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# Wild and Semi-Wild Edible Plants in High Altitude Cold Desert of Ladakh: A Comprehensive Review

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**Abstract:** The cold arid region of Ladakh hosts a rich diversity of wild and semi-wild edible plants (WSWEPs) that play an indispensable role in regional food and nutritional security. This review synthesizes ethnobotanical, nutritional, ecological, and conservation literature to highlight the multidimensional value of 52 documented wild and semi-wild edible plants (WSWEP) species. These plants provide essential macro- and micronutrients, including high levels of protein, carbohydrates, vitamins, and antioxidants, thereby addressing micronutrient deficiencies common in high-altitude regions. Their ecological significance extends to soil stabilization, biodiversity protection, and climate adaptation. However, WSWEP populations are increasingly threatened by overharvesting, overgrazing, habitat destruction, and climate-induced changes. This review identifies critical research gaps and proposes pathways for sustainable utilization, community-based conservation, and policy integration. The synthesis underscores the importance of combining traditional knowledge with scientific evidence to enhance food security and environmental resilience in fragile cold-desert ecosystems.

**Key words**: Wild edible plants, Ladakh, food security, ethnobotany, sustainability, nutritional diversity, cold arid region.





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The cold arid landscapes of Ladakh, located in the trans-Himalayan region of India, represent one of the harshest inhabited environments on Earth. Annual precipitation is extremely low, winter temperatures frequently fall below –30°C, and the effective growing season is limited to just 100 to 120 days. Under these severe ecological constraints, indigenous communities have long relied on wild and semi-wild edible plants (WSWEPs) not only as supplementary food sources but also as essential components of cultural identity, traditional healthcare systems, and environmental stewardship. Collected from barren slopes, riverbanks, and alpine meadows, these species act as critical buffers against seasonal food scarcity by supplying micronutrients largely absent in staple crops such as barley and wheat. Their persistent use reflects an enduring

*Table 1. Potential Fodder plants and uses at high altitude of Ladakh*

| Species | Habitat (m) | Plant characters | Growing period | Harvesting time | Plant part used |
|---|---|---|---|---|---|
| *Cicer microphyllum* Benth. | 4230-4870 | Herb | June-August | September | Whole plant |
| *Convolvulus arvensis* L. | 3540 | Herb | Mid June-August | September | Whole plant |
| *Ephedra gerardiana* Wall. ex Stapf | 3960 | Tufted shrub | June-September | October | Leaves and fruits |
| *Fagopyrum esculentum* Moench | 2780-3890 | Annual herb | June-September | September | Whole plant |
| *Heracleum pinnatum C.B.Clarke* | 3450-4530 | Herb | June-August | September | Leaves |
| *Hippophae rhamnoides* L. | 3150 | Shrub | June- September | October | Leaves |
| *Iris lactea* Pall. | 3450 | Herb | June-August | September | Whole plant |
| *Lepidium latifolium* L. | 3260-3650 | Herb | July-September | September | Leaves |
| *Medicago falcata* L. | 4250 | Herb | Mid June-September | September | Whole plant |
| *Medicago media* Willd. | 4000 | Herb | Mid June-September | September | Whole plant |
| *M. sativa* L. | 4450 | Herb | Mid June-September | September | Whole plant |
| *Melilotus officinalis* (L.) Pall. | 4000 | Herb | Mid June-August | September | Whole plant |
| *Populus nigra* L. | 3700 | Tree | June-August | August | Leaves and Bark |
| *Salix alba* L. | 3550 | Tree | May-August | August | Leaves and Bark |
| *Salix daphnoides* | 2850-3160 | Tree | June-August | August | Whole plant |
| *Sisymbrium loeselii* Vill. | 3105 | Annual/ biennial | July-September | September | Whole plant |
| *Stellaria media* (L.) Vill. | 3450 | Annual herb | June-September | September | Whole plant |

ethnobotanical heritage maintained through generational knowledge transmission, despite the region's geographic isolation and prolonged winter closures caused by snow-blocked passes (Angmo *et al.,* 2022; Murugan *et al.,* 2010; Rana *et al.,* 2012; Gaur, 2025). Similar dependence on wild edible plants has been reported across other cold-desert and high-mountain regions of the Himalaya, Central Asia, and the Tibetan Plateau, underscoring the broader relevance of these resources in marginal environments (Klimeš and Dickoré, 2005; Haq *et al.,* 2021). Table 1 presents potential fodder plants and their uses at high altitude in Ladakh.

