Floral diversity expedition in Ladakh: An insight into the exploration, distribution pattern, ethnobotanical, phytochemical studies and conservation strategies

Sabir Hussain, Sheenu Sharma, Ram Chand Bhatti and Anand Narain Singh

Correspondence

Sabir Hussain[1], Sheenu Sharma[1], Ram Chand Bhatti[1,2] and Anand Narain Singh[1*]

[1]Soil Ecosystem and Restoration Ecology Lab, Department of Botany, Panjab University, Chandigarh, 160014, India.
[2]Department of Botany, Smt. Aruna Asaf Ali Govt. Post Graduate College Kalka, Haryana.

[*]Corresponding Author: dranand1212@gmail.com, ansingh@pu.ac.in

Ethnobotany Research and Applications 26:43 (2023) - http://dx.doi.org/10.32859/era.26.43.1-32
Manuscript received: 19/07/2023 – Revised manuscript received: 08/09/2023 - Published: 12/09/2023

Research

Abstract

Background: Ladakh, located in the Trans-Himalayan region, is characterized by a sparse distribution of plant and animal life that has adapted to the arid and high-altitude environment. Ladakh's unique vegetation provides various benefits to the local population, including medicine, phytochemicals, food, fodder, fuelwood, and many other vital services. Over the years, there have been significant developments and changes in the ethnobotanical knowledge in Ladakh. One of the most notable changes is the extensive documentation and research carried out by researchers to systematically record the traditional knowledge held by local communities. The present study aims to report the expedition of wild floral diversity in Ladakh for their exploration, distribution, ecosystem services, ethnobotanical uses, phytochemical extraction, conservation strategies, challenges, and knowledge gaps in research.

Methods: To compile the review paper, a comprehensive search was conducted on various web-based platforms, including Web of Science, Scopus, Mendeley, and Google Scholar, to gather relevant literature on the wild vegetation of Ladakh. Different combination of keywords pertaining to floral expedition in Ladakh were used as search string for literature survey on various internet databases. For instance, the search strings used for literature survey on Scopus comprises of keywords such as "Ladakh AND vegetation OR plant," "Phytochemical AND Ladakh," "Ethnobotanical* AND Ladakh," "Ladakh AND Flora AND Diversity," "Plant AND Distribution AND Ladakh," and "Medicinal AND Plants AND Ladakh."

Results: Researchers, both from India and abroad, have conducted extensive explorations of the floral diversity in the Ladakh region over the years. They have meticulously documented numerous plant species and conducted in-depth studies covering ethnobotanical significance, phytochemical analysis, distribution patterns, and conservation efforts. Much of this research has been dedicated to understanding the practical benefits of wild plants, including their roles as sources of food, medicine, animal fodder, and fuelwood. The Ladakh region hosts a remarkable diversity of plant species, with more than 150 plant species identified for their medicinal use. Similarly, over 30 species were analyzed for their phytochemical properties and extracted a variety of crucial phytochemicals such as terpenes, alkaloids, phenols, flavonoids, tannins, saponins, and steroids.

Plant distribution and diversity in Ladakh are strongly influenced by altitude, with harsh climatic conditions and high altitudes leading to reduced vegetation cover and species richness.

Conclusions: Ladakh possesses a unique plant diversity in challenging terrains. Despite topographical and climatic hurdles, researchers from India and abroad have explored its rich flora. Plant distribution shifts with elevation and climate change, peaking at 4000 to 5800 meters and diminishing higher up. The extensive documentation and research conducted by scientists and researchers on the plant's ethnobotanical significance, has led to the identification of a large number of plant species with medicinal and other significance. Unfortunately, threats to species survival, such as over-collection of underground parts, overgrazing, and exploitation of resources for fuelwood and fodder have been observed, but protective measures and preservation strategies are lacking.

Keywords: Floral diversity, Ethnomedicinal, Phytochemicals, Ecosystem services, Conservation, Ladakh

Background

The Trans Himalayan region of India comprises the rain shadow region of the Greater Himalaya, which spans over an area of 186000 km^2 that includes parts of the Tibetan plateau and Tibetan Marginal Mountains (Mishra *et al.* 2003). Ladakh region contributes the highest geographical area, covering 96,701 km^2 followed by Lahaul-Spiti of Himachal Pradesh and the northern part of Sikkim and Uttaranchal in India (Kala 2005). The region is known for harsh climatic conditions above the natural tree line zone with sparse vegetation and low species diversity (Kala 2005). Considering the ecological perspective, the Ladakh region comes under the Trans-Himalayan ecosystem (Namgail *et al.* 2012) where flora and fauna are characterised by low distribution density and highly adapted to aridity and elevation. Several protected areas in the region include Hemis National Park, Changthang High-altitude Wetland Reserve, and Karakoram Wildlife Sanctuary for biodiversity protection. They host varied plant communities, which have most of the bushes, shrubs, and trees found in the region, as well as diverse wildlife, including an abundant migratory bird (Koenraads *et al.* 2018, Namgail *et al.* 2013). Due to relatively harsh climatic conditions, herbaceous flora, including *Poa annua*, *Rheum webbianum*, *Anaphalis virgata*, *Aster falconeri*, *Taraxacum campylodes,* and *Verbascum thapsus* predominate the region (Dvorský *et al.* 2011). These harsh climatic conditions are intensified by xeric conditions (Kala & Mathur 2002), which generally result in an abridged growing season in the region. Compared to annuals and biennials, many perennial plants were also reported to be similar to other alpine floras around the globe (Dvorský *et al.* 2011, Brand *et al.* 2019). Perennial plant species can store considerable amounts of total biomass belowground that support them in overcoming harsh winters. They play a vital role in overcoming the harsh and long winter months (Lubbe *et al.* 2021).

Due to heavy snowfall in winter and sometimes in the early spring season, the region remains disconnected from other parts of the country for 3-5 months. However, it is remarkable that many explorers had worked in Ladakh in multiple fields. The floral exploration of the region can be traced back to the times when Ladakh (under the political control of Britain, being a part of the dominions of the Maharajah of Kashmir) was the practicable highway from India to Central Asia (Fewkes 2008). Though several explorers explored Ladakh over the years (Table 1), one noteworthy study was conducted by Stewart in 1916, providing valuable botanical information across different areas of Ladakh by compiling the first-ever flora of Ladakh based on his data from 1911-1913. Hereafter, several Indian researchers have worked in different fields over the years. Since India gained independence in 1947, extensive efforts have been made to study and assess Ladakh's flora for the well-being of its inhabitants. Singh and Chaurasia (1998) reported that the cold desert biome in India is confined to Ladakh and Lahaul-Spiti of Himachal Pradesh; therefore, physio-graphically divided the whole Indian cold desert into six valleys, viz. Leh, Nubra, Changthang, Suru, Zanskar, and Lahul-spiti. Similarly, most Indian authors have described the region's climate as a cold desert type, thus referring to the whole region as a cold desert (Negi 2002, Chauhan *et al.* 2020, Joshi *et al.* 2020). However, Husaini *et al.* (2013) argue that the nomenclature has been based on the commonality of cold and arid environments; henceforth, xerophytes dominate both regions. Similarly, the Suru valley of Ladakh, which acts as a transitional region between Kashmir and Ladakh, possesses plants that are more similar to the vegetation (alpine mesophytes) of Kashmir. However, the alpine meadows were rare in other parts or absent (Stewart 1916). He further reported that Drass is also more fertile than the rest of Ladakh. A similar study conducted by Aswal and Mehrotra (1981), reported that the flora of Suru valley (Ladakh) and parts of Lahaul valley (Himachal Pradesh) display the characteristics of alpine mesophytes. Furthermore, a study conducted on high-altitude plants' growth suggests that these plants possess sufficient soil moisture but have a dry atmosphere (Mani 1990). Many constraints like aridity, extreme diurnal temperature fluctuation, strong wind, solifluction at higher altitudes, and salinity at lower altitudes prevent vegetation growth and development (Dvorský *et al.* 2011). Their study further stated that semi-deserts and steppes are eastern Ladakh's most common vegetation types. The alpine grassland in the east of Ladakh is a species-rich landscape harboring unique species (Rawat & Adhikari 2005, Dvorský *et al.* 2011). Based on Gaussen's criterion of vegetation classification, Tewari and Kapoor (2013) have categorized the vegetation of the Leh district as Eremic (desertic) and the vegetation of the Kargil district as Hemi-eremic (Hemi-desertic). Hence, the studies above indicate that the whole of Ladakh cannot be referred to as a cold desert; instead, cold and arid terms can be linked with the region.

Table 1. Some prominent explorers of the region.

Name of the explorer	Places visited	Number of plants documented
Moorcroft & his colleagues (1819-1825)	Lahaul, Barachala, Rupshu, Leh, Nubra, Zanskar, Drass	Not reported
Royle (1839)	Ladakh (Rupshu)	---
Vigne (1842)	Ladakh	90
Thomson (1852)	Ladakh and Karakoram	--
Stewart (1870)	Ladakh (Rupshu)	---
Henderson *et al.* (1873)	Ladakh and Yarkand	412 plants, of which 276 were listed from Ladakh
Duthie (1893)	Ladakh (Drass) and Kashmir	---
Stewart (1916)	Suru, Zanskar, Upshi, Rupshu, Sapi, and many other places in Leh	---
Kachroo *et al.* (1977)	Kargil	611
Klimeš (2003)	Eastern Ladakh	More than 400
Klimeš & Dickore (2005)	Dah and Khalsi (Lower Ladakh)	More than 500
Rawat & Adhikari (2005)	Tsokar basin and Changthan plateau	232
Kala (2011)	Eastern Ladakh	647

The most vital aspect of the growing vegetation for the region's residents is the supply of numerous goods and benefits. The residents get ecosystem services from the mountains, such as fuelwood, food, medicine, fodder, and many other benefits. Several researchers across the Ladakh region have reported the palatable floral diversity. Ballabh *et al.* (2007) reported 31 wild edible plant species belonging to 15 families. In a similar study conducted by Murugan *et al.* (2010) from the Nubra valley of Ladakh, 27 high-altitude plant species belonging to 18 families were reported to be palatable. Several other studies have been conducted on wild plants' palatability and ethnobotanical significance (Bhattacharyya 1991, Lamo *et al.* 2012, Dorjey *et al.*2012). Similarly, the wild plants growing in Ladakh have been reported for the treatment of numerous diseases such as diarrhea, constipation, asthma, fever, arthritis, menstrual problems, urinary disorder, and many other diseases related to the heart, liver, kidney, and organs (Singh *et al.* 1996, Kumar *et al.* 2009, Dorjey *et al.* 2012, Chauhan *et al.* 2020). In addition to the medicinal significance, the plants have been used for other purposes, such as fuelwood and dye (Haq *et al.* 2021), fodder (Ahmad *et al.* 2020), roofing (Stobdan *et al.* 2013), tea (Verma *et al.* 2016), paper (Dorjey *et al.* 2012), ornamental (Joshi *et al.* 2006) and grazing cattle (Fox *et al.* 1994). Ethnobotanical knowledge in Ladakh plays a crucial role in the lives of its residents and has significant implications for health and well-being. It represents the cultural heritage of Ladakh's indigenous communities and embodies their historical relationship with the natural environment and their reliance on plants for various needs (Angmo *et al.* 2022). Several plant species identified through ethnobotanical knowledge are used in traditional medicinal systems by local practitioners known as Amchis (Ballabh & Chaurasia 2007). This knowledge is passed down through generations and forms the basis of healthcare in remote areas (Angmo *et al.* 2022). Beyond medicine, plants are used for forage and fodder production, fuelwood, dyes, decorative and ornamental purposes, personal hygiene, and as raw materials which reflects the multifaceted role of plants in daily life. Likewise, phytochemical extracts, such as flavonoids, phenols, alkaloids, and others, may have significant health benefits, including antioxidant and anti-inflammatory properties. Traditional medicinal practices often take a holistic approach to health, considering not only the treatment of specific ailments but also overall well-being. This holistic perspective aligns with the principles of preventive medicine and natural healing. The mountainous landscape of Ladakh provides shelter and harbors a diverse assemblage of wild herbivorous animals such as Tibetan gazelle, Tibetan antelope, blue sheep, Ladakh urial, Asiatic ibex, Kiang (Namgail *et al.* 2007). Likewise, carnivores such as brown bears, snow leopards, wolves, foxes, and a variety of birds take refuge in these mountain ecosystems. The various landscapes in the region have been mentioned in Fig. 1. The above statements prove that the wild plants growing in the harsh climate of Ladakh possess enormous benefits and are a resource for the healthy livelihood of wild animals for the people (residents). Exploring Ladakh's flora would help discover and report new species and may provide valuable insights into adaptation to extreme environments. The indigenous communities in Ladakh possess extensive ethnobotanical knowledge, including traditional medicinal systems and plant uses. Understanding and documenting this knowledge can contribute to both cultural preservation and modern healthcare. Likewise, Ladakh is vulnerable to the effects of climate change, including glacial retreat, changing precipitation patterns, and shifts in plant and animal distributions, researching these impacts can provide critical data for climate change mitigation and adaptation efforts. The region's unique ecosystems are home to several endemic, rare, and endangered species. Studies on conservation strategies, habitat protection, and wildlife monitoring are vital for preserving biodiversity. Hence, the studies of regional flora provide a multifaceted advantage in the field of science and could offer opportunities to contribute to environmental conservation, cultural preservation, and scientific knowledge.

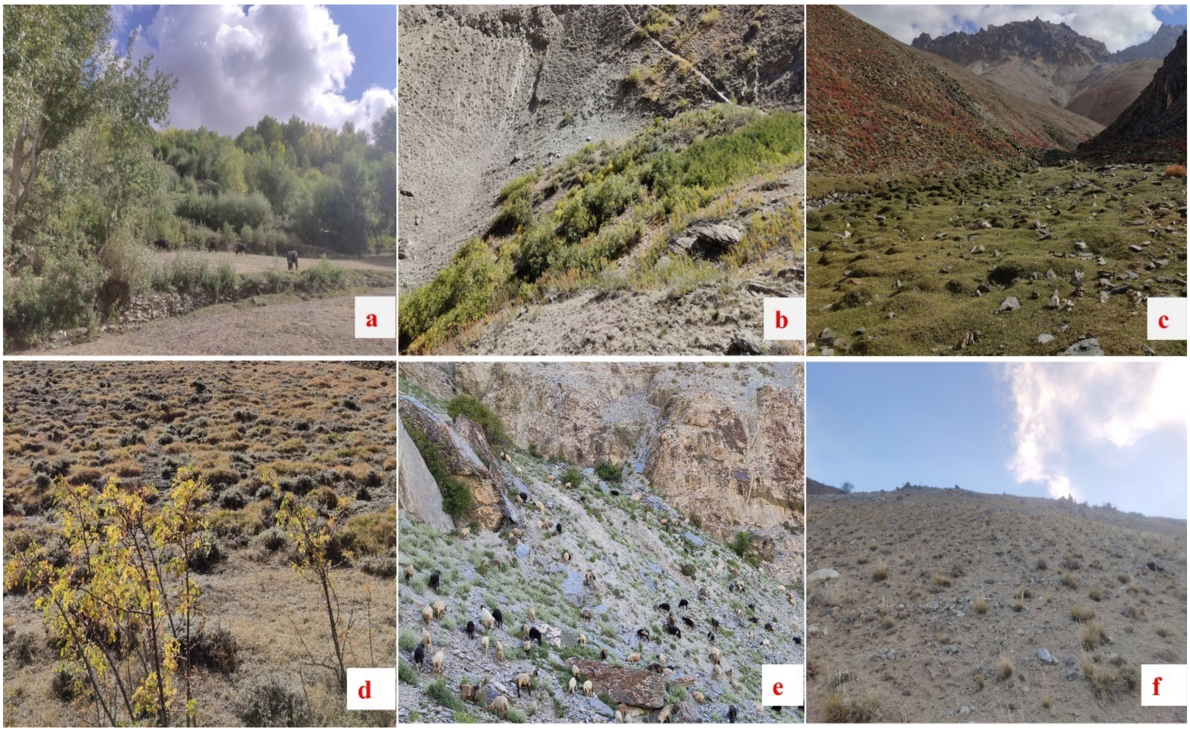

Figure 1. Prominent landscapes in the region a) Oasitic vegetation, b) Shrubland c) Alpine meadow, d) Alpine sedge, e) Grazing land and f) Desertic vegetation

Materials and Methods

The review paper was compiled by searching literature on Ladakh's wild vegetation on a web-based platform such as Web of Science, Scopus, Mendeley, and Google Scholar. The search strings used for the literature survey were comprised of "Ladakh AND vegetation OR plant", "Phytochemical AND Ladakh", "Ethnobotanical* AND Ladakh", "Ladakh AND Flora AND Diversity", "Plant AND Distribution AND Ladakh" and "Medicinal AND Plants AND Ladakh" in the title, abstract and keyword section of the Scopus search string. On the other hand, the search string used for literature search in Web of Science, Google Scholar, and Mendeley consist of; Ladakh and floral diversity, distribution of plants in Ladakh, the ethnobotanical and phytochemical significance of plants in Ladakh, medicinal plants and Ladakh, and exploration of plant diversity in Ladakh. The comprehensive search yielded more than 300 documents which were further processed for full-text screening. Documents explicitly related to the study objectives (155 documents) were considered for synthesizing the review paper.

Results and Discussions

Research trends

Bibliometric analysis

The bibliometric analysis of research on plants/vegetation was performed using a VOS viewer and Delphi software. VOS viewer is a famous visualisation software for bibliometric data presentation (Eck & Waltman 2010). The distance between objects in the VOS viewer displays their connections; the closely associated objects are placed next to each other and are bound by lines, whereas the distantly related things are placed far away from each other (Shinde *et al.* 2021). Keywords that met the threshold were clustered into four groups and further processed for visualisation. Out of 2117 keywords, only 68 met the threshold which was categorized into four clusters. The keywords that appeared the most have larger symbolised circles than others, Ladakh (total link strength 267 and occurrence 63), India (total link strength 351 and occurrence 63), followed by medicine, human and traditional medicine (Fig. 2).

