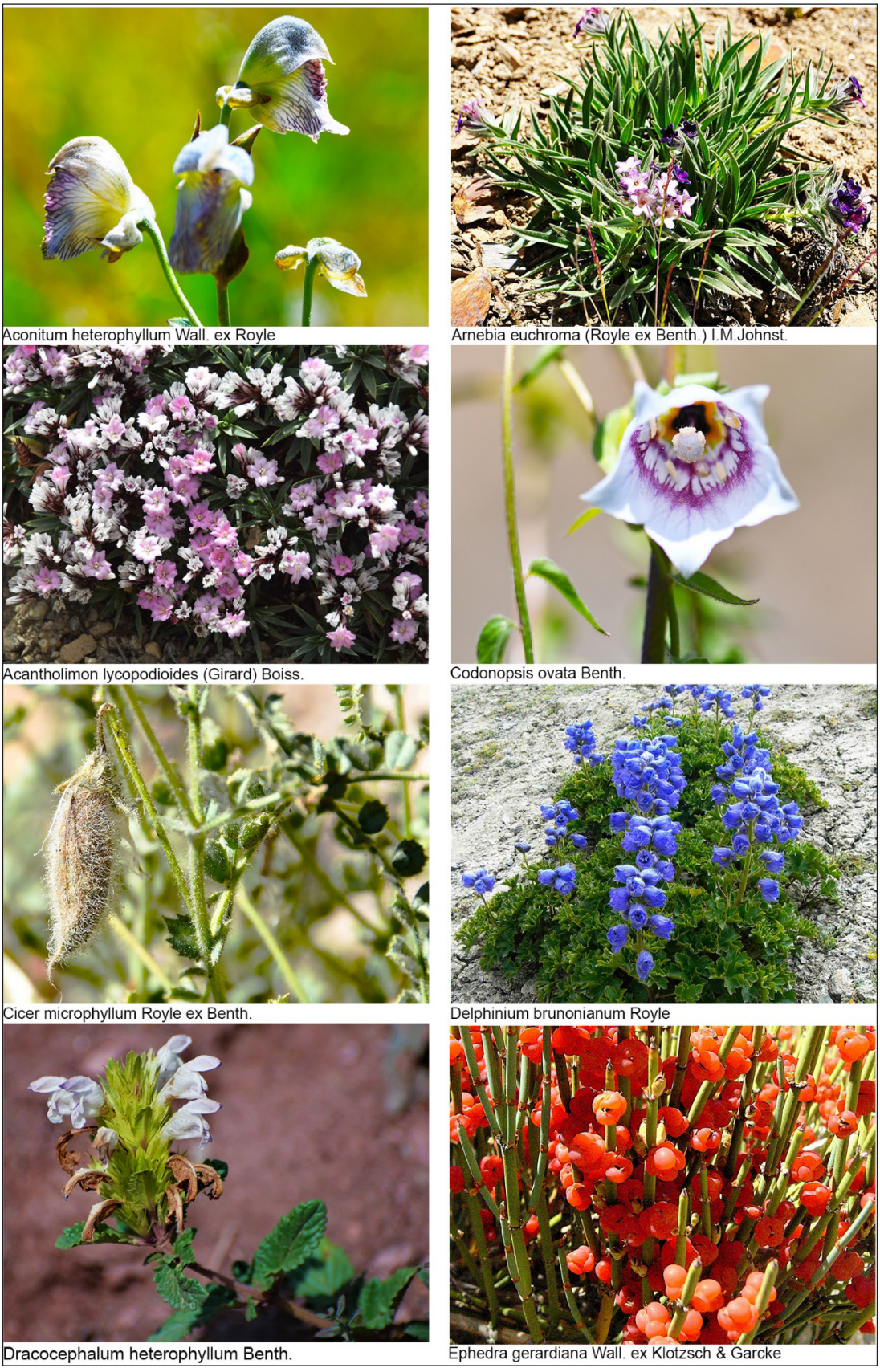

Fig. 2a. Some important medicinal plants of Ladakh (Photographs by Vaneet Jishtu).