Foraging traditions in Ladakh are deeply rooted in Tibetan cultural influences. Classical treatises such as the *Blue Beryl* document numerous plant species used for nutrition and medicine, demonstrating the long-standing recognition of their role in high-altitude survival (Navchoo and Buth, 1990; Angmo *et al.,* 2022; Haq *et al.,* 2021; Boesi, 2014). Nineteenth-century explorers, including Ferdinand von Prunner, similarly noted the widespread consumption of greens such as *Oxyria digyna*, which played a crucial role in preventing scurvy during long winters (Roy *et al.,* 2024). Post-independence botanical explorations expanded the scientific understanding of regional flora; surveys by the Botanical Survey of India recorded more than 900 vascular plant species in Ladakh, of which 10 to 15% possess edible or medicinal properties (Klimes and Dickoré, 2005; Rana *et al.,* 2012; Haq *et al.,* 2021). However, systematic ethnobotanical documentation emerged only in recent decades. Comprehensive field-based studies conducted since the 2000s have documented between 20 and 50 wild edible species per valley, depending on altitude, habitat heterogeneity, and survey intensity (Ballabh *et al.,* 2007; Murugan *et al.,* 2010; Rana *et al.,* 2012; Klimes and Dickore, 2005; Haq *et al.,* 2021; Bhoyar *et al.,* 2011). Contemporary field surveys indicate that WSWEPs contribute up to 30% of annual vegetable intake in rural households particularly during the "hungry gap" between late autumn and early spring (Batool and Gairola, 2025).

A rich diversity of edible species continues to be incorporated into daily diets. Frequently consumed plants include *Allium victorialis*, *Amaranthus dubius*, *Malva neglecta*, *Oxalis corniculata*, *Nasturtium officinale*, *Oxyria digyna*, *Cichorium intybus*, *Plantago depressa*, *Rumex nepalensis*, *Taraxacum officinale*, *Stellaria media*, and *Silene vulgaris*. Mint species such as *Mentha longifolia*, *M. arvensis*, and *M. aquatica* are commonly prepared in salads

and herbal chutneys valued for their flavour and digestive properties. Fungi also form an important component of local cuisine; species such as *Morchella esculenta*, *Rhizopogon villosus*, *Agaricus campestris*, and *Pleurotus ostreatus* are regarded as delicacies and are even served during ceremonial occasions. Their culinary significance reflects a long-standing cultural appreciation for diverse foraged foods (Roy *et al.,* 2024).

Food security in Ladakh remains fragile due to limited arable land—less than 1% of the region's 45,110 km² area—and crop productivity constrained by frost, salinity, short growing periods, and weather extremes. Micronutrient deficiencies, including iron-deficiency anemia (affecting nearly 40% of women) and vitamin A deficiency, remain prevalent. In this context, WSWEPs provide vital nutritional support. For example, berries of *Hippophae rhamnoides* contain exceptionally high vitamin C concentrations, while leaves of *Urtica hyperborea* are rich in iron, calcium, and protein. Dietary assessments from Nubra and Indus valleys demonstrate that incorporation of multiple WSWEP species significantly improves household dietary diversity scores and micronutrient intake, highlighting their potential role in mitigating "hidden hunger" in cold-desert regions (Chongtham *et al.,* 2022; Batool *et al.,* 2024).

Beyond their nutritional importance, these species contribute significantly to environmental sustainability. Sustainable foraging practices help reduce soil erosion, maintain biodiversity, and strengthen ecosystem resilience. Unlike monoculture agriculture, foraging disperses harvesting pressure across landscapes and supports ecological balance. With climate projections indicating a reduction of up to 20 growing-season days by 2050 in parts of the Trans-Himalaya, traditional practices such as selective harvesting and pruning of species like *Rheum spiciforme* exemplify adaptive resource management strategies. Such practices align closely with global sustainability frameworks, including the United Nations Sustainable Development Goals related to zero hunger, climate action, and life on land (Chongtham *et al.,* 2022; Hassan *et al.,* 2024; Roy *et al.,* 2024).

Research on WSWEPs in Ladakh has expanded considerably over the past three decades, encompassing ethnobotany, nutrition, pharmacology, ecology, and sustainability sciences. Early scholarship by Bhattacharyya (1991) emphasized cultural symbolism, while Ballabh *et al*. (2007) and Bhoyar *et al*. (2011) catalogued raw edible species and warned of knowledge erosion among younger generations. Nutritional research gained momentum after 2010. Kaur *et al*. (2013) reported high protein and antioxidant content in *Lepidium latifolium*; Avasthi *et al*. (2016) documented exceptional phenolic levels in *Urtica hyperborea and also* identified substantial micronutrient richness in underutilized species such as *Malva verticillata*. Parallel ethnobotanical studies (Murugan *et al.,* 2010; Rana *et al.,* 2012; Haq *et al.,* 2021) further recorded species diversity, use-reports, and fidelity levels, reaffirming the central role of WSWEPs in local diets and traditional medicine.