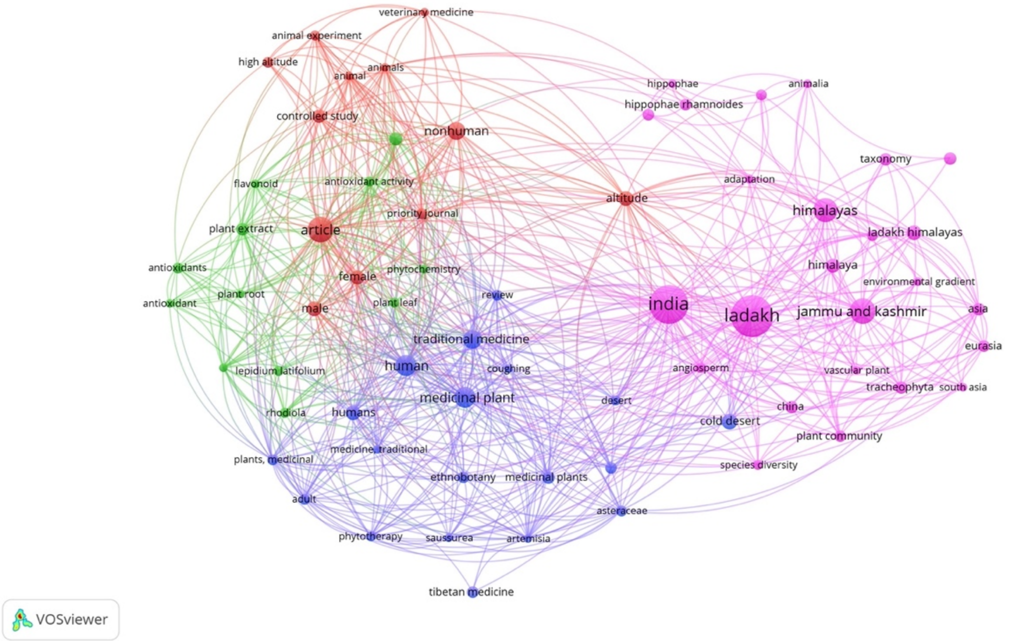

Figure 2. Co-occurrence Analysis of the Author’s Keywords

The Alluvial diagram depicts the correlation between authors, years, and source titles of eighteen highly cited articles. All are clustered according to the publication year and sorted in increasing order of the total citations. The thickness of the waves corresponds to the document citation. The document that received the highest number of citations was Wunnemann et al. (2010) (158 citations), whereas, on a year basis, 2010 (252) received the most citations (Fig. 3).

Exploration of floral diversity in Ladakh

Ladakh occupies the northernmost of India, under the Trans-Himalayan region that includes Himachal Pradesh, and the hilly northern parts of Sikkim and Uttaranchal. It is bordered by Himachal Pradesh to the south, Jammu and Kashmir and Gilgit-Baltistan to the west, Xinjiang and Karakoram Pass to the north, and Tibet to the east. Ladakh extends from Siachen Glacier in the north to the Great Himalayas in the south (Jina 1995). Ladakh was ruled by a succession of local kings until the arrival of the Dogra army led by Zorawar Singh in 1834, and in 1846 it was formally incorporated into the Indian princely state of Jammu and Kashmir within the British Empire (Bray 1998). Although several explorers came to Ladakh through different routes, Moorcroft, with his partner Trebeck (1819-1825), was the first to sightsee the agricultural practices and keenly observed the faunal diversity encountered the usefulness of plants elsewhere (Moorcroft & Trebeck 1841). Stewart (1916) reported that many other explorers visited Ladakh before independence but did not report any botanical information. Jesuits, Desideri, and Freyr entered Ladakh in 1724 on their way to Lhasa.

Similarly, a few explorers, such as Lance, Cayley, Stoliozka, and the Moravian missionaries, Heyde and Jaeschke, might have collected plants but not published their findings. However, Hooker had access to most of these collections (Hooker 1879). Royle (1839) also illustrated his works that were carried out on floral exploration in Ladakh. Likewise, several researchers who had contributed to the exploration of floral diversity include Vigne (1842), who collected ninety plants, and Thomson (I852) devoted most of his time to exploring the plants distributed wildly between the Karakoram and Ladakh Himalayan ranges. Therefore, it is reported that large plant species from Ladakh to the herbarium of the New York Botanical Garden were performed through him (Stewart 1916). Stewart (1870) crossed Ladakh (Ladak) on the 5th of August, 1868, and mentioned some of his findings but did not publish a complete list of plants collected. Other eminent researchers include Henderson *et al*. (1873), who visited Ladakh and collected over four hundred plants from Yarkand (China) and Ladakh. Duthie (1893) visited up to Drass and returned to Kashmir, has not mentioned any plant collected, and Meebold (1905) entered Ladakh from Kashmir and explored Suru, Dah and Kangi regions (Klimeš 2005).

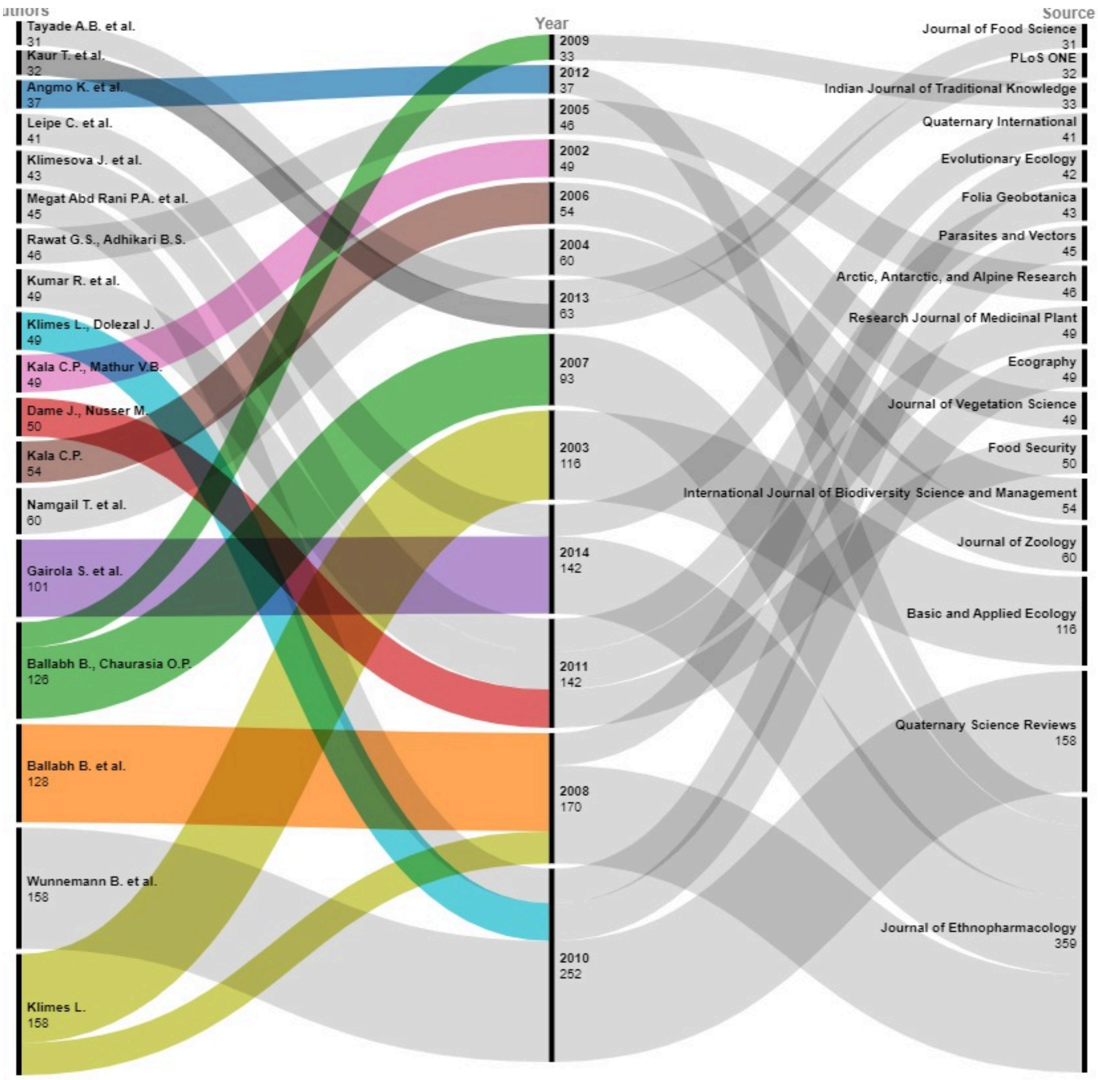

Figure 3. Alluvial diagram showing the correlation between the authors of the most cited documents, years, and source tittles

However, a complete compilation of Ladakh flora was possible with unpaid hard work and determination from Stewart in 1916. He conducted his work in Ladakh in 1912 and 1913 when he explored the vegetation of various regions such as Drass, Suru, Upshi, and Rupshu. He visited such places (Rusila, Sapila, and Yarungshan peaks) in those regions that no other explorers had ever visited at that time (Fig. 4). He provided a piece of significant botanical information after dissecting the whole region into several parts based on the rainfall, plant compositions, and topographical conditions. The pattern of the area's description and their respective feature were comprised of Fotu La and Namika La (Mountain passes on the Srinagar-Leh highway), Suru, Yarungshan La, Sapi La, and Rusi La (Suru is a valley in Kargil district from where the Suru river, an Indus River tributary, drains), Yarungshan La, Rusi La and Sapi La (major mountain passes in the Suru valley, Barsoo and Sapi regions), Baralacha (mountain pass in Zanskar range), Rupshu (high altitude plateau and valley in southeast Ladakh), with many other places of Ladakh including the inhabitation and roadside places. After then, no study seems to have ever been conducted in the region, even for a few decades after the independence of India in 1947.

Re-exploration of botanical investigation in the region might have become possible after resolving the border issues during the 1970s. In the flora of West Pakistan, authored by Nasir and Ali (1970-1979), some border areas of Ladakh were also covered up. Meanwhile, at the same time, Kachroo *et al.* (1977) published the flora of Ladakh in which they reported 611 plant species, of which 400 were reported from Kargil. It included 540 dicots, 65 monocots, and two gymnosperm plant species. Since then, extensive work has been conducted on floral exploration and assessment for people's welfare. It has been reported that more than 20,000 plant specimens have been collected by the Botanical Survey of India just in 15 years from 1975 (Srivastava & Shukla 2015). Over 400 plant species were reported from eastern Ladakh and classified based on life form by Klimeš (2003). Furthermore, Klimeš and Dickore (2005) have opined that there were slightly more than 500 plant species in the lower Ladakh (from Dah to Khalsi villages of Leh district). Further, Rawat and Adhikari (2005) have documented

232 species of vascular plants belonging to 38 families and 101 genera from the Tsokar basin and Changthan plateau of Eastern Ladakh. A total of 647 species of vascular plants were documented during an investigation of the flora of the high-altitude eastern region of Ladakh (Kala 2011). Moreover, several studies were conducted on the medicinal significance of wild flora to the residents through the local practitioner (Amchi) (Kaul 1997, Singh & Chaurasia 1998, Kala 2006, Ballabh & Chaurasia 2007, Ballabh *et al.* 2008, Gairola *et al.* 2014). Likewise, researchers have done phenomenal works on the ethnobotanical significance (Bhattacharyya 1991, Singh *et al.* 1996, Kumar *et al.* 2009, Singh 2013) phytochemical analysis (Raj *et al.* 2010, Avasthi *et al.* 2016, Kumar *et al.* 2011, Gupta & Kaul 2012), distribution pattern (Rawat & Adhikari 2005, Klimeš & Dickoré 2005, Dvorský *et al.* 2015), fodder and fuelwood significances (Jina 1995, Vyas *et al.* 2014, Joshi *et al.* 2006, Haq *et al.* 2021) and conservation of floral diversity (Kumar *et al.* 2011, Warghat *et al.* 2013). The above studies have figured out that research has been conducted in different fields in nexus with the flora of Ladakh. However, the literature survey indicates that researchers were more focused on the medicinal studies and ethnobotanical significances of floral diversity as compared to other research fields. The other numerous past studies conducted on Ladakh's floral diversity have displayed a wide range. New plant species such as *Gentiana aperta* (Shabir *et al.* 2018), *Gentianella devendrae* (Shabir & Tiwari 2021), *Gentianopsis paludosa* var. alpine (Bano *et al.* 2021), and *Swertia drassensis* (Bano *et al.* 2022) have been reported from Ladakh. A new species of *Pinus wallichiana* has been reported in Kaksar's interior mountain of the Kargil district (Banoo *et al.* 2022), which displays the possibility of a *Pinus* spread shortly. The secondary metabolite production and bioactive compounds in plants growing in the wild have also been observed (Gupta & Kaul 2012, Tayade *et al.* 2013, Rattan *et al.* 2020, Kaur *et al.* 2013). Nonetheless, a lot of quality work has been conducted in various fields about the floral diversity of the region.

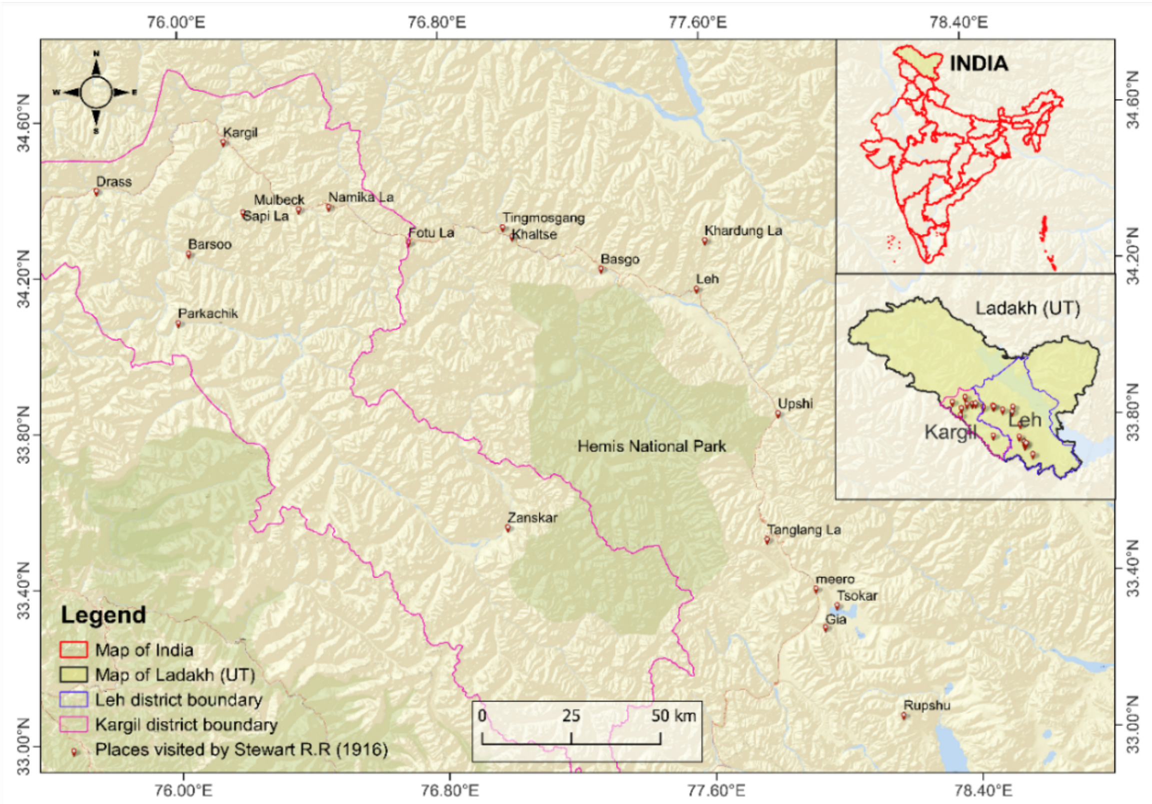

Figure 4. The various sites visited by Stewart (1916) for data collection and compilation on the floral diversity of Ladakh

Distribution and pattern of floral diversity concerning elevation and climate

Studying the floral diversity of Ladakh, considering factors like elevation and climate change, is a challenging task due to the region's rugged terrain, steep slopes, and unpredictable weather conditions. Despite all these constraints, researchers have done a remarkable job to analyze the pattern, life forms, and ecological necessity of floral diversity at different elevations with dynamic conditions. The vegetation in Ladakh has been categorized into three main groups: alpine mesophytes, desertic, and oasitic, as documented by Stewart (1916). Alpine mesophytes are commonly found in the Suru region, which serves as a transitional zone between Kashmir and Kargil. Such mesophytic plants thrive at an elevation above 3000 m asl and include plants such as *Delphinium brunonianum*, *Taraxacum officinale*, *Potentilla bifurca*, *Polygonum affine*, and several species of *Gentiana*, *Leontopodium*, *Aster*, *Kobresia*, and *Stipa*. The Suru region benefits from adequate water supply through numerous streams and springs. Precipitation (mainly in the form of snow) is relatively higher than in other parts of Ladakh, and it is evident that the mountains remain covered with snow till June, and some hills can be snow-capped the whole season. Water availability facilitates the growth of herbaceous vegetation, therefore having higher vegetation cover than other parts of Ladakh (Stewart 1916, Dvorský *et al.* 2011).