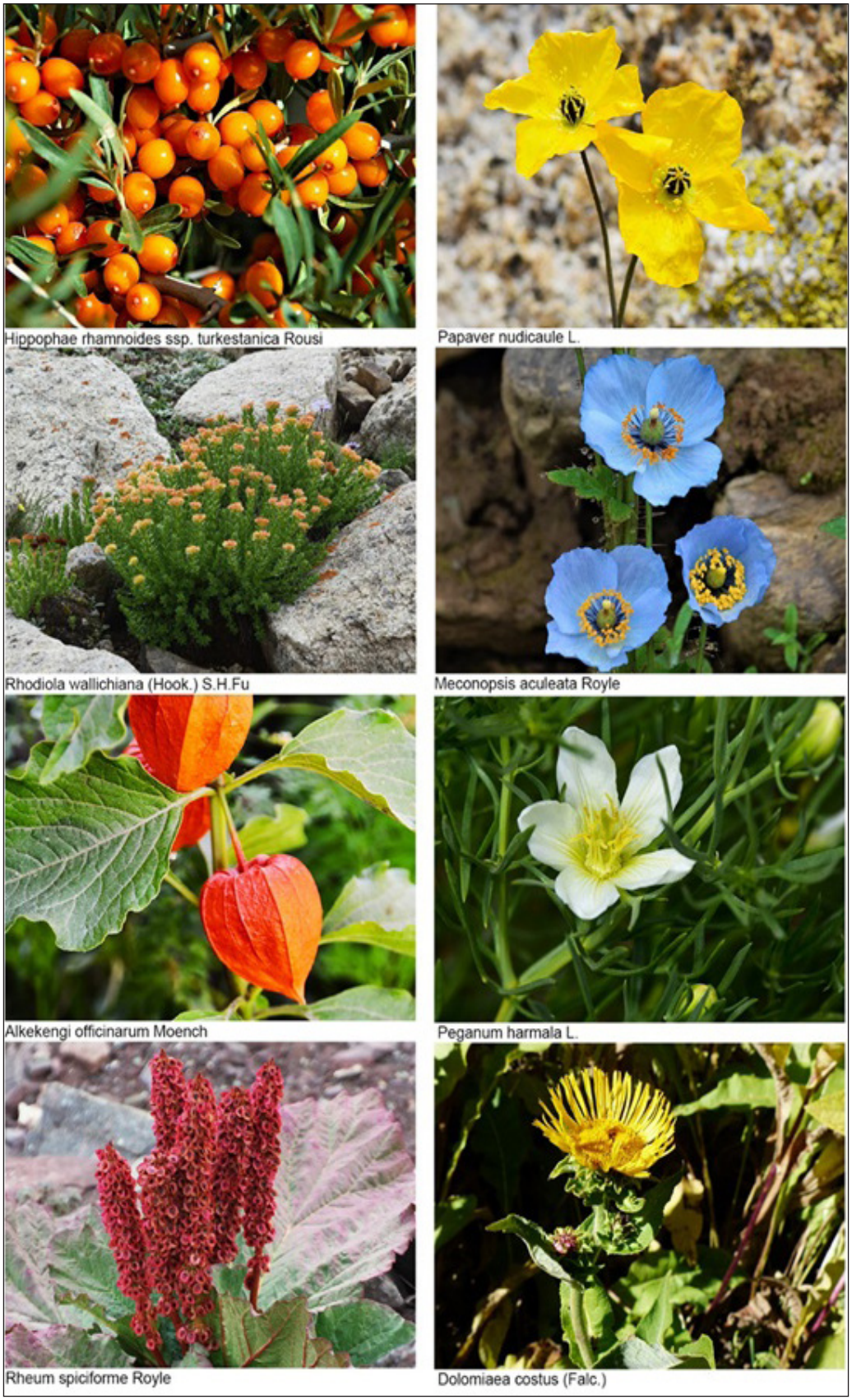

Fig. 2b. Some important medicinal plants of Ladakh (Photographs by Vaneet Jishtu).

Ephedra spp., *Geranium wallichianum*, *Hippophae rhamnoides* subsp. *turkestanica*, *Hyoscyamus niger*, *Inula racemosa*, *Juniperus semiglobosa*, *Meconopsis aculeata*, *Oxytropis microphylla*, *Papaver nudicaule*, *Peganum harmala*, *Picrorhiza kurroa*, *Podophyllum hexandrum*, *Rhodiola imbricata*, *R. heterodonta*, *R. rosea*, *R. wallichiana*, *Thymus linearis*, *Rheum australe*, *R. speciforme*, *Taraxacum officinale*, and *Urtica hyperborea*. Some of them are shown in (Fig. 2a and 2b).