However, sustainability assessments highlight emerging threats. Overgrazing by nearly 1.2 m livestock has degraded approximately 40% of Ladakh's rangelands, while rapid tourism growth has fragmented habitats critical for several edible and medicinal species. Climate-change projections further suggest potential range contractions and phenological shifts in alpine and sub-alpine flora, posing long-term risks to WSWEP availability and associated traditional knowledge systems (Roy *et al.,* 2024; Hassan *et al.,* 2024). Addressing these challenges requires integrated strategies that combine scientific research, community-based management, and policy support. Proposed conservation strategies include establishing in situ gene banks (Rana *et al.,* 2012), promoting home-garden cultivation of leafy WSWEPs to enhance yields by up to 30% (Raghuvanshi *et al.,* 2021), and regulating the harvest of vulnerable taxa such as *Rhodiola imbricata*, a near threatened species (Boesi, 2014; Hassan *et al.,* 2024).

Despite the growing body of research, significant gaps persist. Economic valuations of WSWEP-based value chains are limited, even though seabuckthorn alone contributes over Rs. 500 m annually to the regional economy (Hassan *et al.,* 2024; Chongtham *et al.,* 2022). Gender-disaggregated data remain scarce, despite women contributing nearly 70% of foraging labour. Addressing these gaps is essential for developing integrated, community-centered

*Table 2. Altitude-wise ecological zonation*

| Altitude Range (m) | Dominant life form | Representative species | Ecological niche / adaptation |
|---|---|---|---|
| 2800-3300 | Trees and shrubs | *Salix daphnoides*, *Hippophae rhamnoides* | Moist riparian zones, valley floors |
| 3300-3900 | Annual/herbs | *Fagopyrum esculentum*, *Lepidium latifolium*, *Stellaria media* | Cultivated fields, fallows, pastures |
| 3900-4500 | Legumes and forbs | *Medicago sativa*, *Melilotus officinalis*, *Heracleum pinnatum* | Upland meadows, dry slopes |
| 4500-4900 | Alpine herbs | *Cicer microphyllum*, *M. Falcate* | Harsh alpine environment |

frameworks for sustainable utilization and conservation. Figure 1 present distribution of feed and fodder species across altitude zones.

Overall, existing evidence demonstrates that WSWEPs are not remnants of traditional subsistence but critical pillars of Ladakh's food security, cultural heritage, and ecological resilience. This review synthesizes ethnobotanical, nutritional, and sustainability perspectives to illuminate their multifaceted significance and to outline pathways for integrating WSWEPs into regional food system planning and biodiversity conservation. Ultimately, these species emerge as cornerstones of a climate-resilient and biodiversity-rich future for Ladakh's cold desert ecosystems.

## Ethnobotanical Significance of WSWEPs

*Diversity and cultural relevance*: Ethnobotanical surveys conducted across the diverse valleys of Ladakh consistently highlight a rich and varied assemblage of wild and semi-wild edible plants (WSWEPs), with documented species counts ranging from about 20 in isolated, high-altitude settlements to more than 50 in ecologically diverse valleys such as Indus and Nubra (Murugan *et al.*, 2010; Rana *et al.*, 2012; Haq *et al.*, 2021; Bhoyar *et al.*, 2011). This variation in species diversity is shaped by differences in altitude, microclimate, soil moisture, and proximity to water bodies, all of which influence the distribution and availability of edible flora. Recent assessments further indicate that valleys with greater hydrological connectivity and agro-pastoral activity support higher WSWEP diversity than extremely arid interior basins (Batool and Gairola, 2025). Table 2 and Figure 2 present altitude-wise ecological zonation and distribution of WSWEP species in Ladakh.

Beyond their ecological occurrence, these plants hold deep cultural resonance within Ladakhi society. They are not only seasonal food resources but are intricately embedded in culinary practices, ethnomedicinal systems, and spiritual traditions (Navchoo and Buth, 1990). Leafy greens such as *Urtica hyperborea* (Zatsod), *Lepidium latifolium* (Shangsho), *Rumex patientia* (Shoma), *Taraxacum officinale*, and *Capparis*