The oasitic vegetation (Fig. 1a) represents the flora that occupied the inhabited places of the entire Ladakh, where there is little moisture to support plant growth and constitutes a variety of endemic and exotic plants (Kala & Mathur 2002, Stewart 1916). All types of plant Life forms (Trees, shrubs and herbs) are prevalent in this zone, where the dominant genera comprise *Medicago*, *Lactuca*, *Carum*, *Potentilla*, *Arabidopsis*, *Mentha*, *Myricaria*, *Hippophae*, *Rosa*, *Clematis* and several tree genera such as *Salix*, *Populus*, *Prunus*, *Pyrus*, *Morus*, *Juglans*, *Juniperus* and *Robinia*. Among trees, except *Juniperus*, all are non-native and introduced. However, only *Salix* trees are found at some of the coldest inhabitation places in both the Leh and Kargil districts. Similarly, agricultural practices vary from one place to another.

The desertic vegetation (Fig. 1f) grows at places with little rainfall, low moisture and less humidity, extreme temperature fluctuation and frequent high wind velocity (Dvorský *et al.* 2011). Therefore, due to such stressful conditions, the vegetation has acquired features such as prostrate habit, cushion, and bushy form with deep roots and small succulent leaves (Shukla & Srivastava 2013). The various passes within Leh and Kargil have thrived with desert-type vegetation except for Suru valley, Drass, and places with more moisture (where snow remains frozen until May and provides water for the growing vegetation during the early spring and summer seasons). Desertic vegetation can be easily noticeable at passes like Penzi La (mountain pass in the Zanskar range), Fotu La, Namika La, Barachala, Lachalung La (Leh-Manali highway), and many other passes of the region. Vegetation of the region has also been classified into Eremic (desertic: Leh) and Hemi-eremic (sub-desertic: Kargil) based on Gaussen's criterion (Tewari & Kapoor 2013).

The Ladakh flora was similar to Central Asian flora in general aspects and phytogeographic affinities (Kachroo 1993). The distribution and diversity of life-forms change with elevation (Klimeš 2003, Kala 2011), and the vegetation distribution is highly influenced by the presence of water and forms of water such as running water, stagnant rivers and streams. The species richness and vegetation cover in eastern Ladakh has been reported to decrease with elevation. Therefore, only 67 out of 306 species were found above 5600 m (Dvorský *et al.* 2015). The plains at 4600-5000 m flourished with semi-desert vegetation, which gradually changed into cold steppes with increasing elevation and alpine vegetation represented by close alpine sedge heaths lying along the streams between 5200 and 5600 m. They further claimed that more than 58% of the species had their center of the distribution below 5800 m, with typical alpine plants such as *Arenaria bryophylla*, *Potentilla pamirica*, *Saxifraga cernua*, and *Stellaria depressa*, whereas 40% of the plant species were distributed above 5800 m and were consider subnival with typical plants such as *Desideria pumila*, *Ladakiella Klimesii*, *Saussurea inversa*, and *Draba* species. In a similar study conducted by Klimeš (2003) in the Rupshu region of Ladakh, he observed that the area has predominant desert-steppe and steppe vegetation with hemicryptophytes (62.1%), therophytes (22.3%), chamaephytes (5.4%) and geophytes (4.2%). However, the diversity of life-forms was reported to decline with elevation; phanerophytes and hydrophytes were found up to 5150 m, therophytes declined gradually, and geophytes and chamaephytes were constant up to 5800 m. Only Hemicryptophytes were found at extreme elevations (Dvorský 2014). Similarly, Hemicryptophytes were found to be the largest life forms among species co-occurring with *Arnebia euchroma* comprising (59.05%) of species, followed by Therophytes, Geophytes, Phanerophyte, and Chamaephytes, respectively (Sofi *et al.* 2022). Kala and Mathur (2002) further reported that the number of plant species varied with elevation and was most concentrated between 4000-4500 mean sea level (asl), followed by a sharp decline.

Temperature is found to decrease with increasing elevation linearly. However, water availability correlated with elevation moderately. The occurrence of most species rapidly decreased with the increasing cold, suggesting that drought is a less restrictive determinant of range limits than cold (Dvorský *et al.* 2017). On the contrary, Rawat and Adhikari (2005) observed that vegetation cover, density, species richness, and diversity depended on the gradients of soil moisture and landscape type rather than the altitudinal gradient. Based on differences in floristic composition, Dvorský et al. (2011) delimited eight major vegetation types, viz. salt marsh, shrublands, water bodies, semi-deserts and steppes, alpine grassland, resting places for animals, screes and subnival zones. However, they reported that alpine grasslands and subnival vegetation were the most common at the highest elevations, and shrublands were the least common. Rawat and Adhikari (2005), categorized the vegetation of the Tsokar basin into scrub formations, desert steppe, and marsh meadows. The vegetation cover was highest in marsh meadows (92%) and lowest within the desert steppe (37%).

Furthermore, a study conducted on the coloniality of plants in eastern Ladakh by Klimeš (2008) noticed that the integrators had occupied a higher mean maximum elevation than splitters. In contrast, no difference was found between splitters and non-clonal plants except for the Stot area. In most of the studies conducted so far on the distribution pattern of the region, it is explicit that the vegetation forms a vertical stratum. The lower parts inhabited by the residents have been occupied by oasitic vegetation. The vegetation gradually changes to the desert due to moving towards higher elevation followed by steppes, alpine grassland, and sub-nival vegetation (Fig. 5). The most dominant families that have thrived over the region's landscapes were Poaceae, Asteraceae, Brassicaceae, Fabaceae and so on (Fig. 6). However, the species richness concerning elevation has differed from one area to another. For example, Namgail *et al.* (2012) observed that the species-richness at a single mountain peaked between 5,000 and 5,200 m, while more species diversity was found between 3500 to 4000 m for the entire Ladakh. Various factors like precipitation, temperature, soil, elevation, and wind velocity trigger the change in vegetation in multiple places in the region. Similarly, Dvorský *et al.* (2015) noted that species richness was highest at elevations between 4600 to 5000 m. Another noteworthy thing regarding research on the distribution and pattern of floral diversity in the region is that studies are more concentrated in the Leh region of Ladakh. At the same time, no such research has been conducted in the Kargil region except by Stewart (1916). Moreover, the distribution of floral diversity in Ladakh could differ significantly between Leh and Kargil districts, as annual precipitation at Leh is only 83 mm. Kargil has a yearly precipitation of 266 mm (Klimeš & Dickore 2005).

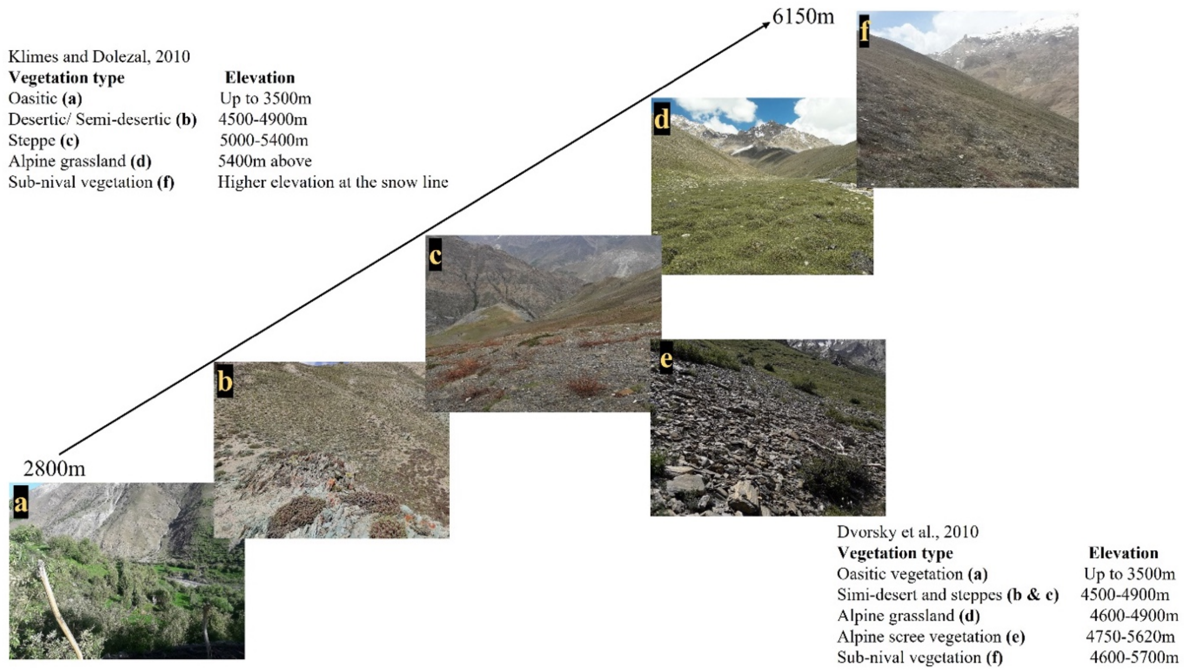

Figure 5. Changes in vegetation type for increasing elevational gradients

Plant resources and ecosystem services

Ecosystem services refer to the benefits people obtain from an ecosystem (MEA 2005, Costanza *et al.* 1997). These ecosystem services directly (food, freshwater) or indirectly (air purification, regulation of extreme events) impact human well-being. However, research on landscapes/ecosystems in the region in merely in the context of some services that are conclusive to the locals such as food, fodder, fuelwood, and medicine. In contrast, other important services that have cultural, regulating, and supporting significance were unnoticed and undocumented. Ladakh is a mountain region and a popular tourist destination; its cultural significance is highly appreciated (Vannelli *et al.* 2019). At the same time, no accountability has ever been done to analyze the importance of vegetation for cultural attractions. Several landscape types have been reported from the region that comprises alpine meadows, steep slopes, rocky terrain, plains, and beautiful snow-covered peaks (Kala & Mathur, 2002), which are the striking features of the region's landscape. These landscapes have diverse plant compositions that are vital for the people's sustenance by various means. Most of the underutilized plants, such as *Allium carolinianum*, *Capparis spinosa*, *Cicer microphyllum*, and *Eurotia ceretoides* were reported to contain nutrients essential for human health (Uniyal *et al.* 2005, Ballabh *et al.* 2007, Chandra-Hioe *et al.* 2016, Sun *et al.* 2022). Likewise, *Cicer microphyllum*, *Heracleum pinnatum*, *Geranium himalayense*, and *Aconogonum tortuosum* were documented as crucial fodder sources for the cattle

(Ahmad *et al.* 2020). People living in the far-flung mountains of the Ladakh region have access to such services and share a strong interaction with the mountain ecosystem (Hussain *et al.* 2022). In harsh winters, the locals also collect fuelwood from the mountain, usually produced by plants such as *Myricaria germanica*, *Juniperus communis*, *Lonicera* species, *Betula utilis*, *and Aconogonum tortuosum* (Haq *et al.* 2021). Furthermore, grazing is another crucial service supplied by the mountains worldwide. Nearly 25% of the global land area is maintained for grazing cattle (Asner *et al.* 2004), and Ladakh has landscapes devoted to grazing (Khara *et al.* 2021). All these services and their prominent phytochemical and ethnobotanical importance have been reported to influence the livelihood of the regional people. However, several other services usually associated with the mountain ecosystems are unreported. These include services such as regulation of extreme events, water and air purification, soil erosion and flood regulation, water regulation, aesthetic, arts, and inspirational and habitat provision (Zhang *et al.* 2019, Mengist *et al.* 2020, Yu *et al.* 2021).

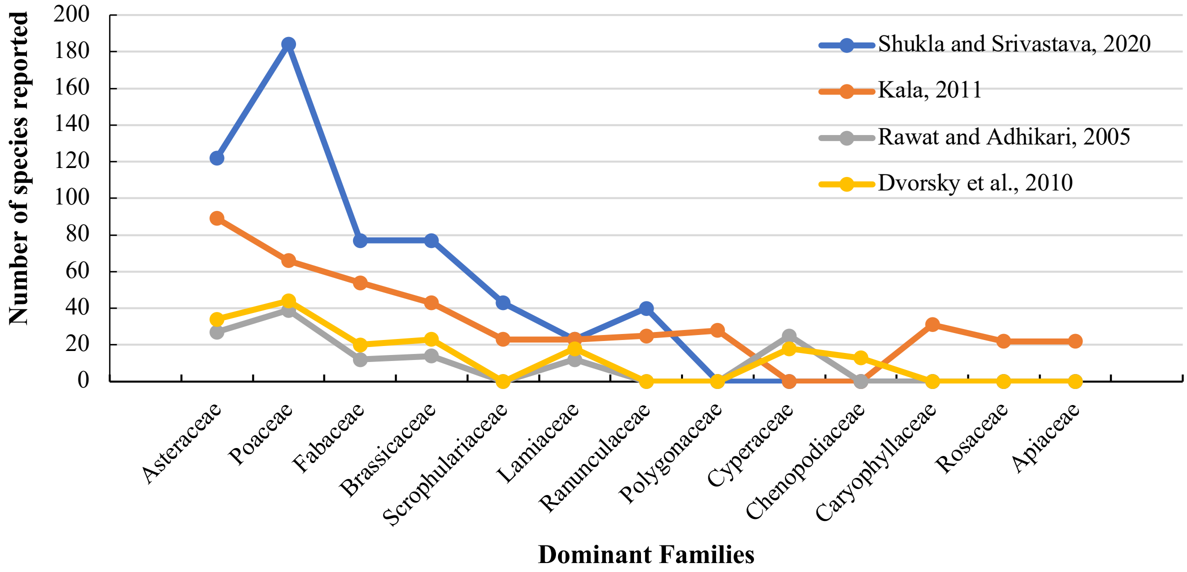

Figure 6. Family-wise distribution of plant species reported from Ladakh

Phytochemical significance and ethnobotanical uses

Ladakh flourished with numerous typical floral diversities with vast ethnobotanical and phytochemical significance. A great deal of work has been done by researchers over the years with much emphasis on the utilization of plants for different purposes by the residents. It includes traditional medicinal systems, forage and fodder production, fuelwood, dyes, decorative, ornamentals, and production of raw materials. Similarly, as research progressed, the researchers were keen to assess and evaluate the vegetation for the production of phytochemicals. Although plants might have been utilized for medicinal purposes for ages, Abrol and Chopra (1962) researched some important medicinal plants of the Ladakh region used by the local traditional practitioner (Amchi) to treat various diseases. More than 40 plant species growing in the Leh region used as a medicinal resource were described by Buth and Navchoo (1988). The residents have used wild plants growing in the mountains of Ladakh as vegetables, ceremonial observations, material culture, personal hygiene, and fodder (Bhattacharyya 1991). Similarly, 51 plant species of Ladakh were reported for the treatment of gynecological disorders (Chaurasia 2011), 68 plants belonging to 29 families and 58 genera were documented for the treatment of kidney and urinary disorders (Ballabh *et al.* 2008), 56 plants were utilized against cough, cold and fever (Ballabh & Chaurasia 2007), 128 plant species belonging to 45 families were used as home remedies against diseases (Singh *et al.* 1996), and as many as 425 plant species of medicinal importance were collected by Singh and Chaurasia (1998). Some notable research has even highlighted herbal formulations for medicinal purposes. For instance, Ballabh and Chaurasia (2007) documented the use of 56 plant species in Ladakh Himalaya to combat cold, cough, and fever. They also described the herbal formulations derived from these plants, which typically involved using the whole plant body and roots. These formulations were commonly prepared as tablets, powders, or decoctions and administered in single or double doses for a week. Similarly, Ballabh and Chaurasia (2011) conducted a study on 51 medicinal plants used to address gynecological disorders. They reported varying treatment durations, ranging from seven to 30 days, with twice-daily doses. The specific treatment duration depended on factors such as the plant's potency, the parts used, dosage, and combinations. In a related study, Ballabh *et al.* (2008) investigated 68 plants used in the treatment of kidney and urinary disorders among tribal communities in the Ladakh region of India. They observed that tablets, powders, and decoctions were the most common forms of preparations. These herbal remedies were administered once, twice, or thrice a day for one to two weeks by Amchi practitioners. An Unstructured and semi-structured questionnaire survey was conducted by Kala (2006) with 83 Amchis living in Ladakh and Lahaul-Spiti, recording 335 medicinal plant species utilized for treating various diseases. Furthermore, plants wildly grown in the region have been used against various diseases such as stomach disorders (Ballabh & Chaurasia 2009), cardiac and ulcer (Dawa *et al.* 2021), dysentery and diarrhea (Chaurasia *et al.* 1998), wound infection and intestinal disorder (Kumar *et al.* 2010), arthritis (Buth & Navchoo 1998) and many other diseases (Kumar *et al.* 2011). A comprehensive literature search on various research databases has identified more than 150 plant species with medicinal and other significance (Table 2). Asteraceae, Ranunculaceae, Polygonaceae, Brassicaceae, and Lamiaceae were the families with the most significant number of medicinal plant species (Fig. 7). Furthermore, these medicinal plants are used against kidney diseases, liver diseases, fever, chest pain, colds, stomach pain, abdominal pain, eye diseases, and several other many diseases that are prevalent in the region. Although, the portion of the plant used for treating a disease comprises either the whole plant body or some part of the plant body such as leaves, roots, stems, flowers, or seeds. In most cases, the entire plant is used for treatment (28%), followed by leaves (24), root and shoot (15%), seed (10%), and flower (8%) (Fig. 8). The local practitioners when preparing a medicine, take utmost care of the combination and proportion of plants used for a particular formulation. *Saussurea lappa* has been reported to be used very frequently in preparing medicinal formulations by Amchi. *Saussurea lappa*, *Inula racemose*, *Oxytropis chiliophylla*, *Picrorhiza kurrooa*, *Rubia cordifolia,* and many other plants given in Table 3, were the most used plant species in the medicinal formulation.