Many of these species are integral to Sowa-Rigpa medicine (Chaurasia and Gurmet, 2003; Ballabh and Chaurasia, 2007, 2008, 2009, 2011; Farouk *et al*., 2008; Dekhang, 2008; Singh *et al*., 2010; Kumar *et al*., 2011; Dhar *et al*., 2011; Chaurasia *et al*., 2012; Pant and Rinchen, 2012; Sofi *et al*., 2014; Dorjey, 2015; Angmo *et al*., 2017; Bashir *et al*., 2018; Chauhan *et al*., 2020; Thaneshwari and Mehdi, 2021; Abbas *et al*., 2021; Dawa *et al*., 2021, 2022; Jishtu *et al*., 2022, 2023a, 2023b, 2025; Batool *et al*., 2023, 2024; Jigmet *et al*., 2025; Zomba *et al*., 2025). Agnihotri (2025) emphasized the need to ensure the quality, safety, and integrity of medicinal and aromatic plants (MAPs) and wild edible plants of the Indian Himalayan arid region, highlighting quality control, prevention of contamination and adulteration, standardized harvesting and processing practices, sustainable utilization, and the significant pharmacological potential of these plants for traditional and modern healthcare systems.

However, limited research has been conducted on the propagation of these medicinal plants. Hadi *et al*. (2023) developed a comprehensive *in vitro* propagation protocol for *Aconitum violaceum*, demonstrating potential for large-scale multiplication, germplasm conservation, and ecological restoration. Belwal *et al*. (2016) reported successful micropropagation of the critically endangered medicinal plant *Aconitum heterophyllum* using low concentrations of plant growth regulators (PGRs), along with molecular validation of clonal fidelity. Similarly, Sood and Chauhan (2009) established a cost-effective micropropagation technique for *Picrorhiza kurroa*. With regard to the medicinal flora of Ladakh, future prospects remain highly promising, as many species are still insufficiently explored for their pharmacological properties. The untapped therapeutic potential of these plants may prove crucial in addressing critical ailments and emerging health challenges in the future (Chauhan *et al*., 2020).

Sowa Rigpa (Amchi System): Among recent anthropologists, communities of the trans-Himalayan region historically practiced shamanistic healing traditions collectively referred to as Bon or Bonpo, which were widely prevalent across northern Asia, particularly in Tibet and Nepal (Kvaerne, 1995; Bjerken, 2004). In the pre-Buddhist period, the region was home to a plurality of medical traditions, including healing practices performed by Ihaba (shamans) and Onpo (astrologer-diviners). Over time, the most influential indigenous therapeutic tradition to emerge was Tibetan medicine (Amchi), which developed through sustained interaction with local flora, mineral resources, and the region's embedded cultural and cosmological belief systems (Kala, 2005). Although the system has its origins in India and is commonly found in areas like Sikkim, Arunachal Pradesh, Darjeeling, Lahaul and Spiti, and Ladakh, it is also widely practiced in Tibet, Bhutan, Mongolia, China, and Nepal (Namgyal and Phuntsog, 1990; Gurmet, 2004; Phuntsog, 2005a; Tsering, 2008; Dawa, 2009). The Sowa-Rigpa system of medicine received official recognition on 25th August 2011 (Angmo *et al*., 2012).

Sowa Rigpa, also known as the Amchi system of medicine forms the backbone of traditional healing systems in Ladakh and fosters about 60% of public health of Ladakh (Chaurasia and Singh, 1996; Kala, 2005; Navchoo and Buth, 1989; Gurmet, 2004; Kala, 2005; Angmo *et al*., 2012; Smanla and Millard, 2013; Chauhan *et al*., 2020; Thaneshwari and Mehdi, 2021; Jishtu *et al*., 2023). This system is deeply rooted in Buddhist philosophy and emphasizes the balance between body, mind, and environment, representing a holistic medical tradition practiced across the region (Angmo *et al*., 2024). Placed among the world's oldest continuously practiced, well-documented scholarly medical traditions, dating back *ca* 2,500 years (Phuntsok, 2005a; Gurmet, 2004 and 2005; Angmo *et al*., 2017; Jishtu *et al*., 2025). The unique diversity of Medicinal plants in Ladakh, constitutes the backbone of this traditional healing system. Medication is prepared from locally available medicinal plants, minerals, and animal products, making the system closely linked to Ladakh's ecology and culture. Due to their low

side effects, these plants have strong potential as sources of alternative medicines (Raza *et al*., 2024). The effective integration of traditional knowledge with locally available natural resources has enabled Ladakhi communities to adapt to and thrive in an otherwise inhospitable environment.