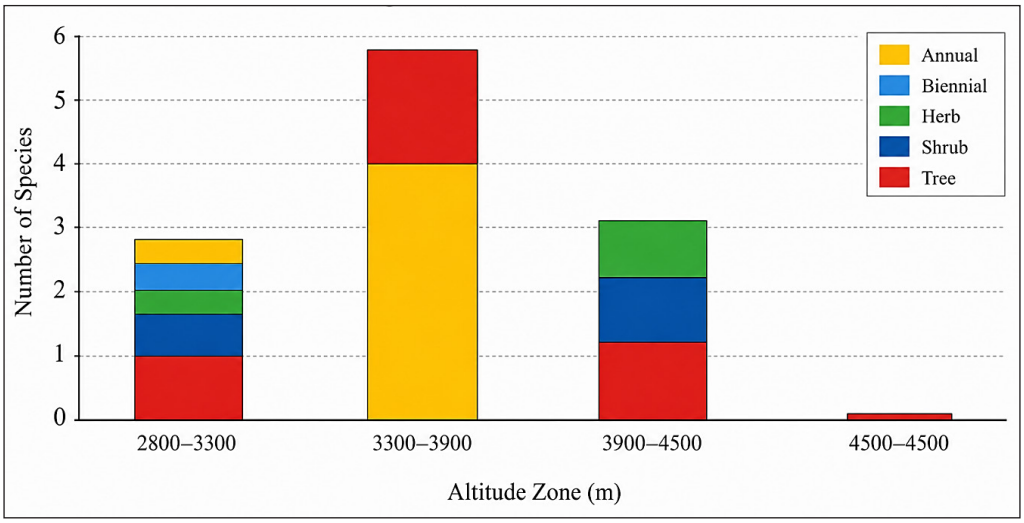


*Fig. 1. Distribution of feed and fodder species across altitudinal zones based on standardized life-form categories (annuals, biennials, herbs, shrubs and trees).*

*Table 3. Diversity and uses of selected WSWEPs in Indus Valley*

| Scientific name | Family | Local name | Edible part | Primary use | UR | CI |
|---|---|---|---|---|---|---|
| *Lepidium latifolium* L. | Brassicaceae | Shangsho | Leaves | Vegetable (*Shangsho tsodma*) | 24 | 0.40 |
| *Mentha longifolia* (L.) L. | Lamiaceae | Phololing | Leaves | Chutney, Flavoring | 28 | 0.47 |
| *Allium przewalskianum* Regel | Amaryllidaceae | Skotse | Leaves | Spice | 15 | 0.25 |
| *Hippophae rhamnoides* L. | Elaeagnaceae | Tsestalulu | Berries/Leaves | Juice/Tea | 17 | 0.28 |
| *Rumex patientia* L. | Polygonaceae | Shoma | Leaves | Vegetable | 21 | 0.35 |
| *Urtica hyperborea* Jacq. ex Wedd. | Urticaceae | Zatsod | Leaves | Soup (*Zathuk*) | 26 | 0.43 |

UR = Use reports; CI = Cultural importance index.

*spinosa* (Kabra) feature prominently in local diets and form the basis of widely consumed dishes including *Thukpa* (noodle soup), *Zathuk* (herbal nettle soup), and *tangtur* (curd-based herb accompaniment). Their recurring presence in daily meals illustrates both their nutritional importance and the retention of traditional culinary knowledge across generations. The preparation and consumption of these foods are often linked with seasonal rituals, communal labour practices, and household-level food-sharing systems, reinforcing social cohesion in remote mountain communities.

Many WSWEPs are also valued for their perceived therapeutic properties, reflecting a long-standing integration of food and medicine within Ladakh's cultural landscape. Species such as *Urtica hyperborea, Allium przewalskianum*, and *Mentha longifolia* are believed to improve digestion, enhance circulation, and alleviate cold-related ailments—attributes that are particularly valued in high-altitude environments. This food–medicine continuum is a defining feature of Himalayan ethnobotany and highlights the adaptive strategies developed by communities to cope with climatic stress and limited healthcare access (Ballabh *et al.,* 2007; Haq *et al.,* 2021; Gaur *et al.,* 2024a). Together, the diversity and extensive cultural embedding of WSWEPs underscore their indispensable role in sustaining livelihoods, preserving traditional ecological knowledge, and maintaining food and health security in Ladakh's challenging cold-desert environment.

Tables 3 to 6 present the diversity and uses of selected WSWEPs across the Indus, Nubra, Sham, and Changthang valleys. UR (Use Reports) and CI (Cultural Importance Index) values indicate the relative frequency of use and cultural significance of individual species