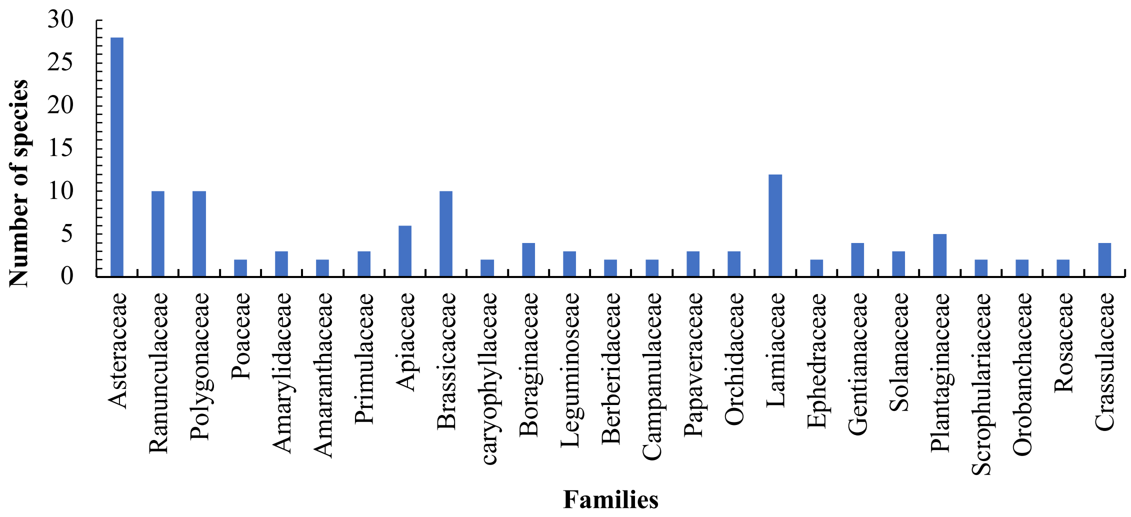

Figure 7. Family-wise number of plant species used in the medicinal formulation

The plants growing in the region have been explored to produce phytochemicals. Phytochemical extracts include terpenes, alkaloids, phenols, flavonoids, tannins, saponins, and steroids (Fig. 9). A high flavonoid and phenolic content were extracted from *Mentha longifolia* (Raj *et al.* 2010). *Dracocephalum heterophyllum* has been reported as fairly rich in tannins, flavonoids, saponins, steroids, and alkaloids (Raj & Bala 2010). Rich phenolic contents were observed in *Radiola imbricata* and have a significant potential to be used as a natural anti-oxidant agent (Raj *et al.* 2010). In the same context, phytochemicals such as phenols, phenylethanoids, phenylpropanoids, flavonoids, iridoids, lignans, and alkaloids were obtained from *Pedicularis* species. (Yatoo *et al.* 2017). An essential oil containing lavandulol as a major constituent was obtained from *Tanacetum gracile* in Ladakh (Kitchlu *et al.* 2006). A glucoside, apigenin 7-glucoside was isolated for the first time from *Stachys_tibetica* roots. (Kumar & Bhat 2014). A high content of 2-propenyl glucosinolate was obtained from the seed sprouts of *Lepidium latifolium* L. along with a higher amount of nutritionally important vitamin C, carotenoids, phenolic acids, and fatty acid (Ali *et al.* 2021). Numerous essential wild plants have been identified for the extraction of phytochemicals (Table 4).

Table 2. Medicinal plants of Ladakh with local name, part used for medicinal purpose and other important uses

Botanical name	Local name	Family	Part used	Medicinal use	Other uses	References
Acantholimon lycopodioides (Girard) Boiss.	**Longze**	Plumbaginaceae	Whole plant	Cardiac disorder	Fuelwood	Kala 2006, Ballabh *et al.* 2008, Kumar *et al.* 2009
Achillea millefolium L.	**Chuang**	Asteraceae	Leaves	Anti-inflammatory, kidney, bladder and urinary problems and stomachache	Fodder	Kaul 1997, Kala 2006, Ballabh & Chaurasia 2007, Kumar *et al.* 2009, Raj *et al.* 2010
Aconitum heterophyllum Wall. Ex Royle.	**Bona-karpo**	Ranunculaceae	Root	Stomachache, vomiting, gastric, abdominal pain, antidiabetic	--	Kala 2006, Ballabh & Chaurasia 2007, Kumar *et al.* 2009
Aconitum violaceum Jacq. ex Stapf.	**Bona-Nagpo**	Ranunculaceae	Root	Cold, cough, asthma, fever and gastric problem	--	Kaul 1997, Kala 2006, Ballabh & Chaurasia 2007, Kumar *et al.* 2009
Aconogonum tortuosum (D.Don), Hara.	**Serpalulu, Sngalo**	Polygonaceae	Whole plant	Painful urination	Fodder	Ballabh *et al.* 2008, Kumar *et al.* 2009
Agropyron repens (L.) P. Beauv	**Zamak**	Poaceae	Rhizome	Kidney and urinary tract problem	Fodder	Ballabh *et al.* 2008
Allium carolinianum DC.	**Skotse**	Amarylidaceae	Leaves	Indigestion, antidiabetic,	Spices	Kala 2006, Singh 2013
Allium stoiczki Regel	**Skotse**	Amarylidaceae	bulb	Women delivery, constipation	Spices	Buth & Navchoo 1988
Amaranthus spinosus L.	**Snue**	Amaranthaceae	Leaves	Promote kidney function	Vegetable	Murugan *et al.* 2008, Ballabh *et al.* 2008
Anaphalis triplinervis (Sims) C.B.Clarke	**Spra-Rok**	Asteraceae	Leaves and flowers	Skin diseases	Fodder	Kala 2006, Ballabh *et al.* 2007
Androsace sps.	--	Primulaceae	Shoot	Abdominal pain	Ornamental	Kala 2006, Kumar *et al.* 2009
Anemone rivularis Buch.	**Kikisorng**	Ranunculaceae	Fruits	Indigestion	--	Kala 2006, Ballabh & Chaurasia 2009
Anthriscus nemerosa Spreng	**Sunak**	Apiaceae	Whole	Rheumatism,	--	Buth & Navchoo 1988
Aquilegia fragrans Benth.	--	Ranunculaceae	Flowers	Jaundice, asthma, diabetes, headache, body pain	Ornamental	Kala 2006, Singh 2013
Arabidopsis himalaica (Edgew.). Schulz.	**Byiulaphug**	Brassica	Whole plant	Control apatite and indigestion	Fodder	Kala 2006, Ballabh & Chaurasia 2009
Arabis tibetica Hk. f. & Th.	--	Brassicaceae	Leaves	Wound	--	Kala 2006, Shabir *et al.* 2018
Arctium lappa L.	**Pizum**	Asteraceae	Roots	Diuretics, remove kidney stone	--	Kala 2006, Ballabh *et al.* 2008
Arenaria serpyllifolia L.	**Lekhum**	Caryophyllaceae	Whole plant	--	--	Ballabh *et al.* 2008

Arnebia euchroma (Royle) Jhon	**Demok**	Boraginaceae	Roots	Blood purification, pulmonary, kidney and bladder problems, cough	Dye	Kala 2006, Kumar *et al.* 2009, Murugan *et al.* 2008
Artemisia biennis Willd.	**Khampa**	Asteraceae	Shoot	Intestinal worm	Fodder	Kala 2006, Singh 2013, Shabir *et al.* 2018
Artemisia brevifolia Wall. ex DC.	**Burse, khamchu**	Asteraceae	Whole	Fever, Stomach and intestinal problem	Fuelwood and fodder	Ballabh & Chaurasia 2007, Ballabh & Chaurasia 2009
Artemisia dracunculus L.	**Burtse**	Asteraceae	Whole plant	Bladder and kidney problem, tooth pain	Fodder and fuelwood	Kala 2006, Ballabh *et al.* 2008, Kumar *et al.* 2009, Ballabh & Chaurasia 2009, Raj *et al.* 2010
Artemisia gmelinii Web ex. Stechm	**Khampa**	Astereceae	Leaves and flower	Stomach and abdominal pain	Fuelwood, fodder	Ballabh & Chaurasia 2007, Ballabh & Chaurasia 2009
Artemisia maritima L.	**Nakz-Bur**	Asteraceae	Leaves and stem	Headache, stomach pain and inflammation	--	Singh 2013, Gairola *et al.* 2014
Artemisia perviflora Roxb.	**Khamang, Khampa**	Asteraceae	Whole plant	Improve urine discharge	--	Ballabh *et al.* 2008
Asperugo procumbens L.	**Zingsha**	Boraginaceae	Roots	Stomach complaints	Fodder	Shabir *et al.* 2018
Aster diploslephoides Benth	**Utpal Vanpo**	Ateraceae	flower	Cough and respiratory problem	--	Buth & Navchoo 1988, Ballabh & Chaurasia 2007
Aster flaccidus Bunge.	**--**	Asteracae	Leave	Fever	Ornamental	
Astragalus rhizanthus Royle ex Benth.	**Zbi-chu**	Leguminosae	Whole plant	Skin diseases	fuelwood	Shabir *et al.* 2018
Astragalus Zanskaensis Benth. Ex Bunge.	**Chisigma**	Fabaceae	Root	Intestinal problem	--	Buth & Navchoo 1988
Avena fatua L	**--**	Poaceae	Shoot	Wound	Grain as flour	Kala 2006, Murugan *et al.* 2008
Berberis ulicina Hk. F. & Th.	**Sinskingnama**	Berberidaceae	Fruits	Ring worm, arthritis, cough, fever	--	Buth & Navchoo 1988, Kumar *et al.* 2009
Bergenia stracheyi (Hk. f. & T.) Engl.	**Tiang**	Saxifragaceae	Rhizome, roots	Diuretics and stomach-ache	--	Ballabh *et al.* 2008, Ballabh & Chaurasia 2009
Betula utilis D. Don	**Stakpa**	Betulaceae	Bark	Bark possesses antiseptic property, Nose bleeding	Writing paper, fuelwood	Kala 2006, Singh 2013
Bidens pilosa L.	**Gurgur Chai**	Asteraceae	Leaves		Tea preparation	Ballabh & Chaurasia 2007, Raj *et al.* 2010
Bunium persicum (Boiss.) Fedtsch.	**Kala zeera**	Apiaceae	Seeds	Indigestion, dysentery and carminative	Vegetable	Kaul 1997, Murugan *et al.* 2008

Campanula latifolia L.	--	Campanulaceae	--	--	Ornamental	Shabir *et al.* 2018
Capparis spinosa L.	**Kabra**	Capparaceae	Buds and leaves	Viral hepatitis, cirrhosis of liver, diabetes	Vegetable	Buth & Navchoo 1988, Mollica *et al.* 2017
Capsella bursa-pastoris	**Sog-ka**	Brassicaceae	--	Abdominal pain, intestinal problem	Vegetable	Murugan *et al.* 2008, Gairola *et al.* 2014
Carum carvi L.	**hyocy**	Apiaceae	Seeds and roots	Indigestion, poisoning and urinary problems	Roots are eaten raw	Buth & Navchoo 1988, Raj *et al.* 2010, Singh 2013
Cerastium vulgatum L.	--	Caryophyllaceae	Shoot	fever	--	Kala 2006,
Chaerophyllum reflexum Lindl.	**Young**	Apiaceae	Roots	Improve urine discharge	--	Ballabh *et al.* 2008
Chenopodium album L.	**Snue**	Amaranthaceae	Leaves	Gastric troubles, painful urination	vegetable	Buth & Navchoo 1988, Gairola *et al.* 2014
Christolea crassifolia Camb.	**Sanak**	Brassicaceae	Shoot	Liver problem	--	Shabir *et al.* 2018
Cicer microphyllum Benth.	**Sari**	Fabaceae	Whole plant	Seeds are a good source of lecithin.	Whole shoot is eaten raw	Ballabh *et al.* 2007, Shabir *et al.* 2018
Cirsium wallichii D.C	**Zbangsar**	Asteraceae	Whole plant	Stomach pain	Fodder	Shabir *et al.* 2018
Clematis orientalis L. var. acutifolia Hk.f.et T.	**Tiktikma**	Ranunculaceae	Shoot	Indigestion	--	Ballabh & Chaurasia 2009
Codonopsis clematidea (Schrenk) Cl.	**Mokhting**	Campanulaceae	Whole plant	Stomachache, digestion, arthritis, rheumatism, stiffening of ligaments, nerves, paralysis and leprosy.	Root is edible, Fodder	Ballabh *et al.* 2007
Conringia planisiliqua Fisch. & Mey.	**Lu-sunma**	Brassicaceae	Root	Diuretic	Vegetable	Kala 2006
Corydalis meifolia Wall.	**Makshang**	Papaveraceae	Leaves	Stomach pain	--	Kala 2006
Corydalis govaniana Wall.	--	Papaveraceae	Flower	Fever	--	Kaul 1997, Ballabh & Chaurasia 2007, Gairola *et al.* 2014
Cousinia thomsonii Cass.	--	Asteraceae	Flower	Arthritis, body pain	--	Kala 2006, Singh 2013
Cremanthodium ellisii (Hk. f.) Kitam.	--	Asteraceae	Shoot	Fever	--	Kala 2006, Ballabh & Chaurasia 2007
Cuscuta capitata Roxb.	--	Cuscutaceae	Whole plant	Used against burning sensation	--	Ballabh *et al.* 2008
Cynoglossum wallichii G.Don	**Shoamer**	Boraginiaceae	Whole plant	Against swelling, vomiting	--	Shabir *et al.* 2018

Dactylorhiza hatagirea (D. Don.) Soo	**Ambolakpa**	Orchidaceae	Tubers	Used as sedatives and stomach pain, asthma, skin disorder	--	Ballabh & Chaurasia 2007, Ballabh & Chaurasia 2009, Kumar *et al.* 2009
Delphinium brunonianum Royle.	**Lunde-Kaown**	Ranunculaceae	Whole part	Used for colic	Ornamental plant	Buth & Navchoo 1988
Delphinium cashmerianum Royle	--	Ranunculacea	Seed, Flower	Throat infection	Fodder	Kala.2006
Descurainia Sophia Webb	--	Brassicaceae	Shoot	Body ache and headache	--	Shabir *et al.* 2018
Dysphania botrys (L.)	**Snuee, Sanyek**	Chenopodiaceae	Shoot	Indigestion problems	--	Shabir *et al.* 2018
Echinops cornigerus DC.	**Aczema**	Asteraceae	Whole plant	Wound healing	Fodder	Kaul 1997, Shabir *et al.* 2018
Elsholtzia densa Benth.	**Bye-rug nagpo**	Lamiaceae	Shoot	Anti-inflammatory	Leaves are eaten raw, Fodder	Ballabh *et al.* 2007
Ephedra gerardiana Wall ex. Stapf.	**Tsepat**	Ephedraceae	Whole plant	Fever, hepatic diseases and bronchial asthma.	Fruits are edible	Buth & Navchoo 1988, Kumar *et al.* 2009
Ephedra intermedia Schrenk ex C.A. Mey.	**Schapat**	Ephedraceae	Stems	Asthma, fever	Fruits are edible	Kala 2006
Epilobium angustifolium L.	**Utpalwanabo**	Onagracea	Whole	Abdominal pain, intestinal, kidney	Fodder	Ballabh & Chaurasia 2009, Gairola *et al.* 2014
Erigeron canadensis L		Asteraceae	Shoot	Dysentery and diarrhea	Fodder	
Galium aparine L.	**Ranche**	Rubiaceae.	Leaves	Wound	Fodder	Ballabh *et al.* 2008, Ballabh & Chaurasia 2009, Singh 2013
Gentiana algida Pallas.	**Ziang**	Gentianaceae	Seeds	Regulate urine discharge	--	Ballabh & Chaurasia 2007,
Geranium pratense L.	**Gadur**	Gereniaceae	Leaves	Diarrhea, cold, jaundice	Fodder	Ballabh & Chaurasia 2007, Singh 2013
Heracleum pinnatum C. B. Clark	**Khras**	Apiaceae	Whole plant	Knee pain, inflammation, fever, checks hemorrhage and abdominal cramps.	Some parts are edible, Fodder	Ballabh & Chaurasia 2007, Raj *et al.* 2010,
Herminium monorchis (L.) R. Br.	**Peo**	Orchidaceae	Bulb	Sedative	--	Ballabh *et al.* 2008
Hippophae rhamnoides L.	**Tsermang**	Elaeagnaceae	Fruits and leaves	Anti-ageing, anti-cold and source of Vit-C,	Whole plant is used as fuelwood and hedge	Buth & Navchoo 1988, Raj *et al.* 2010
Hyocyamus niger L.	**Rga-lantang**	Solanaceae	Seed and leaves	Seed are used for teeth infection and seeds for asthma, nervous diseases	Fodder	Kumar *et al.* 2009, Singh 2013