Raghunathan (1976); Dhar (1980); Srivastava and Gupta (1982); Viswanathan and Mankad (1984) were among the pioneering scholars who documented and catalogued the medicinal plants employed by local practitioners of the Amchi medical system in Ladakh. Some studies reflects that the Tibetan system of medicine is declining in the region due to shift in socio-economic patterns and unwillingness of the younger generation to adopt Amchi as a profession (Kala, 2005). Kumar (2012) explored medicinal plant diversity and the traditional Amchi system of medicine in Zanskar, documenting key medicinal species and outlining the system's philosophical foundations and disease causation concepts. Ballabh and Chaurasia (2007) reported traditional remedies for cold, cough, and fever used by the Boto (Buddhist) tribal community of Ladakh, while Ballabh *et al*. (2008) documented medicinal plants employed in the treatment of kidney and urinary tract disorders. Dekhang (2008) from the Tibetan Medical and Astrological Institute (Men-Tsee-Khang), Dharamshala details nearly 200 Tibetan medicinal plants, presenting knowledge from traditional texts, and serves as a significant contribution to Tibetan *materia medica*. Gurmet and Stobgais (2016), provided a key reference for plants used in Sowa-Rigpa, focusing on plant-based remedies from high-altitude regions across Ladakh.

Rigzen *et al*. (2019) documented medicinal plants of the Suru Valley used in the Sowa-Rigpa (Amchi) system of medicine. Although the inhabitants of the Suru Valley belong mainly to the Shia Muslim Balti scheduled tribe, they show strong respect for and belief in the Sowa-Rigpa tradition. Similarly, Haq *et al*. (2021) recorded indigenous knowledge of plant resources among the Balti, Beda, and Brokpa communities, who also place high trust in the Amchi system. Kumar *et al*. (2011), Chauhan *et al*. (2020) and Jishtu *et al*. (2022, 2025), assessed the rich medicinal flora and traditional Amchi medicine system across Ladakh, highlighting the need for conservation due to over-extraction and exploring potential value-added products and sustainable utilization strategies for the region's medicinal plants. Namgial *et al*. (2025) conducted an exploratory survey in Sham valley and collected information on 61 valuable medicinal plants and their use in the Amchi system, used widely in traditional medicine to treat a range of ailments.

Traditional knowledge concerning plant identification, appropriate harvesting seasons, processing methods, and therapeutic applications has been passed down orally through generations, primarily by trained Amchis, and continues to form an integral part of the region's cultural heritage. As custodians of this rich ethno-medical tradition, Amchis have long held high social status and respect within trans-Himalayan communities. In Ladakh, the practice of Sowa-Rigpa is supported by nearly 180 to 250 Amchi practitioners, including monks and nuns, who utilize an estimated 500 plants in their traditional medical practice (Gurmet, 2004; Kala, 2003, 2005, 2006; Goraya and Ved, 2017; Angmo *et al*., 2017). The Tibetans settled in Ladakh have set up a full-fledged medical centre based on Amchi system called '*Mentse Khang*' in the Leh town, where routine check-ups, diagnose and cure take place, and medicines are available. Smanla and Millard (2013) examined the preservation and development of Sowa -Rigpa, highlighting the traditional role of Amchi practitioners and the system's transformation over time. Their study emphasized that rapid socio-economic development in Ladakh has substantially altered traditional social structures, posing significant challenges to the continuity of the Amchi system and prompting various initiatives aimed at its adaptation and long-term sustainability.

Ethnomedicinal uses and cultural importance: Ladakh is inhabited by diverse ethnic groups, broadly categorized into three main communities: (1) Buddhists—including Ladakhi Bodh/Bhot/Boto/Bot, Gara, Mon Dolba, Beda, Changpa (pastoralists of Changthang), and Brokpa (Buddhist Dards). (2) Muslims, comprising Balti, Purigpa, Argons, and Drokpa (Muslim Dards); and (3) recently settled Tibetan migratory populations (Dolkar *et al*., 2017; Ghosh *et al*., 2020; Haq *et al*., 2021; Bhasin *et al*., 2023; Pandit *et al*., 2024). Medicinal plants form an integral part of their

traditional healthcare systems, with these communities utilizing a wide range of plants to manage respiratory disorders, digestive ailments, fever, rheumatism, headaches, kidney problems, as well as pregnancy and childcare-related health issues. In addition to their medicinal value, several plant species hold considerable cultural and religious importance and are closely associated with their rituals and traditional ceremonies, underscoring the deep-rooted spiritual relationship between local communities and their surrounding natural environment (Navchoo and Buth, 1990; Bhattacharyya, 1991; Angchok, 2009; Dorjey *et al*., 2012; Kumar, 2012; Jishtu *et al*., 2022, 2025).