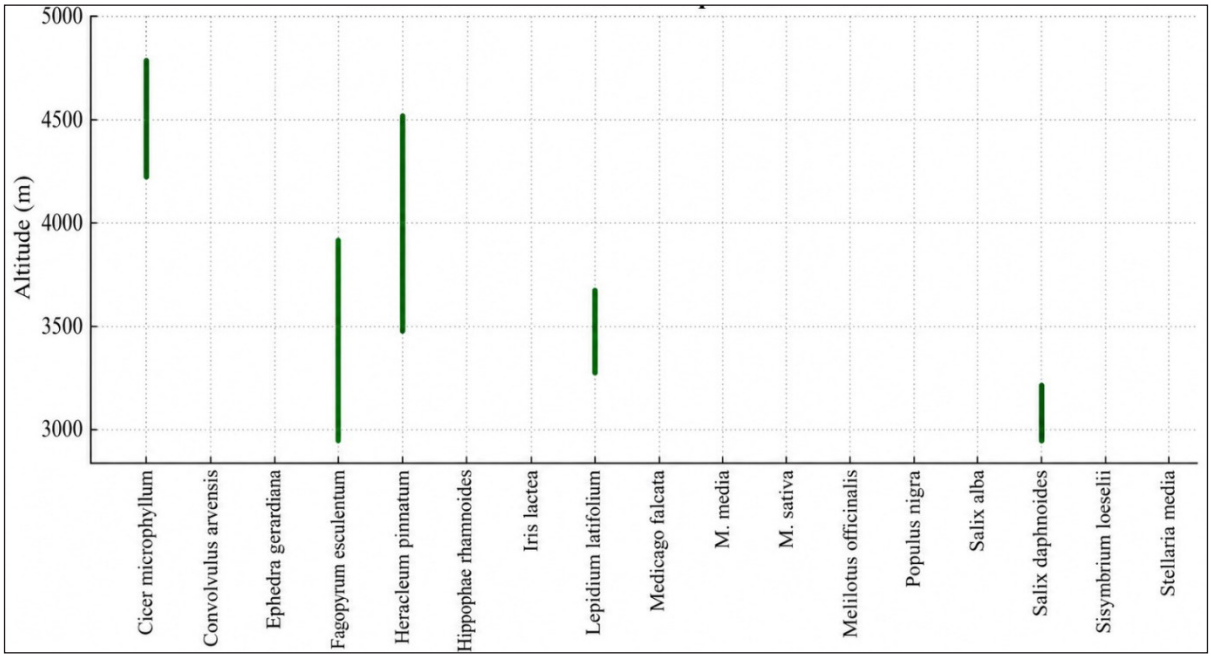


*Fig. 2. Altitudinal distribution of species in Ladakh.*

*Table 4. Prominent WSWEPs in Nubra Valley*

| Scientific name | Family | Local name | Edible part | Primary use | UR | CI |
|---|---|---|---|---|---|---|
| *Capparis spinosa* L. | Capparaceae | Kabra | Leaves/fruit | Tsodma dish | 31 | 0.52 |
| *Dysphania botrys* (L.) Mosyakin and Clemants | Amaranthaceae | Hama | Leaves | Chutney | 21 | 0.35 |
| *Thymus linearis* Benth. | Lamiaceae | Tumburu | Shoots | Flavoring | 38 | 0.63 |
| *Allium humile* Kunth | Amaryllidaceae | Kue | Leaves | Curry | 15 | 0.25 |
| *Bunium persicum* (Boiss.) Fedtsch. | Apiaceae | Korneet | Seeds | Spice | 10 | 0.17 |
| *Hippophae rhamnoides* L. | Elaeagnaceae | Sermang | Fruits | Juice | 17 | 0.28 |

UR = Use reports; CI = Cultural importance index.

*Table 5. Selected WSWEPs in Sham Valley*

| Scientific name | Family | Local name | Edible part | Primary use | UR | CI |
|---|---|---|---|---|---|---|
| *Rheum spiciforme* | Polygonaceae | Lachu | Stem | Flour | 9 | 0.15 |
| *Cichorium intybus* L. | Asteraceae | Shianthi | Shoots | Vegetable | 20 | 0.33 |
| *Rhodiola imbricata Edgew.* | Crassulaceae | Shrolo-karpo | Leaves | Dishes | 21 | 0.35 |
| *Taraxacum officinale F.H.Wigg.* | Asteraceae | Khorma | Leaves | Vegetable | 22 | 0.37 |
| *Brassica rapa* L. | Brassicaceae | Mulak | Tuber | Vegetable | 9 | 0.15 |
| *Ranunculus hirtellus Royle* | Ranunculaceae | Spang-ner | Whole plant | Spice | 5 | 0.08 |

UR = Use reports; CI = Cultural importance index.

within each valley, reflecting both ecological availability and cultural preference. These data reveal that several species—such as *Lepidium latifolium, Urtica hyperborea, Capparis spinosa*, and *Hippophae rhamnoides*—are consistently important across multiple valleys, emphasizing their central role in Ladakhi food systems.