Inula racemosa Hooker	**Manu**	Asteraceae	Roots	Bronchial asthma, blood, inflammation due to phlegm, fever and pain in upper body	Fodder	Raj *et al.* 2010, Singh 2013
Inula royleana DC.	**Rupmak**	Asteraceae	Shoots	Dermatitis, inflammation	Fodder	Kala 2006, Gairola *et al.* 2014
Iris hookeriana	**Tesma**	Iridaceae	flower	Urine discharge	Ornamental	Ballabh *et al.* 2008
Juniperus macropoda Boiss.	**Shukpa**	Cupressaceae	Leaves, fruits	constipation, gout, menstrual problems, inflammation of lung, liver, kidney and gall bladder and diuretic	Used as Incense	Kaul 1997, Buth & Navchoo 1988
Lagotis kunawurensis (Royle ex Benth.) Rupr.	**--**	Plantaginacea	Leaves	Cough and cold	Fodder	Kala 2006, Ballabh & Chaurasia 2007
Lancea tibetica Hk. f. & T.	**Spa-yang sta**	Scrophulariaceae	Fruits	cardio diseases and retention of menses	Tonic	Kumar *et al.* 2009
Leontopodium nanum (Hk. f.) Hand.	**--**	Asteraceae	Whole	Septic wound	Fodder	Bhattacharyya 1991
Lepidium latifolium L.	**Seoji**	Brassicaceae	Whole plant	Rheumatism, prevent hemorrhage of kidney	--	Buth & Navchoo 1988
Lindelofia longiflora (Benth.) Baill.	**Bong-rna**	Boraginaceae	Leaves	Diarrhea	Fodder	Kala 2006
Lomatogonium rotatum (L.) Fries ex Nym.		Gentianaceae	Shoot	Fever	Ornamental	Kala 2006
Lycium ruthenicum Murray ex Dunal.	**Umila**	Solanaceae	Leaves	Diuretic, Removes blocked urine	Fuelwood	Ballabh *et al.* 2008
Malaxis muscifera (Lindl.) Ktze.	**Jeewak**	Orchidaceae	Roots	Tonic, Promote kidney function	--	Kala 2006, Ballabh *et al.* 2008
Malva verticillata L.	**suchili**	Malvaceae	Whole plant	Kidney problems	Fodder	Ballabh & Chaurasia 2007, Ballabh *et al.* 2008, Singh 2013
Meconopsis aculeata Royle	**--**	Papaveraceae.	Leaves, Flowers	Fracture, Tonic	Ornamental	Kaul 1997, Ballabh & Chaurasia 2009
Mentha longifolia (L.) Huds.	**Fololing**	Lamiaceae.	Leaves	Anti-dysenteric	Vegetable	Ballabh & Chaurasia 2009, Raj *et al.* 2010
Morina longifolia Wall.	**Aczema**	Caprifoliaceae,	Seeds	Seeds are highly nutritious for children	--	Kaul 1997, Buth & Navchoo 1988
Myricaria germanica (L.) Desr	**Umboo**	Myricaceae	Leaves	Leaves taken as blood purifier	Stem were used as a writing pen	Buth & Navchoo 1988

Nepeta coerulascens Maxim.	**Khora**	Lamiaceae	Whole plant	Dysentery and stomach-ache	Used as flavoring agent	Ballabh & Chaurasia 2009
Nepeta errecta Benth.	**Eripantso**	Lamiaceae	----	----	Used as flavoring agent	Ballabh & Chaurasia 2009
Nepeta floccosa Benth.	**Shamalolo, Tseeing**	Lamiaceae	Leaves	Cough, cold and malaria	Condiments	Ballabh & Chaurasia 2007
Nepeta glutinosa Benth.	**Shakmazok**	Lamiaceae.	Leaves	Diarrhea	Spice	Ballabh & Chaurasia 2009
Nepeta longibracteata Benth.	**Prianku**	Lamiaceae	Shoot	For liver disorder, stomach ache, indigestion	Condiments	Shabir *et al.* 2018
Origanum vulgare L.	**--**	Lamiaceae	Whole plant		Fragrance	Ballabh & Chaurasia 2009, Raj *et al.* 2010
Orobanche hansii Ker.	**Gro-shang-rtse**	Orobanchaceae	Whole plant	Prevent hemorrhage of kidney		Ballabh *et al.* 2008
Oxyria digyna (L.) Hill	**Skurbu, Chumcha**	Polygonaceae	Shoot	Appetizer, gastritis	Leaves are edible	Buth & Navchoo 1988
Oxytropis microphylla (Pall.) D.C.	**Stag-sha Nagpo**	Leguminosae	Whole plant	Used in septicemia, joint pain	Fuelwood	Shabir *et al.* 2018
Pedicularis longiflora Rudolphh.var tubiformid (koltz) Pennel.	**Lugru-serpo**	Orobanchaceae	Flowers	Diuretic, Cure Inflammation and bleeding in the kidney	Fodder	Yatoo *et al.* 2017, Buth & Navchoo 1988
Peganum harmala L.	**Sepan**	Nitrariaceae	Seeds	Asthma, fever, aphrodisiac, Reduce irritable condition of bladder	Fodder	Raj *et al.* 2010,
Perovskia abrotanoides Kiril.	**Starobu**	Lamiaceae	Leaves	Control painful urination, cough and headache	Fodder	Ballabh *et al.* 2008, Kumar *et al.* 2009
Physochlania praealta (Decne) Hiers.	**Langtang**	Solanaceae	Leaves	Used for ulcer and eye diseases	Fodder	Shabir *et al.* 2018
Picrorhiza kurroa Royle ex Benth.	**Hanglang**	Plantaginaceae	Roots	Kidney and Urinary disorder, fever, and blood purification, diabetes	--	Ballabh & Chaurasia 2007, Ballabh & Chaurasia 2009
Plantago asiatica L.	**Karache**	Plantaginaceae	Leaves	Leaves are used as blood purifier	Fodder	Buth & Navchoo 1988,
Plantago depressa Willd.	**Rambusuk**	Plantaginaceae	Whole plant	Cold, cough, stomach pain, dysentery	Fodder	Ballabh & Chaurasia 2007, Ballabh & Chaurasia 2009
Plantago himaliaca L.	**Tharum**	Plantaginaceae	Seeds	Diarrhea	Fodder	Buth & Navchoo 1988
Podophyllum hexandrum Royle.	**Demokushu**	Berberidaceae	Fruits	Kidney disorder, constipation	--	Ballabh *et al.* 2008, Singh 2013

Polygonatum verticellatum (L.) All.	**Ra-myne**	Polygonaceae	Rhizome	Removes painful urination	--	Ballabh *et al.* 2008, Ballabh & Chaurasia 2009
Polygonum affine D. Don	**Famer-rtso**	Polygonaceae	Flower	Abdominal pain	--	Kala 2006
Polygonum aviculare L.	**Rambo**	Polygonaceae	Leaves		--	Ballabh *et al.* 2008
Polygonum rottboellioides Jaub. & Spach	**Famer rcha**	Polygonaceae			--	Shabir *et al.* 2018
Potentilla anserina L.	**Troma**	Rosaceae	Roots	Diarrhea, kidney problem	Roots are eaten raw	Ballabh *et al.* 2008,
Prangos pabularia Lindl	**Palano**	Apiaceae	Roots	Indigestion and carminative	--	Ballabh *et al.* 2008, Ballabh & Chaurasia 2009
Primula denticulata Smith	**--**	Primulaceae	Leaves, Roots	Cough and cold	Ornamental	Gairola *et al.* 2014
Primula macrophylla	**Puner- mindoq**	Primulaceae	Whole	Cold and cough	Ornamental	Ballabh & Chaurasia 2007
Ranunculus brotherusii Freyn.	**--**	Ranunculacea	Whole	Blood purification	Fodder	Kala 2006
Ranunculus trichophyllus Chaix.	**Rengo**	Ranunculaceae	Whole plant	Diarrhea	Fodder	Kala 2006, Ballabh & Chaurasia 2009
Raphanus sativus L.	**Labook, Muli**	Brassicaceae	Whole part	Diuretics	Vegetable	Ballabh & Chaurasia 2009
Rheum spiciforme Royle.	**Lhachhu**	Polygonaceae	Whole part	Rheumatism, chronic bronchitis, piles and as purgative	Shoot and root are edible	Kumar *et al.* 2009
Rheum webbianum Royle.	**Khakhol, Chu-rtsa**	Polygonaceae	Roots	Chronic diarrhea, chronic bronchitis	Edible	Kumar *et al.* 2009
Rhodiola imbricate Edger.	**Shrolo- serpo**	Crassulaceae	Shoot	Cough, fever, lungs problem	Vegetable	Ballabh & Chaurasia 2007, Raj *et al.* 2010
Rhodiola tibetica Hk. f & T	**Shrolo- marpo**	Crassulaceae	Shoot	Health tonic	Vegetable	
Ribes alpestre Wall. ex. Decne	**Akskota**	Grossulariaceae	Plant ashes	Ashes are used against the rabies and wolf infections and have anti-inflammatory properties.	Fruits are edible, Fuelwood source	Ballabh *et al.* 2007
Rosa webbiana Wall. ex. Royle	**Siahh**	Rosaceae	Flower	Food positioning, Hepatitis	Used as fodder and fuelwood	Ballabh & Chaurasia 2007, Raj *et al.* 2010
Rumex acetosa L.	**Shoma**	Polygonaceae	Whole plant	Treatment of back pain, knee pain and inflammation	Fodder	Kala. 2006
Saussurea bracteata Decne.	**--**	Asteraceae	Flower	Headache, cold and cough	Fodder	Ballabh & Chaurasia 2007
Saussurea gnaphaloides Hk. f. & T.	**Yuliang**	Asteraceae	Whole plant	Promotes urine discharge, arthritis	--	Ballabh *et al.* 2008, Raj *et al.* 2010

Saussurea jacea (Klotz.) Clarke	**Pashuk, Shirut**	Asteraceae	Whole plant	Control painful urination	--	Ballabh *et al.* 2008, Ballabh & Chaurasia 2009
Saussurea lappa L.	**Rustha**	Asteraceae	Roots	Cold, cough, chest pains, kidney and liver diseases.	Fodder	Ballabh & Chaurasia 2007
Sedum ewersii Ledeb	**Shurupa**	Crassulaceae	Shoot	Dysentery	--	Ballabh & Chaurasia 2009
Sedum tibeticum Hk. f. & T	**Sholo**	Crassulaceae	Leaves	Heart and lungs disorder	--	Buth & Navchoo 1988, Singh 2013
Sisymbrium orientale L.	**Staga**	Brassicaceae	Seeds	Appetizer an carminative	--	Buth & Navchoo 1988
Stachys tibetica Vatke	**Kakzas**	Lamiaceae		Anxiety, depression, fever	--	Ballabh & Chaurasia 2007,
Swertia petiolata Royal ex. D. Don	**Zantik**	Gentianaceae	Whole plant	Fever, headache, body ache	--	Buth & Navchoo 1988, Ballabh & Chaurasia 2007,
Swertia thomsonii Cl. ex Hk. F.& T.	**Tikta**	Gentianaceae	Whole plant	Stomach	--	Ballabh & Chaurasia 2009
Tanacetum gracile Hk. f. & T.	**Khamchu**	Asteraceae	Shoot	Intestinal disease, fever	fodder	Ballabh & Chaurasia 2007, Raj *et al.* 2010
Taraxacum officinale Wigg.	**Khurma**	Asteraceae	Roots and leaves	Anti-inflammation, promotes milk production	Vegetables	Ballabh & Chaurasia 2007, Singh 2013
Thalictrum minus L.	**Chak- achoo**	Ranunculaceae	Shoot	gout and rheumatism	--	Buth & Navchoo 1988
Thermopsis inflata Camb.		Leguminosae	Leaves	Wounds, arthritis	--	Singh 2013
Thlaspi alpestre L. ex Hk. f. & T	**Bumbuk/Makha**	Brassicaceae	Seeds	Kidney inflammation, appendicitis, seminal discharge	--	Ballabh *et al.* 2008, Ballabh & Chaurasia 2009
Thymus serpyllum L.	**Tumburik**	Lamiaceae	Whole plant	Gastrointestinal problem and stomach pain	Spice	Ballabh & Chaurasia 2009, Gairola *et al.* 2014
Tribulus terrestris L.	**Gzema**	Zygophyllaceae	Fruits	Kidney and urinary disorder	Fodder	Ballabh *et al.* 2008
Triglochin palustris L.		Juncaginaceae.	Root	Indigestion	Fodder	Kala 2006
Urtica paviflora Roxb.	**Dzazut**	Urticaceae	Leaves	goitre, cough, allergies, alopecia and fevers	--	Ballabh *et al.* 2008
Verbascum thapsus L.	**Rchwa**	Scrophulariaceae	Whole plant	For treating skin infections	--	Gairola *et al.* 2014, Shabir *et al.* 2018
Waldheimia glabra (Decne) Regel.	**Palu**	Asteraceae	Whole	Wounds	Sacred plant	Kala 2006
Waldheimia tomentosa (Decne) Regel.	**Palu-karpo**	Asteraceae	Whole plant	Wounds, arthritis, fever	Use of Incense	Buth & Navchoo 1988,

Table 3. Important medicinal plants of Ladakh used in Amchi's therapeutic formulations (Source: Kumar *et al.* 2011).

Scientific name	Local name	No. of formulations
Saussurea lappa L.	**Rustha**	38
Inula racemosa Hooker	**Manu**	31
Oxytropis chiliophylla Royle.	**Staqsha**	17
Picrorhiza kurroa Royle ex Benth.	**Honglen**	17
Rubia cordifolia L.	**Btsod**	15
Aconitum violaceum Jacq. Ex Stapf.	**Bona-Naqpo**	14
Hippophae rhamnoides L.	**Tsermang**	13
Hypecoum leptocarpum	**Perpata**	11
Rheum spiciforme Royle.	**Lhachu**	11
Rhododendron anthopogon D. Don	**Dalis**	8
Carum carvi L.	**Kosnyot**	6
Hyoscyamus niger L.	**Rga-lantang**	5

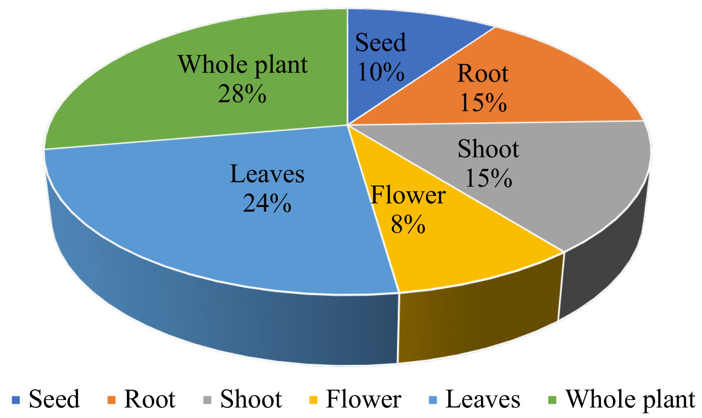

Figure 8. Parts of the plant used by the practitioners for medicinal purposes

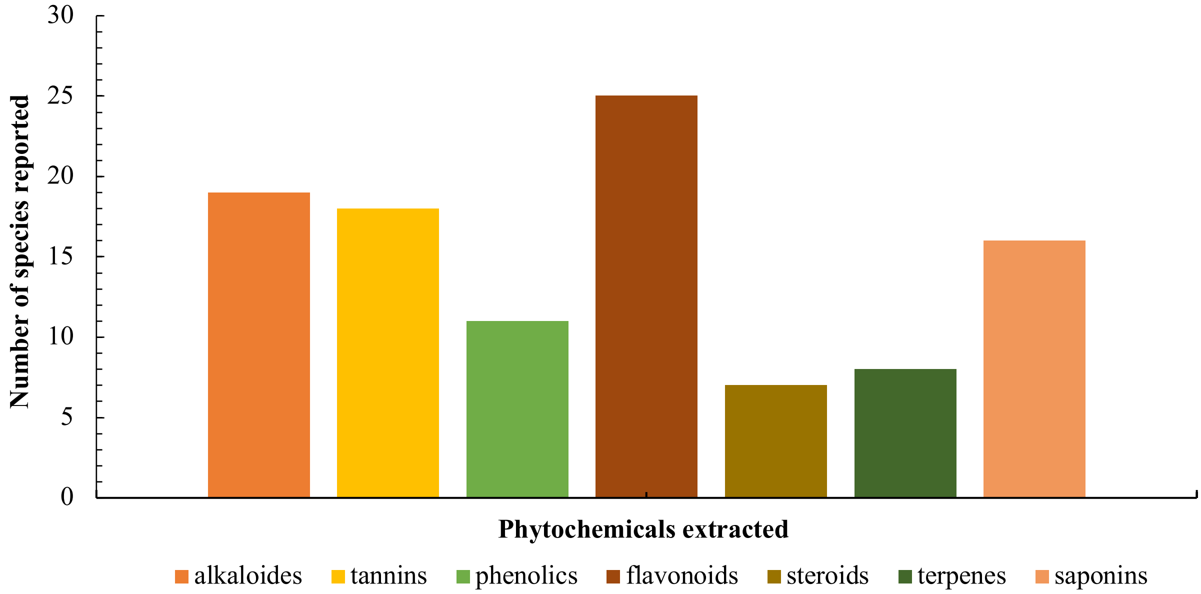

Figure 9. Production of secondary metabolites from various plant species found in Ladakh region

Table 4. Plants documented for the production of secondary metabolites.