This close relationship with indigenous biological resources is further exemplified by Ladakh receiving its first Geographical Indication (GI) tag in 2022 for the Raktsey Karpo apricot (Anonymous[2]). Besides, some of the wild edible plant species (WEPs) of Ladakh besides serving as crucial source of food and nutrition, also provide important traditional medicine to the local communities. Despite their importance, comprehensive data on their nutritional and antioxidant properties remains limited (Raj *et al*., 2012; Kaur *et al*., 2013; Avasthi *et al*., 2016). Although research on their nutraceutical potential was scarce over the past decade (Comer and Debus, 1996), recent efforts by regional researchers have begun to strengthen focus on this area (Batool *et al*., 2024).

*Economics and cultivation***:** In many developing countries, plants serve as the main source of medicinal treatments. China and India rank among the world's largest consumers of medicinal herbs, with traditional medical systems utilizing approximately 7,000 plant species each (Rates, 2001; Ramawat and Goyal, 2008; Nath *et al*., 2023). Within this broader Asian context, indigenous communities maintain extensive ethnomedicinal knowledge that underpins local healthcare systems and cultural identity. These species that support traditional healthcare systems, have potential to feed the emerging nutraceutical markets (Agnihotri, 2025). The World Health Organization strategy emphasizes integrating traditional medicine into national healthcare systems, strengthening regulation and research, and promoting the safe, effective, and sustainable use of medicinal plant resources worldwide (WHO, 2013).

Rising demand at both national and global levels for plant-based wellness products has strengthened India's role as a major supplier of raw materials, with Ladakh gaining prominence due to its rich diversity of rare medicinal plants and the Sowa Rigpa (Amchi) tradition grounded in deep ecological knowledge (Bhasin *et al*., 2023). A review of existing studies indicates that Ladakh represents a rich repository of rare, endangered and threatened (RET) medicinal plants, many of which are endemic to the region. The depth of traditional plant knowledge is reflected in their Amchi system of medicine and healthcare. However, increasing extraction of these medicinal plant resources, largely driven by industrial demand, has led to the degradation of their natural populations. The growing commercial trade of Himalayan medicinal plants has put pressure on many high-value plants from remote regions such as Ladakh, where unregulated collection and unregulated trade contribute to overexploitation. Sustainable harvesting practices, improved trade regulation, and the promotion of cultivation are essential to conserve these resources while simultaneously supporting indigenous livelihoods (Schippmann, 2002; Olsen, 2005; Sharma *et al*., 2014). Phuntsog (2005a) identifies major challenges for cultivation, including short growing season, lack of quality planting material, limited technical knowledge, and inadequate market linkages. He further suggests, integrating conservation with livelihood opportunities, promoting *ex-situ* cultivation, and sustainable harvesting practices for long-term resource management.

Conservation: Over time, local communities have played a significant role in conserving native plant diversity and, in doing so, have developed distinctive indigenous knowledge regarding their potential value, particularly for medicinal use. Therefore, conservation efforts, especially *in situ* conservation, needs to be encouraged to ensure that responsibility remains with local communities, who are well positioned to sustainably manage native medicinal plant diversity (Nautiyal *et al*., 2002; Pant and Samant, 2010). Studies also suggested for habitat-based conservation planning, establishment of protected areas, cultivation, and involvement of local communities to ensure effective conservation and sustainable management of medicinal plants in the

region. (Rao *et al*., 2000; Phuntsog, 2005b; Rana *et al*., 2010). Myers *et al*. (2000) first identified regions such as the Himalaya, as major global biodiversity hotspots requiring urgent conservation attention, which was later reinforced by Mittermeier *et al*. (2004).

One of the key economic benefits of biodiversity lies in the commercial value of medicinal plants (Kumar, 2004). Rising demand for natural products is driving changes in the harvesting and commercialization of these plant resources, whose market values vary with product form and active constituent content (Agnihotri, 2025). Olsen and Larsen (2003) did highlight the resource pressure and sustainability concerns, and stated that the high demand and unregulated harvesting has led to overexploitation of several high-value species, threatening long-term ecological and economic sustainability. Several MAPs from Ladakh also hold international market value and are reportedly being exported illegally (Chaurasia and Gurmet, 2003). Goraya and Ved (2017) documented 36 medicinal plants from the Himalaya that are traded in high volume, including 14 Red listed species, of which 6 occur in Ladakh - *Aconitum heterophyllum* (CR), *Arnebia benthamii* (CR), *Betula utilis* (CR), *Ephedra gerardiana* (EN), *Hyoscyamus niger* (EN), and *Rheum australe* (EN).