Species such as *Urtica hyperborea Jacq. ex Wedd.*, *Lepidium latifolium*, *Rumex patientia*, *Taraxacum officinale*, and *Capparis spinosa* contribute essential vitamins and minerals to local diets and are incorporated into widely consumed meals such as *Thukpa* (noodle soup), *Zathuk* (nettle-based porridge), and *tangtur* (yogurt-based herbal preparation). Their regular use illustrates a long-standing culinary relationship shaped by necessity, ecological adaptation, and sensory preference. Importantly, these plants extend beyond nutritional roles; many are also associated with religious rituals, local healing traditions, and cultural celebrations, emphasizing their integral place in Ladakh's socio-cultural fabric.

*Aromatic and Medicinal Plants*: Several WSWEPs also hold prominent positions as aromatic herbs and medicinal plants. Species such as *Allium przewalskianum*, *Mentha longifolia*, *Thymus linearis*, and *Bunium persicum* are widely used to enhance the flavour of traditional dishes while simultaneously providing therapeutic benefits. These plants are valued not only for their distinctive aromas but also for their functional properties, including digestive stimulation, antimicrobial activity, and relief from respiratory discomfort. Their frequent inclusion in everyday meals reflects a sophisticated understanding of plant properties embedded within local knowledge systems.

*Table 6. Core WSWEPs in Changthang Valley*

| Scientific name | Family | Local name | Edible part | Primary use | UR | CI |
|---|---|---|---|---|---|---|
| *Allium oreoprasum* Schrenk | Amaryllidaceae | Skotze | Leaves | Onion substitute | 10 | 0.17 |
| *Plantago major* L. | Plantaginaceae | Karatse | Shoots | Vegetable | 19 | 0.32 |
| *Rhodiola tibetica (Hook.f. & Thomson) S.H.Fu* | Crassulaceae | Shrolo | Leaves | Chutney | 6 | 0.10 |
| *Capsella bursa-pastoris (L.) Medik.* | Brassicaceae | Sokapa | Leaves | Vegetable | 11 | 0.18 |
| *Chesneya cuneata* (D. Don) Ali | Fabaceae | Bigangbu | Fruit | Vegetable | 9 | 0.15 |
| *Rosa webbiana* Wall. ex Royle | Rosaceae | Siah marpo | Fruit | Tea | 6 | 0.10 |

UR = Use reports; CI = Cultural importance index.

In traditional Tibetan medicine (*Sowa Rigpa*) and Ladakhi folk healing practices, aromatic WSWEPs play vital roles. *Thymus linearis* is commonly used to treat cold-related ailments and chest congestion, while *Mentha longifolia* serves as a digestive aid and is consumed as herbal tea and chutneys. *Allium przewalskianum*, often used as a substitute for cultivated onions and garlic, is believed to promote warmth and vitality—attributes highly valued in the region's extreme winters. Ethnobotanical evidence suggests that such species often occupy a dual status as both daily food ingredients and household remedies, blurring the distinction between nutrition and medicine (Rana *et al.,* 2012; Haq *et al.,* 2021). This dual utility underscores the adaptive knowledge systems developed by Ladakhi communities in response to environmental constraints.

*Raw and foraged foods*: Beyond cooked dishes and herbal preparations, many WSWEPs are consumed raw, particularly by children, shepherds, and nomadic pastoralists. Species such as *Rheum tibeticum* and *Rheum spiciforme Royle* are relished for their tangy, refreshing stalks, which provide a natural source of hydration and micronutrients during long hours spent in the fields or pastures (Bhoyar *et al.,* 2011). Likewise, wild berries, including *Ribes glaciale* and *Lycium ruthenicum*, are foraged seasonally and eaten fresh for their sweet-tart flavours and energizing qualities.

These foraging practices serve a purpose far beyond nutrition. They contribute to early childhood learning, helping younger generations develop plant identification skills, ecological awareness, and an understanding of safe and sustainable harvesting methods. For nomadic and semi-nomadic pastoralists, raw foraged foods also function as convenient, portable low-input dietary supplements during transhumance movements, reinforcing food self-reliance in remote rangeland environment. As such, raw plant consumption forms an essential component of Ladakh's ethnobotanical traditions, linking ecological knowledge, cultural identity and everyday livelihood activities.

*Nutritional and functional potential*: A growing body of nutritional research demonstrates that wild and semi-wild edible plants from Ladakh possess remarkably high nutrient densities, often surpassing commonly cultivated vegetables. Multiple analyses have documented substantial levels of carbohydrates (14-36 mg $g^{-1}$ DW), proteins (11-38 mg $g^{-1}$ DW), and vitamin C (27-50 mg $g^{-1}$ DW), alongside significant concentrations of antioxidant compounds such as phenolics, flavonoids, and elevated ferric reducing antioxidant power (FRAP) values. These nutritional properties are especially valuable in high-altitude environments where limited dietary diversity, physiological stress and elevated oxidative load increases vulnerability to micronutrient deficiencies (Avasthi *et al.,* 2016; Batool *et al.,* 2024).