Botanical name	Family	Phytochemicals extracted	Reference
Achillea millefolium	Asteraceae	Alkaloids, tannins, flavonoids, saponins, cardiac glycoside, steroids, terpenoids	Raj *et al.,* 2010
Allium carolinianum	Amaryllidaceae	Cinnamoylphenethylamine, phenol and flavonoid.	Yatoo *et al.,* 2018
Artemesia dracunculus	Asteraceae	Alkaloids, tannins, flavonoids, saponins, coumarins and alkamide	Ekiert *et al.,* 2021; Duric *et al.,* 2015
Capparis spinosa	Capparaceae	Phenols and flavonoids	Bhoyar *et al.,* 2018
Carum carvi	Apiaceae	Alkaloids, tannins, flavonoids, saponins	Aly *et al.,* 2018, Showraki *et al.,* 2016
Chenopodium album	Amaranthaceae	Polyphenols, alkaloids, flavonoids, terpenoids	Pandey and Gupta, 2014; Chamkhi *et al.,* 2022
Dactylorhiza hatagirea	Orchidaceae	albumin, butanedioic acid, hydroquinone, lesoglossin, militarrin, pyranoside, pyrocatechol, indole alkaloids, phenoilcs, saponins, ascorbic acid and Dactylorhins A-E	Kizu *et al.,* 1999; Dhiman *et al.,* 2019; Wani *et al.,* 2020
Delphinium brunonianum	Ranunculaceae	glucoside, malic acid, dehydroascorbic acid, quinic acid and scopolin, amide alkaloid	Asif *et al.,* 2021; Zou *et al.,* 2019
Dracocephalum heterophyllum	Lamiaceae	tannins, flavonoids, saponins, steroids, phenolic, alkaloids, triterpenes, and lignans	Raj and Bala, 2010; Shi *et al.,* 2018
Echinacea purpurea	Asteraceae	Flavonoids, steroids, terpenoids, phyllobatannins	Avasthi *et al.,* 2017
Gallium pauciflorum	Rubiaceae.	Alkaloids, tannins, flavonoids, saponins, cardiac glycoside	Raj *et al.,* 2010
Heracleum pinnatum	Apiaceae	Alkaloids, tannins, flavonoids, saponins,	Raj *et al.,* 2010
Hippophae rhamnoides	Elaeagnaceae	Alkaloids, tannins, flavonoids, terpenoids	Madawala *et al.,* 2018
Hyoscyamus pusillus	Solanaceae	Phenols and flavonoids	Tantray *et al.,* 2021
Inula racemosa	Asteraceae	Alkaloids, Tannins, saponins, steroids, glycoside	Mohan and Gupta, 2017
Lepidium latifolium	Brassicaceae	Glucosinolates, phenols, gallic acid, flavonoids, vitamin C, fatty acids, carotenoids	Kaur *et al.,* 2013; Ali *et al.,* 2021
Lycium ruthenicum	Solanaceae	Flavonoids, phenolic acids, carotenoids, vitamins B 1, B2, vitamin C; iron, zinc and selenium and alkaloid	Dhar *et al.,* 2011; Zhang *et al.,* 2018
Mentha longifolia	Lamiaceae	Polyphenols, flavonoid, saponins, tannins, terpenoids, phlobatannins, steroids, and anthraquinones	Janifer *et al.,* 2010; Shah *et al.,* 2020
Nepeta sps.	Lamiaceae	Phenols, flavonoids, gallic acid, rosmarinic acid, apigenin	Avasth *et al.,* 2016
Origanum vulgare	Lamiaceae	alkaloids, tannins, flavonoids, saponins,	Raj *et al.,* 2010
Pedicularis sps.	Orobanchaceae	Lavendulol, phenylethanoid glycosides, iridoid glucosides, secoiridoids, ligustroside, flavonoids, polyphenols, lignans, and alkaloids	Kitchlu *et al.,* 2006; Venditti *et al.,* 2016; Yatoo *et al.,* 2017
Peganum harmala	Nitrariaceae	Alkaloids, Flavonoids, Saponins, tannin, steroid, terpenes	Fatma *et al.,* 2016
Perovskia abrotanoides	Lamiaceae	(E)-9-dodecenal, octadecanoic acid, methyl ester, 2,2,5,5-tetramethylhexane, hexadecanoic acid, methyl ester, lupeol, octadecenoic acid, methyl ester, eicosane and tetradecane, phenolics and flavonoids	Ashraf *et al.,* 2014; Avasthi *et al.,* 2016
Podophyllum hexandrum	Berberidaceae	Podophyloresin, podophyllotoxin, epipodophyllotoxin, podophyllotoxone, flavonoids	Chaurasia *et al.,* 2012; Anand *et al.,* 2022

Rhodiola imbricata	Crassulaceae	Polyphenols, flavonoids, monoterpenes, fatty acids, tocopherols, aliphatic hydrocarbons, and ethers	Raj *et al.,* 2010; Tayade *et al.,* 2013
Rosa webbiana	Rosaceae	Alkaloids, tannins, flavonoids, saponins, cardiac glycoside, quercetin, kaempferol, ascorbic acid	Sharma and Gulati, 2023; Raj *et al.,* 2010
Rubia cordifolia	Rubiaceae	Alkaloids, tannins, flavonoids, saponins, terpenes, phenols	Gupta and Gupta, 2017
Rubia tibetica	Rubiaceae	Tannins, saponins, flavonoid, alkaloid	Raj *et al.,* 2010
Stachys tibetica	Lamiaceae	Tannins, phenolics, flavonoids, saponin, glycosides and carbohydrates	Kumar and Bhat, 2014
Tanacetum gracile	Asteraceae	Alkaloids, tannins, flavonoids, saponins, cardiac glycoside, steroids, terpenoids	Sinha *et al.,* 2015; Raj *et al.,* 2010; Bhat al., 2016
Waldheimia tomentosa	Asteraceae	Alkaloids, flavonoids, steroids, tannin, triterpenoids, anthraquinones,	Avasth *et al.,* 2016; Bhatnagar *et al.,* 2017

Threat status and conservation strategies for the regions' plant resources

The distribution of snow starts at around 4,500 m and continues to the highest altitudinal point in the region. There is an apparent difference in the distribution of the floral diversity between the mountain's slopes facing south and north positions, mainly caused by solar radiation and precipitation (Behera *et al.* 2014). It is worth mentioning that the increase in altitude is characterised by the decrease in agroforest, dominated by the desertic wild vegetation in the continuity of the moist alpine pastures and moist alpine scrub (Dvorský 2014). The maximum number of plant species was identified between 3350 to 4500 m asl and then decreased with an increase in altitude (Kumar *et al.* 2011). The populations keep changing in size and density over time, and such changes may make plant species rare, endangered, and threatened, eventually leading to their extinction (Maikhuri *et al.* 1998, Kala 2000). The higher Himalayas are rich in native and endemic biodiversity, and trees are few or completely absent (Dhar *et al.* 1999).

Understanding vegetation distribution patterns concerning various factors is important, and research has been conducted regarding their roles (Turner & Gardner 1992, Henebry 1993). The main controlling factor in vegetation growth is the topographical factor (elevation, aspect, and slope), whereas climatic factors are secondary to the topographical characters (Behera *et al.* 2014). The composition of plant diversity differs from one place to another in the region, subject to the availability of light, moisture, and soil types (Kala & Mathur 2002). The locals use most of the species at various places for different purposes, such as medicine, food, fodder, feed, ornamental, and fuelwood (Haq *et al.* 2021). Unfortunately, it has been reported that the important medicinal and aromatic plants of Ladakh have considerably declined due to their unscientific exploitation, natural calamities, road construction, uprooting for fuel, overgrazing, and other activities (Dar *et al.* 2006, Kumar *et al.* 2011, Angmo *et al.* 2016).

Similarly, several other factors cause diversity declination throughout the world. According to the Convention on Biological Diversity (CBD 2011), climate change has been a significant cause of biodiversity loss. The major shift in species ranges and marked reorganisation of biological communities, landscapes, and biomes were some events of the past changes in the global climate (CBD 2011). The other major natural threats to habitat include its unique topography, physical features, and harsh climatic conditions that have significantly contributed to a drastic decline of various taxa in an ecosystem (Kala 2000, Singh *et al.* 2008, Srivastava & Shukla 2015). Unfortunately, many species such as *Dactylorhiza hatagirea*, *Picrorhiza kurrooa*, *Rheum webbianum*, *R. moorcroftianum,* and *Aconitum heterophyllum* have faced major threats to their survival because of the collection of their underground parts, such as rhizomes, tubers, bulbs and roots (Kala 2006). Overcollection in the Himalayan and trans-Himalayan regions was the primary cause of diversity loss (Kala 2005). It must also be noted that the present global biota has been affected by fluctuating concentrations in the Pleistocene (the past 1.8 million years) of atmospheric carbon dioxide, temperature, and precipitation (CBD 2011). Such changes have brought evolutionary changes, species plasticity, range movements, or the ability to survive in small patches of favorable habitat (Hambler & Canney 2013).

The International recognition of the plant's irreparable values and the increasing threat to their existence by various anthropogenic and natural agents has led to an urgent global meeting to protect living diversity. These include the Convention on Biological Diversity (Outlook 2010), Strategic Plan for Biodiversity 2011-2020 (SCBD 2012), United Nations Sustainable Development Goal (SDG) 2.5 (United Nations 2015), The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO 2009). However, it is reported that no country is currently getting plant conservation rights as plants are becoming rare globally (Heywood 2017). It is argued that plants are more frequently not fully protected by national policies, and their conservation is undervalued, underfunded, and unappreciated (Havens *et al.* 2014). Although many initiatives have been endorsed at regional and global levels, the lack of necessary institutions and training halt conservation in a real sense (Heywood 2017).

Furthermore, it is reported that less than three out of every 100 beneficial wild species are sufficiently protected or of low priority for further conservation globally (Khoury *et al.* 2019). However, plenty of approaches have been implemented in the world, including both in-situ (Wang & Li 2021) and ex-situ conservations (Werden *et al.* 2021). *In-situ* conservation is considered the most appropriate conservation approach for preserving species as it preserves the original genetic and geographical centers of biodiversity (González-Benito & Martín 2011). Likewise, *ex-situ* conservation approaches have successfully maintained genetic diversity and could contribute significantly to threatened plant protection (Mounce *et al.* 2017). The various methods of in-situ and ex-situ conservation have been discussed thoroughly worldwide. In contrast, numerous simplistic approaches could provide a better conservation outcome, particularly for pant conservation (Fig. 10). The fundamental step in plant conservation is identifying the floral Status and associated threats. Mapping threatened plant species would be the key to locating their occurrences so that conservation policies and their implementation would have a higher impact.

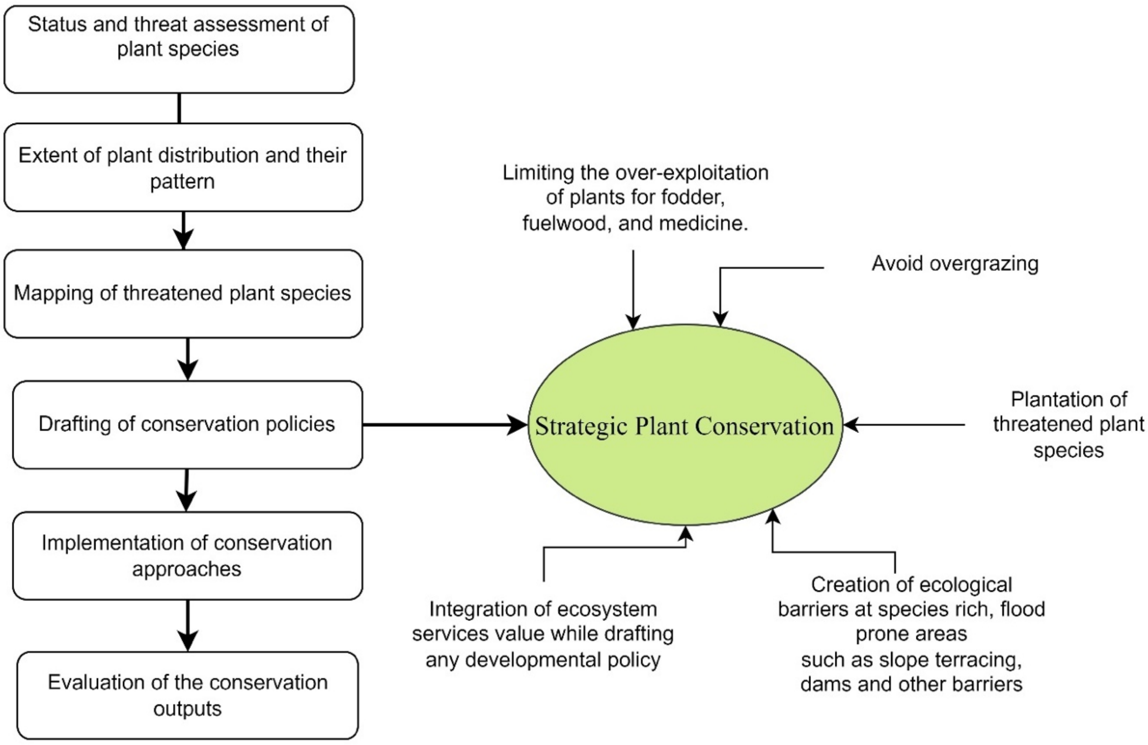

Figure 10. Basic framework for plant diversity conservation

Challenges in research and knowledge gap

Due to its topographical and climatic conditions, the Ladakh region has been one of the most challenging areas to research. The region is accompanied by steep slopes, rocky hills, plains, valleys, and meadows, with most places lying above 4000 m asl. Ladakh remains cut off from the outside world for nearly four to six months when the roads (Kargil –Srinagar Highway: Leh to Manali Highway) are blocked by snow avalanches. Additionally, in the whole season, only the summer (May-September) can be accounted for to carry out the floristic research as weather conditions are the most suitable. The mountain vegetation at the higher elevation can be well noticed in late summer, and a more significant amount of green can be seen on the hills with good vegetation cover (Stewart 1919). So, it could be tough in spring, early summer, and late autumn to get a complete notion of floristic diversity and associated features. The high-altitude ecosystems of Ladakh, with harsh climatic conditions, provide only a limited (3–4 month) growth season and cause concerns for low primary production (Kala & Mathur 2002). Likewise, constraints such as extreme temperature fluctuation, high wind velocity, unpredictable weather, high steep slopes, uneven rugged plains, and untrodden valleys would cause hindrances to smooth research work. Therefore, only trained and skillful persons could resist these constraints and might conduct research works efficiently.

Similarly, it was observed that most of the research was conducted in the Leh region of Ladakh (Ballabh & Chaurasia 2007, Namgail *et al.* 2012), and only a small portion of work has been performed on the floral diversity of the Kargil region. The distribution and pattern of plants in the region have been well studied. However, no such studies were conducted in Drass, Zanskar, and Suru valley (except for Stewart 1919), which possesses a unique set of floral diversity than the Leh region. Furthermore, studies are more concentrated on ethnobotanical significance, emphasizing medicinal and traditional uses (Chaurasia 2011, Ballabh & Chaurasia 2007). Some quality works have been conducted on the phytochemical constituents of important plants endemic to the region. Furthermore, some studies have been conducted on plant nutrient content (Macek 2012), phyto-foods (Murugan *et al.* 2010), genetic characterisation of plants (Kumar *et al.* 2009), and resource conservation (Joshi *et al.* 2006). Nevertheless, efforts were made to work in multidisciplinary fields associated with vegetation. However, no work has been performed in the entire region that explains and discusses important issues like biomass production, carbon storage (in plants and soil), impacts of climate changes on vegetation, regulation of extreme events, and the importance of the mountain ecosystem for the supply of crucial cultural services like recreation, inspiration, and aesthetic. Medicinal significances of floral diversity have been dealt with great efforts and arguably have made an outstanding effort in the field of research. However, in contrast, there has been equal negligence in preserving and conserving such incredible natural resources. Therefore, researchers should pay adequate focus on vegetation monitoring, climate change's impact on floral diversity, drivers of change in ecosystem structure and services, consequences of vegetation loss on people's livelihood, steps and methods for ecosystem restoration, conservation, and preservation of natural resources.

Conclusions

Ladakh is home to a distinct array of flourishing plants across its diverse landscapes. Researchers have dedicated substantial efforts to exploring its floral diversity. However, the formidable combination of high altitudes, arid climate, and rugged terrain in Ladakh presents an exceedingly challenging research environment. This region encompasses a diverse range of ethnic communities, each possessing its unique traditional knowledge regarding plants and their uses. The compilation of Ladakh's flora by Stewart in 1916 marked a significant breakthrough in the field. Subsequent researchers extended their investigations beyond exploration, delving into plant distribution patterns, traditional significance, phytochemical properties, and ethnomedicinal applications. Notably, the focus of research has predominantly cantered on medicinal and ethnobotanical aspects, overshadowing other research domains. Numerous newly discovered species, such as *Gentiana aperta*, *Gentianella devendrae*, *Gentianopsis paludosa* var. alpine, and *Swertia drassensis*, have been reported. These plants tend to thrive in regions situated between 4000 to 5800 meters above sea level, with a noticeable decline in plant diversity beyond 5800 meters, where sub-nival vegetation prevails. Substantial research has also been devoted to understanding the services provided by these plants, including their roles in medicine, forage and fodder production, fuelwood, dye production, decoration, ornamental use, and the generation of raw materials. However, several crucial services, such as recreation, aesthetics, artistic inspiration, water and air purification, as well as various cultural, regulatory, and supportive services, have remained largely unexplored and lacking systematic research. Regrettably, several species, including *Dactylorhiza hatagirea*, *Picrorhiza kurrooa*, *Rheum webbianum*, *R. moorcroftianum*, and *Aconitum heterophyllum,* face severe threats to their survival due to the unsustainable collection of their underground parts, such as rhizomes, tubers, bulbs, and roots. Disturbingly, there has been no research to date explicitly addressing protective measures for these endangered plant species, underscoring a troubling display of human negligence toward natural resources. In contrast to prior plant exploration efforts in the region, our current research transcends mere expeditions. It meticulously emphasizes the significance of previous studies spanning various subjects. Furthermore, our study integrates conservation strategies to mitigate plant losses, identifies research gaps, and contributes to the expansion of existing knowledge. Additionally, our work serves as a blueprint, inspiring fellow researchers to reflect upon and take action for the sustainable management of plant resources in the Ladakh region. To prevent additional declines in ecosystem stability and functioning, thorough research that focuses on mapping, modelling, and implementing preservation methods for the area's significant floral diversity is urgently needed.