Climate change, infrastructure development, unregulated harvesting, and socio-economic transformations are increasing the risks faced by wild plant populations. Despite their cultural and medicinal significance, many medicinal plant species in Ladakh are susceptible to ecological threats. Numerous species are classified on the IUCN Red List as Critically Endangered (CR), Endangered (EN), or Vulnerable (VU), highlighting the impacts of over-exploitation and restricted distribution (Kala, 2000; Ved and Tandon, 1998; Ved *et al*., 2003; Ravikumar *et al*., 2021).

Various efforts are being made to ensure the long-term conservation and sustainable use of Ladakh's medicinal flora. In-situ conservation and cultivation initiatives, including the Trans-Himalayan Herbal Garden managed by the National Institute of Sowa Rigpa (NISR), promotes the propagation of over 110 native MAP species. These include rare, endangered, and high-value species traditionally used in Tibetan medicine as herbal garden, demonstration plots, nurseries for propagation, seed banks and germplasm conservation units to safeguard genetic diversity. Species conserved and promoted include threatened taxa like *Aconitum heterophyllum, Dactylorhiza hatagirea, Arnebia euchroma, Picrorhiza kurroa, Podophyllum hexandrum, Rhodiola imbricata, Saussurea costus,* and *Rheum spiciforme* (NISR, 2021).

Fig. 3. The revered "Shukpa" of Hemis-Shukpachen, Likir area of Leh district, represents a commendable community-led effort toward the conservation of sacred Juniper trees (Photograph by Vaneet Jishtu).

Alongside these measures, workshops, seminars, and policy dialogues are increasingly focusing on conservation strategies, sustainable utilization, market development, and community-based management of medicinal plant resources. The village, Hemis-Shukpachan, is well known for its efforts to conserve the sacred Juniperus semiglobosa trees (Shukpa). With support from the Ladakh Autonomous Hill Development Council (LAHDC) and the Leh Forest Department, the villagers have implemented proactive conservation measures to protect the remaining 30-35 mature trees (Fig. 3), which face threats from low seed germination, livestock grazing, and past over-exploitation (Bushra *et al*., 2024).

Similarly, at Hanupatta, a remote village in Ladakh, women under the banner of "Hanupatta Ama Tsokpa" (Mother Association), have taken a leading role in the conservation of juniper trees (Anonymous[5]). A number of studies have focussed on the conservation status of medicinal plants in Ladakh (Kala, 2000; Kumar *et al*., 2011; Paul *et al*., 2021; Batool *et al*., 2023; Angmo *et al*., 2025).

A recent study by Angmo *et al*. (2025) developed a Conservation Priority Score (CPS) for 84 medicinal plants in Western Ladakh, identifying 33 species as high priority for urgent conservation action. Using participatory rural appraisal, systematic field surveys, and GIS-based mapping, the study quantitatively assessed species distribution, population status, and harvesting pressure, thereby providing a scientific framework for targeted conservation planning in the Trans-Himalayan region of Ladakh.

To promote cultivation of medicinal, aromatic, and flowering plants in Ladakh, CSIR-IIIM, a CSIR lab under the Union Ministry of Science and Technology, have signed an MoU with the Ladakh Autonomous Hill Development Council (LAHDC), Leh, to establish a MAPs demonstration farm at Palam, Leh (Annonymous[4]).

Sustainable management of Ladakh's medicinal plant diversity relies on addressing several interconnected priorities. Firstly, there is a need for scientific validation of traditional uses through rigorous phytochemical and pharmacological studies, ensuring that the therapeutic potential of these plants is accurately understood and documented. Equally important is the standardisation of harvesting practices, which can help prevent over-exploitation and maintain ecological balance (Agnihotri, 2025). Community engagement plays a crucial role in this process, both in transmitting indigenous knowledge to future generations and in ensuring that local communities receive equitable benefits from the use and commercialization of these resources. Finally, robust policy support is essential to facilitate conservation efforts, promote cultivation, encourage value addition, and improve market access for medicinal plants, thereby integrating ecological sustainability with socio-economic development (Hamilton, 2004).

Concerned Ladakhi Amchis and non-Amchis founded the Ladakh Society of Traditional Medicine (LSTM) in 1999 to safeguard Sowa Rigpa. Initially supported by NOMAD RSI (France), LSTM is now an independent Ladakhi non-profit recognized by the governments of Ladakh and India, actively working to revitalize Amchi medicine and ensure its continuity as a vital part of Ladakhi culture and global heritage (Smanla and Millard, 2013). Ved and Goraya (2008), suggested to promote cultivation, community participation, and sustainable harvesting to reduce pressure on wild populations and ensure long-term availability of medicinal plants. Conservation of Ladakh's medicinal plants is vital to the continuity of Amchi medicine. Thus, conserving medicinal plants in Ladakh is important not only for ecological stability, but also for sustaining the local economy and traditional livelihoods (Anonymous[3]).