Several widely consumed WSWEPs exhibit exceptional nutritional and functional properties. *Lepidium latifolium*, for example, has been shown to contain high levels of proteins, essential amino acids, and antioxidant compounds, supporting its classification as a potential phyto-functional food (Kaur *et al.,* 2013). Similarly, *Urtica hyperborea* is rich in minerals such as iron, calcium, and magnesium, along with bioactive compounds that contribute to improved immune function and metabolic health (Avasthi *et al.,* 2016). Such nutrient-dense species play a critical role in compensating for the low availability of fresh vegetables during prolonged winters and early spring in Ladakh (Chongtham *et al.,* 2022; Akbar *et al.,* 2025).

Fruits and berries of several WSWEP species further enhance dietary quality. Berries of *Hippophae rhamnoides* are particularly notable for their exceptionally high vitamin C content, which far exceeds that of most cultivated fruits, making them an important natural defense against scurvy and other deficiency-related ailments (Ali *et al.,* 2012). In addition to vitamin C, seabuckthorn fruits contain carotenoids, flavonoids, and essential fatty acids that collectively contribute to antioxidant, anti-inflammatory, and cardioprotective effects. These functional attributes have led to growing interest in seabuckthorn-based products for both local consumption and commercial value-addition.

Beyond individual species, the collective contribution of WSWEPs to household nutrition is substantial. Dietary assessments from Indus and Nubra valleys indicate that regular consumption of multiple WSWEP species significantly improves household

dietary diversity scores, particularly by enhancing micronutrient intake during lean agricultural periods (Batool *et al.,* 2024). This diversified intake is especially important for women, children, and elderly populations, who are most susceptible to anemia, mineral deficiencies, and diet-related health challenges in high-altitude regions.

In addition to conventional nutrients, many WSWEPs contain bioactive phytochemicals with functional food potential. Elevated levels of phenolics, flavonoids, and antioxidant enzymes have been reported in species such as *Malva verticillata*, *Rumex patientia*, and *Taraxacum officinale*, indicating their role in mitigating oxidative stress associated with cold exposure and hypoxia. Such properties support the traditional perception of these plants as "strength-giving" or "warming" foods and provide a scientific basis for their continued use in high-altitude diets.

Overall, the nutritional and functional attributes of WSWEPs underscore their importance as low-input, climate-resilient food resources. Unlike many cultivated vegetables, these species are well adapted to cold, arid conditions and require minimal external inputs, making them particularly suitable for sustainable food systems in fragile mountain environments. Integrating WSWEPs into local nutrition strategies, value-addition initiatives, and functional food research could significantly enhance food and nutritional security while supporting biodiversity conservation in Ladakh and similar cold-desert regions.

## Ecological Importance

*Soil and ecosystem stability*: Wild and semi-wild edible plants (WSWEPs) play a critical role in maintaining soil stability and ecosystem functioning in Ladakh's fragile cold-desert environment. Many of these species are highly adapted to xerophytic and cryophytic conditions characterized by low precipitation, intense wind action, freeze–thaw cycles, and nutrient-poor soils. Their well-developed root systems help anchor loose substrates on steep slopes and valley sides, thereby reducing soil erosion caused by wind and episodic runoff—processes that are particularly severe in the trans-Himalayan region.

Species such as *Hippophae rhamnoides*, *Salix daphnoides*, and *Populus nigra* function as keystone riparian stabilizers, particularly along riverbanks and alluvial fans, where they reduce bank erosion, trap sediments, and improve micro-site moisture conditions. Herbaceous WSWEPs including *Medicago sativa*, *Melilotus officinalis*, and *Lepidium latifolium* further contribute to soil stabilization by enhancing ground cover and reducing surface runoff during the short but intense growing season (Rana *et al.,* 2012; Klimes and Dickore, 2005).

In addition to physical stabilization, WSWEPs contribute to soil fertility through organic matter inputs and nutrient cycling. Leaf litter, root turnover, and rhizosphere interactions enrich otherwise poor soils with carbon and essential nutrients, improving microbial activity and soil structure. Nitrogen-fixing legumes such as *Medicago sativa* and *Melilotus officinalis* are particularly important in this regard, as they enhance nitrogen availability in alpine and sub-alpine soils where nutrient inputs are otherwise extremely limited. Collectively, these functions support microhabitat formation and sustain plant communities in landscapes that are otherwise highly susceptible to degradation.