Declarations

Ethical approval and consent to participate: The study does not require ethical clearance as it is based on a literature review.
Consent for publication: Not applicable
Availability of data and materials: Data sharing is not applicable to this article, as no new data were created or analyzed in this study.
Competing interests: The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.
Funding: This work was supported by the Council of Scientific and Industrial Research (CSIR), New Delhi, and the University Grants Commission (UGC), Government of India in the form of a Senior research fellowship [09/135(0884)/2019-EMR-I and UGC Ref. No.: 453/ (CSIR-UGC NET DEC. 2018)] to Sabir Hussain and Sheenu Sharma respectively.
Authors' Contributions: Sabir Hussain: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - Original Draft, Funding acquisition. **Sheenu Sharma**: Conceptualization, Methodology, Validation, Investigation, Writing - Review & Editing, Visualization, Funding acquisition. **Ram Chand Bhatti:** Validation, Writing - Review & Editing, Visualization. **Anand Narain Singh:** Conceptualization, Validation, Writing - Review & Editing, Supervision, Project administration.

Acknowledgements

The authors are grateful to the Chairperson, Department of Botany, Panjab University, Chandigarh, for providing all the necessary facilities required for the work.

Literature Cited

Abrol BK, Chopra IC. 1962. Some vegetables drug resources of Ladakh (Little Tibet)- PART I. Current Science 31(8): 324-326.

Ahmad S, Singh JP, Verma DK 2020. Inventory of important fodder plants of Ladakh Himalaya. https://uknowledge.uky.edu/igc/23/1-1-2/3/ (Acessed 05/07/2020).

Ali V, Khajuria M, Bhat R, Rashid A, Faiz S, Vyas D. 2021. Comparative phytochemical analysis of *Lepidium latifolium* L. sprouts from Ladakh Himalayas suggest a novel combination of 2-propenyl and benzyl glucosinolate. LWT-Food Science and Technology 138: 110713.

Aly A, Maraei R, Rezk A, Diab A. 2023. Phytochemical constitutes and biological activities of essential oil extracted from irradiated caraway seeds (*Carum carvi L*). International Journal of Radiation Biology 99(2): 318-328.

Anand U, Biswas P, Kumar V, Ray D, Ray P, Loake VI, Kandimalla R, Chaudhary A, Singh B, Routhu NK, Chen ZS. 2022. *Podophyllum hexandrum* and its active constituents: Novel radioprotectants. Biomedicine and Pharmacotherapy 146: 112555.

Angmo K, Rawat GS, Yatoo MI, Adhikari BS. 2016. Plant resource availability and harvesting pressure in Khardung La, Ladakh. Medicinal Plants - International Journal of Phytomedicines and Related Industries 8(2): 116-126.

Angmo K, Gailson L, Adhikari B, Rawat G, Bhat J, Bussmann RW, Malik ZA. 2022. Prevailing traditional health care services in Western Ladakh, Indian Trans-Himalaya. Ethnobotany Research and Applications 24: 1-12.

Ashraf SN, Zubair M, Rizwan K, Tareen RB, Rasool N, Zia-Ul-Haq M. Ercisli S. 2014. Compositional studies and biological activities of *Perovskia abrotanoides* Kar. oils. Biological Research 47(1) :1-9.

Asif H, Alamgeer, Bukhari IA, Vohra F, Afzal S, Khan SW, Niazi ZR. 2021. Phytochemical analysis of crude extract of *Delphinium brunonianum* and its effect on hypertension and metabolic perturbations in fructose fed rats. Natural Product Research 35(17): 2982-2986.

Asner GP, Elmore AJ, Olander LP, Martin RE, Harris AT. 2004. Grazing systems, ecosystem responses, and global change. Annual Review of Environment and Resources 29: 261-299.

Aswal BS, Mehrotra BN, 1981. Contribution to the flora of Lahaul Valley (North-West Himalaya)-III. A note on the nomenclature of plants. Journal of Economic and Taxonomic Botany 2: 236.

Avasthi AS, Bhatnagar M, Sarkar N, Kitchlu S, Ghosal S. 2016. Bioassay guided screening, optimisation and characterisation of antioxidant compounds from high altitude wild edible plants of Ladakh. Journal of Food Science and Technology 53(8): 3244-3252.

Ballabh B, Chaurasia OP. 2007. Traditional medicinal plants of cold desert Ladakh- Used in treatment of cold, cough and fever. Journal of Ethnopharmacology 112(2): 341-349.

Ballabh B, Chaurasia OP. 2009. Medicinal plants of cold desert Ladakh used in the treatment of stomach disorders. Indian Journal of Traditional Knowledge 8(2): 185-190.

Ballabh B, Chaurasia OP, Pande PC, Ahmed Z. 2007. Raw edible plants of cold desert Ladakh. Indian Journal of Traditional Knowledge 6(1): 182-184.

Ballabh B, Chaurasia OP, Ahmed Z, Singh SB. 2008. Traditional medicinal plants of cold desert Ladakh—used against kidney and urinary disorders. Journal of Ethnopharmacology 118(2): 331-339.

Banoo S, Ali L, Ganie AH, Khuroo AA. 2022. Trees of the Trans-Himalaya: first report of *Pinus wallichiana* AB Jackson from Ladakh. Vegetos.

Banoo S, Gulzar R, Islam T, Ganie AH, Khuroo AA. 2021. *Gentianopsis paludosa* var. *alpina* (Gentianaceae), a new record for India from Ladakh, Trans-Himalaya. Rheedea 31(2): 71-76.

Banoo S, Khuroo AA, Ganie AH. 2022. *Swertia drassensis*, a new species from Drass, Ladakh Himalaya. Phytotaxa 571(2): 219-226.

Behera MD, Matin S, Roy PS. 2014. Biodiversity of Kargil cold desert in the Ladakh Himalaya. In: Nakano Si, Yahara T, Nakashizuka T (eds) Integrative Observations and Assessments. Ecological Research Monographs. Springer, Tokyo.

Bhat G, Masood A, Ganai BA, Hamza B, Ganie S, Shafi T, Idris A, Shawl AS, Tantry MA. 2016. Gracilone, a new sesquiterpene lactone from *Tanacetum gracile* (Tansies). Natural Product Research 30(20): 2291-2298.

Bhatnagar M, Avasthi AS, Singh S, Ghosal S. 2017. Evaluation of anti-leishmanial and antibacterial activity of *Waldheimia tomentosa* (Asteraceae), and chemical profiling of the most bioactive fraction. Tropical Journal of Pharmaceutical Research 16(9): 2169-2178.

Bhattacharyya A. 1991. Ethnobotanical observations in the Ladakh region of northern Jammu and Kashmir State, Indian Economic Botany 45(3): 305-308.

Bhoyar MS, Mishra GP, Naik PK, Singh SB. 2018. Evaluation of antioxidant capacities and total polyphenols in various edible parts of *Capparis spinosa* L. collected from trans-Himalayas. Defence Life Science Journal 3(2): 140-145. doi: 10.14429/dlsj.3.12570

Brand RF, Scott-Shaw CR, O'Connor TG. 2019. The alpine flora on inselberg summits in the Maloti–Drakensberg Park, KwaZulu-Natal, South Africa. Bothalia-African Biodiversity & Conservation 49(1): 1-15.

Bray J. 1998. Recent research on Ladakh: an introductory survey. HIMALAYA, the Journal of the Association for Nepal and Himalayan Studies 18(1): 47-52.

Buth GM, Navchoo IA. 1988. Ethnobotany of Ladakh (India) plants used in health care. Journal of Ethnopharmacology 8(2): 185-194.

Chamkhi I, Charfi S, Hachlafi NE, Mechchate H, Guaouguaou FE, El Omari N, Bakrim S, Balahbib A, Zengin G, Bouyahya A. 2022. Genetic diversity, antimicrobial, nutritional, and phytochemical properties of *Chenopodium album*: a comprehensive review. Food Research International 154: 110979.

Chandra-Hioe MV, Wong CH, Arcot J. 2016. The potential use of fermented chickpea and faba bean flour as food ingredients. Plant Foods for Human Nutrition 71: 90-95.

Chauhan A, Jishtu V, Thakur L, Dolma T. 2020. Medicinal plants of the Trans-Himalayan Cold Desert of Ladakh-a review. International Journal of Science and Environment 9(2): 239-253.

Chaurasia OP. 2011. Herbal formulations from cold desert plants used for gynecological disorders. Ethnobotany Reseasrch and Applications 9: 59-66.

Chaurasia OP, Singh B, Sareen CS. 1998. Traditionally used medicinal flora of Ladakh. Nelumbo-The Bulletin of the Botanical Survey of India 40(1-4): 47-52.

Costanza R, d'Arge R, De Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'neill RV, Paruelo J, Raskin RG. 1997. The value of the world's ecosystem services and natural capital. Nature 387(6630): 253-260.

Dar AR, Dar GH, Reshi Z. 2006. Recovery and Restoration of Some Critically Endangered Endemic Angiosperms of the Kashmir Himalaya. Journal of Biological Sciences 6: 985-991.

Dawa S, Gurmet P, Stobgais T, Rinchen T. 2021. Survey and ethno-botanical study of medicinal plants of some selected villages of singay-lalok region of Leh (UT Ladakh Region). Asian Journal of Research in Botany 5(2): 60-75.

Dhiman N, Sharma NK, Thapa P, Sharma I, Swarnkar MK, Chawla A, Shankar R, Bhattacharya A. 2019. De novo transcriptome provides insights into the growth behavior and resveratrol and trans-stilbenes biosynthesis in *Dactylorhiza hatagirea*—An endangered alpine terrestrial orchid of Western Himalayas. Scientific Reports 9(1): 1-13.

Dorjey K, Tamchos S, & Kumar S. 2012. Ethnobotanical observations in Trans-Himalayan region of Ladakh. Journal of Plant Development Sciences 4(4): 459-464.

Duric K, Kovac-Besovic EE, Niksic H, Muratovic S, Sofic E. 2015. Anticoagulant activity of some *Artemisia dracunculus* leaf extracts. Bosnian Journal of Basic Medical Sciences 15(2): 9-14.

Duthie JF. 1893-94. Report on Botanical Tour to Kashmir, Records of the Botanical Survey of India. 1(1)1-8:25-47.

Dvorský M. 2014. Ecology of alpine plants in NW Himalaya. Ph.D. Thesis Series, No. 2. University of South Bohemia, Faculty of Science, School of Doctoral Studies in Biological Sciences, České Budějovice, Czech Republic. Pp. 196

Dvorský M, Altman J, Kopecký M, Chlumská Z, Řeháková K, Janatková K, Doležal J. 2015. Vascular plants at extreme elevations in eastern Ladakh, northwest Himalayas. Plant Ecology & Diversity 8(4): 571-584.

Dvorský M, Doležal J, De Bello F, Klimešová J, Klimeš L. 2011. Vegetation types of East Ladakh: species and growth form composition along main environmental gradients. Applied Vegetation Science 14(1): 132-147.

Dvorský M, Macek M, Kopecký M, Wild J, Doležal J. 2017. Niche asymmetry of vascular plants increases with elevation. Journal of Biogeography 44(6): 1418-1425.

Eck NJV, Waltman L. 2014. Visualising bibliometric networks. In Measuring scholarly impact. Springer, Cham (pp. 285-320).

Ekiert H, Świątkowska J, Knut E, Klin P, Rzepiela A, Tomczyk M, Szopa A. 2021. *Artemisia dracunculus* (Tarragon): A review of its traditional uses, phytochemistry and pharmacology. Frontiers in Pharmacology 12: 653993.

Fatma B, Fatiha M, Elattafia B, Noureddine D. 2016. Phytochemical and antimicrobial study of the seeds and leaves of *Peganum harmala* L. against urinary tract infection pathogens. Asian Pacific Journal of Tropical Disease 6(10): 822-826.

Fewkes, J. 2008. Trade and contemporary society along the Silk Road: An ethno-history of Ladakh., London and New York: Routledge.

Fox JL, Nurbu C, Bhatt S, Chandola A. 1994. Wildlife conservation and land-use changes in the Trans Himalayan region of Ladakh, India. Mountain Research and Development 14(1): 39-60.

Gairola S, Sharma J, Bedi Y. 2014. A cross-cultural analysis of Jammu, Kashmir and Ladakh (India) medicinal plant use. Journal of Ethnopharmacology 155(2): 925-986.

Geneletti D, Dawa D. 2009. Environmental impact assessment of mountain tourism in developing regions: A study in Ladakh, Indian Himalaya. Environmental Impact Assessment Review 29(4): 229-242.

González-Benito ME, Martín C. 2011. In vitro preservation of Spanish biodiversity. In Vitro Cellular & Developmental Biology-Plant 47: 46-54.

Gupta D, Kaul V. 2012. Phytochemical screening of bioactive compounds from different populations of *Hippophae rhamnoides* L. growing in Kargil district (J & K, India). International Journal of Pharmacy and Biological Sciences 3: 447-455.

Hambler C, Canney SM. 2013. Conservation. 2nd edn. Cambridge University Press. Cambridge.

Haq SM, Yaqoob U, Calixto ES, Rahman IU, Hashem A, Abdallah EF, Alakeel MA, Alqarawi AA, Abdalla M, Hassan M, Bussmann RW. 2021. Plant Resources Utilisation among Different Ethnic Groups of Ladakh in Trans-Himalayan Region. Biology 10(9): 827.

Havens K, Kramer AT, Guerrant Jr. EO. 2014. Getting plant conservation right (or not): the case of the United States. International Journal of Plant Sciences 175(1):3-10.

Henderson G, Hume AO, Forsyth TD. 1873. Lahore to Yarkand: incidents of the route and natural history of the countries traversed by the expedition of 1870, under TD Forsyth. London: L. Reeve & Co.

Henebry GM. 1993. Detecting change in grasslands using measures of spatial dependence with Landsat TM data. Remote Sensing of Environment 46(2): 223-234.

Heywood VH. 2017. Plant conservation in the Anthropocene–challenges and future prospects. Plant diversity 39(6): 314-330.

Hooker JD. 1879. Flora of British India, Vol. II. Flora of British India. London: L. Reeve.

Husaini AM, Bhat MA, Kamili AN, Mir MA. 2013. Is Ladakh a 'cold desert'? Current Science 104(6): 687.

Hussain S, Sharma S, Singh AN. 2022. Evaluation of ecosystem supply services and calculation of economic value in Kargil District, India. Regional Sustainability 3(2): 157-169.

Janifer RX, Bajpjpai PK, Phani KG, Pal MM, Jitendra K, Chaurasia OP, Shashi BS. 2010. Determination of Total Phenols, Free Radical Scavenging and Antibacterial Activities of *Mentha longifolia* L. Hudson from the Cold Desert, Ladakh, India. Pharmacognosy Journal 2(12): 470-475.

Jina PS. 1995. High pasturelands of Ladakh Himalaya. Indus Publishing. New Delhi.

Joshi PK, Rawat GS, Padilya H, Roy PS. 2006. Biodiversity characterisation in Nubra Valley, Ladakh with special reference to plant resource conservation and bioprospecting. Biodiversity Conservation 15(13): 4253-4270.

Joshi Y, Kumar P, Yadav AL, Suda N, Halda JP. 2020. Distribution and diversity of lichenicolous fungi from western Himalayan Cold Deserts of India, including a new Zwackhiomyces species. Sydowia 73: 171-183.

Kachroo P. 1993. Plant diversity in Northwest Himalaya a preliminary survey. Himalayan biodiversity: Conservation Strategies 111-132.

Kachroo P, Sapru BL, Dhar U. 1977. Flora of Ladakh: an ecological and taxonomical appraisal. Bishen Singh Mahendra Pal Singh. Publishers, Dehra Dun, India.

Kala CP. 2000. Status and conservation of rare and endangered medicinal plants in the Indian trans-Himalaya. Biological Conservation 93(3): 371-379.

Kala CP. 2005. Health traditions of Buddhist community and role of amchis in trans-Himalayan region of India. Current Science 1331-1338.

Kala CP. 2011. Floral diversity and distribution in the high-altitude cold desert of Ladakh, India. Journal of Sustainable Forestry 30(5): 360-369.

Kala CP, Mathur VB. 2002. Patterns of plant species distribution in the Trans-Himalayan region of Ladakh, India. Journal of Vegetation Science 13(6): 751-754.

Kala CP. 2006. Medicinal plants of the high-altitude cold desert in India: diversity, distribution and traditional uses. The International Journal of Biodiversity Science and Management 2(1): 43-56.

Kaul MK. 1997. Medicinal plants of Kashmir and Ladakh: temperate and cold arid Himalaya. Indus publishing. New Delhi.

Kaur T, Bhat HA, Raina A, Koul S, Vyas D. 2013. Glutathione regulates enzymatic antioxidant defense with differential thiol content in perennial pepper weed and helps adapting to extreme environment. Acta Physiologiae Plantarum 35(8): 2501-2511.

Kaur T. Hussain K, Koul S, Vishwakarma R, Vyas D. 2013. Evaluation of nutritional and antioxidant Status of *Lepidium latifolium* L.: a novel phyto food from Ladakh. PLoS One 8(8): e69112.

Khara A, Khanyari M, Ghoshal A, Rathore D, Pawar UR, Bhatnagar YV, Suryawanshi KR. 2021. The forgotten mountain monarch? Understanding conservation status of the Vulnerable Ladakh urial in India. European Journal of Wildlife Research 67: 1-10.

Khoury CK, Amariles D, Soto JS, Diaz MV, Sotelo S, Sosa CC, Ramírez-Villegas J, Achicanoy HA, Velásquez-Tibatá J, Guarino L, León B, Navarro-Racines C, Castañeda-Álvarez NP, Dempewolf H, Wiersema JH, Andy Jarvis, Jarvis A. 2019. Comprehensiveness of conservation of useful wild plants: An operational indicator for biodiversity and sustainable development targets. Ecological Indicator 98: 420-429.