Threat Status: Medicinal plants in Ladakh are increasingly threatened by habitat degradation, overexploitation, and rapid environmental changes due to global warming and invasive alien species (Tandon and Kapoor, 2008; NBA, 2014; Agnihotri, 2025; Zargar *et al*., 2025) underscoring the urgent need for both *in situ* and *ex situ* conservation measures (Paul *et al*., 2021). The major threats to this habitat include its unique topography, physical features and harsh climatic conditions which have resulted into drastic decline of various *taxa* represented in the ecosystem (Kala, 2000; Porwal *et al*., 2003; Kumar *et al*., 2011: Shukla and Srivastava, 2020, Paul *et al*., 2021). As a consequence, *ex situ* conservation and sustainable utilization would

prevent their permanent depletion from the area (Devi *et al*., 2013). Rao and Hajra (1980), provided one of the earliest assessments of threatened plants in India, highlighting the need for urgent conservation attention. The Red Data Book by the Botanical Survey of India (Nair and Rastogi, 1967; Nayar and Sastry, 1987-1990 and Murthy, 2012) provides a national list of state-wise tally of threatened *taxa*. For Jammu and Kashmir (the erstwhile state including Ladakh) it lists 23 species, however, this figure covers the entire region (not region-specific breakdown for Ladakh) and is drawn from the older database of 625 threatened species compiled for the country. These publications are outdated, old, and requires to be updated for better understanding of the threats.

Earlier assessments by Ved and Tandon (1998) and then by Kumar *et al*. (2011) identified 41 threatened medicinal plant species from the region based on the criteria of Nayar and Sastry (1987) and IUCN (2001); however, as mentioned earlier, Ladakh was administratively part of Jammu and Kashmir at the time, regional-level precision in threat assessment was limited. More recent evaluations using the IUCN Red List framework have provided clearer insights, with Batool *et al*. (2023) documenting 7 Critically Endangered (CR), 9 Endangered (EN), and 13 Vulnerable (VU) medicinal plant species from Ladakh. Beyond their ecological significance, medicinal plants also contribute substantially to the livelihoods of indigenous communities and serve as vital resources for treating a wide range of ailments (Haq *et al*., 2021). Recognizing both their ecological and socioeconomic importance, a Conservation Assessment and Management Prioritization (CAMP) workshop was conducted at the National Institute of Sowa-Rigpa (NISR), Leh, during September 2021 to prioritize wild medicinal plant species of Ladakh using IUCN Red List categories and criteria. Total 40 *taxa* were assessed in which 3 were CR, 11 EN, 10 VU, 11 NT, 3 LC and 2 Data Deficient (DD). Out of 40 *taxa* assessed, 31 are herbs, 7 are shrubs and 2 are trees. All plants assessed are locally traded and habitat loss was a common threat (Ravikumar *et al*., 2021). This conservation concern is further amplified by the presence of several endemic species in the region (Samant *et al*., 2007), whose extinction would represent an irreversible loss to global biodiversity. Negi *et al*. (2011) also recommend the involvement of local communities and traditional healers in conservation programs and sustainable harvesting practices.

Conclusions

Ladakh, despite its harsh trans-Himalayan environment, supports a rich diversity of *ca* 500 medicinal plants, that form the foundation of the traditional Amchi or Sowa-Rigpa healthcare system, contributing significantly to the region's cultural identity. Growing global interest in ethnobotany, particularly in India and China, has highlighted the importance of documenting and conserving traditional medicinal knowledge (Salmerón-Manzano *et al*., 2020). In Ladakh, ethnomedicinal research has emphasized the need for scientific validation of traditional remedies, including studies on their therapeutic efficacy and safety. Integrating traditional phytotherapy with modern healthcare systems, while respecting indigenous knowledge and cultural heritage, offers significant potential for healthcare advancement, pharmacological research, and sustainable resource management. Documentation and digitization of traditional knowledge through modern technologies and biodiversity databases can further aid in preserving this invaluable heritage and bridging the gap between traditional wisdom and modern science.

The Amchi system (Sowa-Rigpa) is a vital part of Ladakh's traditional healthcare. However, its medicinal practices require proper documentation and scientific validation to assess both their effectiveness and safety. Integrating traditional phytotherapy with modern healthcare systems, while preserving indigenous knowledge and cultural heritage, is essential for its sustainable future (Shekhar, 2024; Jishtu *et al*., 2025). However, Ladakh's traditional medicinal systems and plant resources are increasingly threatened by modernization, lifestyle changes, declining intergenerational knowledge transfer, and overexploitation of natural resources (Dorjey *et al*., 2012; Hadi *et al*., 2022; Angmo *et al*., 2024). Since much of the ethnomedicinal knowledge is orally transmitted, it remains highly vulnerable to erosion due to urbanization, tourism, and reduced interest among younger generations (Batool *et al*., 2023). Ecological pressures such as habitat destruction, unscientific harvesting, livestock grazing, industrial extraction, and

natural disasters have also contributed to the decline of trans-Himalayan medicinal plants in Ladakh (Dar *et al*., 2006; Kumar *et al*., 2011; Jishtu *et al*., 2022; Gaur *et al*., 2024; Batool and Gairola, 2025). Although extensive work has been conducted on biodiversity conservation, the socio-cultural and ecological dynamics influencing medicinal plant use remain insufficiently understood. Therefore, systematic documentation, community-based conservation strategies, and sustainable management practices are urgently needed to protect Ladakh's medicinal plant diversity and preserve its traditional healthcare heritage for future generations.

Recent ethnomedicinal research has increasingly focused on documenting traditional oral knowledge and exploring the therapeutic potential of medicinal plants, recognizing its importance for cultural preservation, pharmacological and phytochemical studies, novel drug discovery, and sustainable resource management (Chikowe *et al*., 2020; Jishtu *et al*., 2023; Banoo *et al*., 2025). In Ladakh, despite the documentation of over 500 medicinal plant species, many remain scientifically unvalidated, while the socio-cultural and ecological factors influencing traditional knowledge systems are still poorly understood (Boom, 1996; Mahmood *et al*., 2013; Wolde, 2025). Digitisation and systematic documentation of orally transmitted knowledge can help bridge traditional wisdom with modern science, preserve threatened indigenous practices, and support sustainable conservation strategies through databases such as GBIF (Kumar and Kosuri, 2023; Junaid *et al*., 2022; Magare and Patil, 2025). Regular updating of ethnomedicinal knowledge is therefore essential to document evolving practices, support future pharmacological research, and safeguard the invaluable medicinal plant resources and ecological knowledge held by indigenous communities, which are critical for resilient healthcare systems, livelihoods, and biodiversity conservation (Smanla and Millard, 2013; Haq *et al*., 2021). The importance of strengthening research, education, and quality control in traditional medicine had been emphasized by the Planning Commission (2013). Thus, to understand the community knowledge, and their reliance on plant-based traditional medicine is crucial for developing effective and sustainable conservation strategies for medicinal plant resources (Ginjo *et al*., 2025).

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Competing Interests

The authors declare no competing interests.

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About the Authors

Vaneet Jishtu - Retired Forestry Scientist (Field Botanist) from ICFRE-Himalayan Forest Research Institute (Shimla) with over three decades of experience in Himalayan ecology and biodiversity conservation, particularly in Ladakh. Has led and contributed to over 30 research projects and consultancies, including ecological surveys in Ladakh, long-term climate change monitoring in high-altitude Himalayan transition zones, and the environmental impact assessment of the Doklam road in Sikkim.

He also played a key role in establishing the Western Himalayan Temperate Arboretum at Shimla. An FAO Fellow for the Cold Desert Afforestation Programme with USDA, he also represented ICFRE at forums such as UNCCD COP14, the Carbon Neutral Ladakh Summit 2020, and the International Conference on Junipers. He was also part of the team that presented the flora of Great Himalayan National Park for its UNESCO World Heritage recognition. He has guided doctoral scholars, authored over 150 publications, and received honours including the Brandis Award (2016), Rotary Shreyas Award (2022-23), and State-Level Recognition for Biodiversity Conservation (2024-25) from the Government of Himachal Pradesh. Featured among "50 People to Know Across the Himalaya" by Condé Nast Traveller, he is also associated with several professional societies and serves on the Editorial Board of the Journal of Traditional and Folk Practices.

G.S. Goraya, Ph.D. is a Forestry Professional, retired from Indian Forest Service, Himachal Pradesh Cadre as Principal Chief Conservator of Forests & Head of Forest Force (HoFF). He carries credible experience in forest and wildlife management, documentation and research on floristic diversity, and in conservation education. He contributed immensely to medicinal plants sector by institutionalising a new model for *in situ* conservation - entitled as Medicinal Plants Conservation Areas (MPCAs). He also led two important Government of India (GoI) sponsored research studies on demand-supply of medicinal plants in India. He established 'Van Sampada', an interpretation center for non-timber forest produce in Himachal Pradesh, which has since become a model for promoting public awareness on the theme.

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