Kitchlu S, Bakshi SK, Kaul MK, Bhan MK, Thapa RK, Agarwal SG. 2006. *Tanacetum gracile* Hook. f & T. A new source of lavandulol from Ladakh Himalaya (India). Flavour and Fragrance Journal 21(4): 690-692.

Kizu H, Kaneko EI, Tomimore T. 1999. Studies on Nepalese Crude Drugs. XXVI.1) Chemical Constituents of Panch Aunle, the Roots of *Dactylorhiza hatagirea* D. DON. Chemical and Pharmaceutical Bulletin 11: 1618–1625.

Klimeš L. 2003. Life-forms and clonality of vascular plants along an altitudinal gradient in E Ladakh (NW Himalayas). Basic and Applied Ecology 4(4): 317-328.

Klimeš L. 2008. Clonal splitters and integrators in harsh environments of the Trans-Himalaya. Evolutionary Ecology 22: 351-367.

Klimeš L. Dickoré B. 2005. A contribution to the vascular plant flora of Lower Ladakh (Jammu & Kashmir, India). Willdenowia 35(1): 125-153.

KLIMEŠ L, German D. 2008. *Draba alshehbazii* (Brassicaceae), a new species from extreme altitudes of eastern Ladakh (Jammu and Kashmir, India). Botanical Journal of the L.ean Society 158(4): 749-754.

Koenraads KA, Lemmers P, Hofhuis HD, de Nijs N, Namgail T. 2018. Avifauna of Ladakh: four new wetland bird species recorded. BIRDING 29: 53-58.

Kumar GP, Gupta S, Murugan MP, Bala Singh S. 2009. Ethnobotanical studies of Nubra Valley-A cold arid zone of Himalaya. Ethnobotanical leaflets 13(6), 752-765.

Kumar D, Bhat ZA. 2014. Apigenin 7-glucoside from *Stachys tibetica* Vatke and its anxiolytic effect in rats. Phytomedicine 21(7): 1010-1014.

Kumar GP, Kumar R, Chaurasia OP, Singh SB. 2011. Current Status and potential prospects of medicinal plant sector in trans-Himalayan Ladakh. Journal of Medicinal Plants Research 5(14): 2929-2940.

Kumar R, Badere R, Singh SB. 2010. Antibacterial and antioxidant activities of ethanol extracts from trans Himalayan medicinal plants. Pharmacognosy journal 2(17): 66-69.

Kumar R, Phani Kumar G, Chaurasia OP, Singh SB. 2011. Phytochemical and pharmacological profile of seabuckthorn oil: A review. Research Journal of Medicinal Plants 5(5): 491-499.

Lamo K, Akbar PI, Mir MS. 2012. Underexplored and underutilised traditional vegetables of cold arid Ladakh region of India. Vegetos 25: 271-273.

Lubbe FC, Klimešová J, Henry HA. 2021. Winter belowground: Changing winters and the perennating organs of herbaceous plants Functional Ecology 35(8): 1627-1639.

Mani, M.S. 1990. Fundamentals of high altitude biology. 2nd Ed. Oxford and IBM Publishing Co. Pvt. Ltd., New Delhi.

Ma Y, Chen G, Edward Grumbine R, Dao Z, Sun W, Guo H, 2013. Conserving plant species with extremely small populations (PSESP) in China. Biodiversity and Conservation 22: 803-809.

Madawala SR, Brunius C, Adholeya A, Tripathi SB, Hanhineva K, Hajazimi E, Shi L, Dimberg L, Landberg R. 2018. Impact of location on composition of selected phytochemicals in wild sea buckthorn (*Hippophae rhamnoides*). Journal of Food Composition and Analysis 72: 115-121.

Maikhuri RK, Nautiyal S, Rao KS, Saxena KG. 1998. Medicinal plant cultivation and biosphere reserve management: a case study from the Nanda Devi Biosphere Reserve, Himalaya. Current Science 157-163.

Mengist W, Soromessa T, Legese G. 2020. Ecosystem services research in mountainous regions: A systematic literature review on current knowledge and research gaps. Science of Total Environment 702: 134581.

Millennium ecosystem assessment, MEA. 2005. Ecosystems and human well-being (Vol. 5). Washington DC. Island press.

Mishra C, Prins HH, Van Wieren SE. 2003. Diversity, risk mediation, and change in a Trans-Himalayan agropastoral system. Human Ecology 31: 595-609.

Mohan S, Gupta D, 2017. Phytochemical analysis and differential in vitro cytotoxicity assessment of root extracts of *Inula racemosa*. Biomedicine and pharmacotherapy 89: 781-795.

Mollica A, Zengin G, Locatelli M, Stefanucci A, Mocan A, Macedonio G, Carradori S, Onaolapo O, Onaolapo A, Adegoke J, Olaniyan M. 2017. Anti-diabetic and anti-hyperlipidemic properties of *Capparis spinosa* L.: in vivo and in vitro evaluation of its nutraceutical potential. Journal of Functional Foods 35: 32-42.

Moorcroft, W., and G. Trebeck. 1841. Travels in the Himalayan Provinces of Hindustan and the Panjab, in Ladakh and Kashmir, in Peshawar, Kabul, Kunduz, and Bokhara from 1819 to 1825. London: J. Murray.

Mounce R, Smith P, Brockington S. 2017. Ex situ conservation of plant diversity in the world's botanic gardens. Nature Plants 3(10): 795-802.

Murugan MP, Raj XJ, Kumar GP, Sunil G, Singh SB. 2010. Phytofoods of Nubra valley, Ladakh-the cold desert. Indian Journal of Traditional Knowledge 9(2): 303-308.

Namgail T, Fox JL, Bhatnagar YV, 2007. Habitat shift and time budget of the Tibetan argali: the influence of livestock grazing. Ecological Research 22(1): 25-31.

Namgail T, Mudappa D, Raman TS. 2013. Waterbird numbers at high altitude lakes in eastern Ladakh, India. Wildfow 59(59): 135-142.

Namgail T, Rawat GS, Mishra C, van Wieren SE, Prins HH. 2012. Biomass and diversity of dry alpine plant communities along altitudinal gradients in the Himalayas. Journal of Plant Research 125(1): 93-101.

Nasir E, Ali SI. 1970-1989. Flora of Pakistan. National Herbarium, PARC, Islamabad and Department of Botany, University of Karachi, Karachi, Pakistan

Negi SS. 2002. Cold deserts of India. Indus Publishing.New Delhi

Outlook GB. 2010. Global biodiversity outlook 3. In Montréal, Canada: Secretariat of the Convention on Biological Diversity. (http://gbo3. cbd. int/) Phil. Trans. R. Soc. B (Vol. 9).

Pandey S, Gupta RK. 2014. Screening of nutritional, phytochemical, antioxidant and antibacterial activity of *Chenopodium album* (Bathua). Journal of Pharmacognosy and Phytochemistry 3(3): 1-9.

Raj J, Bala SS. 2010. Antioxidative activity and Phytochemical investigation on a High-Altitude Medicinal Plant *Dracocephalum heterophyllum* Benth. Pharmacognosy Journal 2(6): 112-117.

Raj J, Basant B, Murugan PM, da Silva JAT, Saurav K, Chaurasia OP, Singh SB. 2010. Screening phytochemical constituents of 21 medicinal plants of trans-Himalayan region. Medicinal and Aromatic Plant Science and Biotechnology 4: 90-93.

Rattan S, Sood A, Kumar P, Kumar A, Kumar D, Warghat AR. 2020. Phenylethanoids, phenylpropanoids, and phenolic acids quantification vis-à-vis gene expression profiling in leaf and root derived callus lines of *Rhodiola imbricata* (Edgew.). Industrial Crops and Products 154: 112708.

Rawat GS, Adhikari BS. 2005. Floristics and distribution of plant communities across moisture and topographic gradients in Tso Kar basin, Changthang plateau, eastern Ladakh. Arctic, Antarctic, and Alpine Research 37(4): 539-544.

Royle JF. 1970. Illustrations of the botany and other branches of the natural history of the Himalayan mountains, and of the flora of cashmere. Volume plates. Reprint 1970, New Delhi: Today & Tomorrow’s Printers & Publishers 71:1835–1940a.

SCBD. 2012. Report of the high-level panel on global assessment of resources for implementing the strategic plan for biodiversity 2011–2020 (No. UNEP/CBD/COP/11/INF/20).

Shabir M, Tiwari JK. 2021. *Gentianella devendrae* (Gentianaceaea)-A new species from Trans-Himalayan region of India. Taiwania 66(1).

Shabir M, Agnihotri P, Tiwari JK, Husain T. 2018. *Gentiana aperta* (Gentianaceae)-a new record to India from Ladakh Himalaya. Journal of Threatened Taxa 10(9): 12286-12289.

Shabir M, Tiwari J, & Agnihotri P. 2018. Bio-Cultural Diversity of Kargil District (J&K), with Special References to Ethno-Botany. Angiosperm Systematics: Recent Trends and Emerging Issues 329-348.

Shah SM, Amin M, Gul B, Begum M. 2020. Ethnoecological, Elemental, and Phytochemical Evaluation of Five Plant Species of Lamiaceae in Peshawar, Pakistan. Scientifica. doi: 10.1155/2020/2982934

Sharma E, Lal MK, Gulati A. 2022. Targeted UHPLC-QTOF-IMS based metabolite profiling for bioactive compounds in *Rosa webbiana* Wallich ex Royle: An unexploited native from western Himalayas. Plant Physiology and Biochemistry 195: 58-66.

Shi QQ, Zhao JQ, Dang J, Yuan X, Wang QL. 2018. Triterpenes, Flavonoids, and Lignans from *Dracocephalum heterophyllum*. Chemistry of Natural Compounds 54(5): 970-972.

Shinde R, Patil S, Kotecha K, Ruikar K. 2021. Blockchain for securing ai applications and open innovations. Journal of Open Innovation: Technology, Market, and Complexity 7(3): 189.

Showraki A, Emamghoreishi M, Oftadegan S. 2016. Anticonvulsant effect of the aqueous extract and essential oil of *Carum carvi* L. seeds in a pentylenetetrazol model of seizure in mice. Iranian Journal of Medical Sciences 41(3): 200.

Shukla AN, Srivastava SK. 2013. Vegetation and taxonomic profile of the flora of Indian cold desert: A highly fragile and vulnerable mountain ecosystem in the country. Climate Change & Himalayan Informatics 61-72.

Shukla AN, Srivastava SK. 2020. Flora of Ladakh: an annotated inventory of flowering plants. In Biodiversity of the Himalaya: Jammu and Kashmir State. Springer, Singapore. pp. 673-730

Singh B, Chaurasia OP. 1998. Medicinal flora of Indian cold desert. In XXV International Horticultural Congress, Part 13: New and Specialised Crops and Products, Botanic Gardens and Human-Horticulture relationship. 523: 65-74.

Singh B, Chaurasia OP, Jadhav KL.1996. An ethnobotanical study of Indus valley (Ladakh). Journal of Economic and Taxonomic Botany 12: 92-101.

Singh KN. 2013. Traditional knowledge on ethnobotanical uses of plant biodiversity: a detailed study from the Indian western Himalaya. Biodiversity Research and Conservation 28: 63-77.

Singh V, Kapahi BK, Srivastava TN. 1996. Medicinal herbs of Ladakh especially used in home remedies. Fitoterapia 67(1): 38-48.

Sofi II, Zargar SA, Ganie AH, Shah MA. 2022. Distribution dynamics of *Arnebia euchroma* (Royle) IM Johnst. and associated plant communities in Trans-Himalayan Ladakh region in relation to local livelihoods under climate change. Trees, Forests and People 7: 100213.

Srivastava SK, Shukla AN. 2015. Flora of cold desert Western Himalaya. Vol II. Botanical Survey of India, Kolkata.

Stewart JL. 1870, January. I. Notes of a Botanical Tour in Ladak or Western Tibet. In Transactions of the Botanical Society of Edinburgh (Vol. 10, No. 1-4, pp. 207-239). Taylor & Francis Group.

Stewart RR. 1916. The Flora of Ladak, Western Tibet. I. Discussion of the Flora. Bulletin of the Torrey Botanical Club. 43(11): 571-590.

Stobdan T, Targais K, Lamo D, Srivastava RB. 2013. Judicious use of natural resources: A case study of traditional uses of seabuckthorn (*Hippophae rhamnoides* L.) in trans-Himalayan Ladakh, India. National Academy Science Letters 36(6): 609-613.

Sun Y, Yang T, Wang C. 2022. *Capparis spinosa* L. as a potential source of nutrition and its health benefits in foods: a comprehensive review of its phytochemistry, bioactivities, safety, and application. Food Chemistry 135258.

Tantray YR, Wani MS, Pradhan SK, Jan I, Singhal VK, Gupta RC. 2021. Variation in Phytochemical Content in Polyploid Populations of *Hyoscyamus pusillus* Thriving at Different Altitudes in Cold Deserts of Ladakh, India. Analytical Chemistry Letters 11(2): 255-270.

Tayade AB, Dhar P, Sharma M, Chauhan RS, Chaurasia OP, Srivastava RB. 2013. Antioxidant capacities, phenolic contents, and GC/MS analysis of *Rhodiola imbricata* Edgew. Root extracts from Trans-Himalaya. Journal of Food Sciences 78(3): C402-C410.

Tewari VP, Kapoor KS. 2013. Western Himalayan cold deserts: biodiversity, eco-restoration, ecological concerns and securities. Annals of Arid Zone. 52(3 & 4): 225-232.

The International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) (FAO, 2009). https://www.fao.org/3/i0510e/i0510e.pdf.

Thomson T. 1852. Western Himalaya and Tibet, a narrative of a journey through the mountains of Northern India, during the years I847-48. London.

Turner M, Gardner RH. 1991. Quantitative methods in landscape ecology: the analysis and interpretation of landscape heterogeneity. Ecological studies (USA).

United Nations Sustainable Development Goal (SDG) 2.5 (2015). https://www.fao.org/3/CA3121EN/ca3121en.pdf.

Uniyal SK, Awasthi A, Rawat GS. 2005. Biomass availability and forage quality of *Eurotia ceratoides* Mey in the rangelands of Changthang, eastern Ladakh. Current Science 201-205.

Vannelli K, Hampton MP, Namgail T, Black SA. 2019. Community participation in ecotourism and its effect on local perceptions of snow leopard (*Panthera uncia*) conservation. Human Dimensions of Wildlife 24(2): 180-193.

Venditti A, Frezza C, Sciubba F, Foddai S, Serafini M, Nicoletti M, Bianco A. 2016. Secoiridoids and other chemotaxonomically relevant compounds in *Pedicularis*: phytochemical analysis and comparison of *Pedicularis rostratocapitata* Crantz and *Pedicularis verticillata* L. from Dolomites. Natural Product Research 30(15): 1698-1705.

Verma RS, Padalia RC, Goswami P, Verma SK, Chauhan A, Darokar MP. 2016. Chemical composition and antibacterial activity of *Bidens pilosa*. Chemistry of Natural Compounds 52(2): 340-341.

Vign GT. 1842. Travels in Kashmir & Ladakh, Iscardo, the countries adjoining the mountain-course of the Indus, and the Himalaya, north of the Punjab. I, 2. London.

Vyas S, Sheikh FD, Singh S, Sena DS, Bissa UK, Sharma N. 2014. Sea Buckthorn (*Hippophae rhamnoides*)-An important fodder for Bactrian camel in Ladakh region. Journal of Camel Practice and Research 21(1): 89-91.

Wang W, Li J. 2021. In-situ conservation of biodiversity in China: Advances and prospects. Biodiversity Science 29(2): 133.

Warghat AR, Bajpai PK, Srivastava RB, Chaurasia OP, Sood H. 2013. Population genetic structure and conservation of small fragmented locations of *Dactylorhiza hatagirea* in Ladakh region of India. Scientia Horticulturae 164: 448-454.

Werden LK, Sugii NC, Weisenberger L, Keir MJ, Koob G, Zahawi RA. 2020. Ex situ conservation of threatened plant species in island biodiversity hotspots: A case study from Hawai'. Biological Conservation 243: 108435.

Yatoo MI, Dimri U, Gopalakrishnan A, Saxena A, Wani SA, Dhama K. 2018. In vitro and in vivo immunomodulatory potential of *Pedicularis longiflora* and *Allium carolinianum* in alloxan-induced diabetes in rats. Biomedicine and Pharmacotherapy 97: 375-384.

Yatoo MI, Dimri U, Gopalakrishnan A, Karthik K, Gopi M, Khandia R, Saminathan M, Saxena A, Alagawany M, Farag MR, Munjal A. 2017. Beneficial health applications and medicinal values of Pedicularis plants: A review. Biomedicine and Pharmacotherapy 95: 1301-1313.

Yu Y, Li J, Zhou Z, Ma X, Zhang X. 2021. Response of multiple mountain ecosystem services on environmental gradients: How to respond, and where should be priority conservation? Journal of Cleaner Production 278: 123264.

Zhang G, Chen S, Zhou W, Meng J, Deng K, Zhou H, Hu N, Suo Y. 2018. Rapid qualitative and quantitative analyses of eighteen phenolic compounds from *Lycium ruthenicum* Murray by UPLC-Q-Orbitrap MS and their antioxidant activity. Food chemistry 269: 150-156.

Zhang H, Gao Y, Hua Y, Zhang Y, Liu K. 2019. Assessing and mapping recreationists perceived social values for ecosystem services in the Qinling Mountains, China. Ecosystem Services 39: 101006.

Zou YS, Dawa Z, Lin CZ, Zhang QY, Yao YF, Yuan Y, Zhu CC, Wang ZY. 2019. New amide alkaloids from *Delphinium brunonianum*. Fitoterapia. 36: 104186