## Biodiversity and Climate Resilience

The diversity of WSWEPs significantly enhances plant species richness and ecological heterogeneity across Ladakh's altitudinal gradients. These species form complex ecological networks involving pollinators, herbivores, soil micro-organisms, and associated flora (Chongtham *et al.,* 2022; Gaur, 2025). Flowering WSWEPs such as *Thymus linearis*, *Taraxacum officinale*, and *Allium* spp. provide critical nectar and pollen resources for native pollinators during short alpine summers, thereby supporting broader ecosystem productivity.

WSWEPs are also characterized by remarkable physiological tolerance to extreme cold, high ultraviolet radiation, and large diurnal temperature fluctuations. Such traits make them key components of climate-resilient ecosystems and valuable reservoirs of adaptive genetic resources (Haq *et al.,* 2021; Chongtham *et al.,* 2022). As climate warming accelerates in the trans-Himalayan region, these hardy species are likely to play an increasingly important role in stabilizing ecosystem processes and

buffering against biodiversity loss (Haq *et al.,* 2021; Gaur *et al.,* 2024b).

Several WSWEPs, including *Hippophae rhamnoides*, *Rheum spiciforme*, and *Urtica hyperborea*, exhibit broad ecological amplitudes, enabling them to persist across multiple habitats and altitudinal zones. This ecological plasticity enhances overall landscape resilience by maintaining functional redundancy within plant communities, thereby reducing the risk of ecosystem collapse under climatic stress. Moreover, their adaptive traits offer promising avenues for future research in climate-resilient agriculture and restoration ecology.

## Rangeland Functionality

Rangelands constitute a dominant land-use system in Ladakh and form the ecological backbone of pastoral livelihoods. Herbaceous and shrubby WSWEPs are integral to maintaining rangeland productivity, forage quality, and ecosystem balance. Species such as *Cicer microphyllum*, *Medicago falcata*, *Melilotus officinalis*, and *Chesneya cuneata* provide highly palatable and nutritious forage for yaks, sheep, goats, and cattle, particularly during the short alpine growing season when biomass production peaks.

However, rising livestock populations and shifts in grazing patterns have intensified pressure on rangeland ecosystems. Recent assessments indicate that nearly 40 % of Ladakh's rangelands exhibit varying degrees of degradation, manifested through reduced vegetation cover, soil compaction, and loss of palatable forage species (Roy *et al.,* 2024). Overgrazing disrupts plant regeneration cycles and alters species composition, often favouring unpalatable or invasive taxa at the expense of nutritionally valuable WSWEPs.

Maintaining the diversity of WSWEPs is therefore essential for sustaining rangeland functionality and pastoral resilience. Community-managed grazing systems, seasonal movement patterns, and protection of key forage habitats can help preserve edible plant diversity while ensuring long-term livestock productivity. Given the strong interdependence between WSWEP diversity and pastoral livelihoods, rangeland management strategies that integrate ecological and ethnobotanical knowledge are critical for the sustainable development of Ladakh's cold-desert landscapes.

## Threats to WSWEP Resources

Wild and semi-wild edible plants (WSWEPs) of Ladakh are increasingly exposed to multiple, often interacting, anthropogenic and environmental pressures. While these species have historically been resilient to climatic extremes, the intensity and pace of recent changes pose significant challenges to their long-term survival and sustainable use.

*Overharvesting and commercial pressure*: Several WSWEP species face growing pressure from overharvesting, particularly those with high medicinal, culinary, or commercial value. Species such as *Arnebia euchroma*, *Rheum tibeticum*, and *Rhodiola imbricata* are heavily collected for their use in traditional medicine, natural dyes, and emerging herbal markets. Unregulated extraction, often involving destructive harvesting methods such as uprooting whole plants or removal of entire rhizomes, severely limits natural regeneration and threatens local population persistence (Boesi, 2014; Rana *et al.,* 2012).

Commercialization has further intensified harvesting pressure, especially in easily accessible valleys and along transport corridors. The growing demand for wild medicinal and nutraceutical products has shifted collection practices from subsistence-based use to market-oriented extraction, frequently exceeding sustainable harvest thresholds. In the absence of enforceable harvesting guidelines, such trends pose serious risks to slow-growing alpine and sub-alpine species with narrow ecological niches.

*Overgrazing and livestock pressure*: Overgrazing represents one of the most pervasive threats to WSWEP diversity in Ladakh. The region supports nearly 1.2 million livestock, including sheep, goats, yaks, and cattle, which graze across extensive rangeland systems. Intensive grazing pressure leads to vegetation thinning, soil compaction, and selective removal of palatable species, many of which are also important WSWEPs.

Overgrazing disrupts plant regeneration cycles, alters species composition, and accelerates erosion, thereby compounding the impacts of climatic stressors. Species such as *Medicago falcata*, *Cicer microphyllum*, and

*Chesneya cuneata*, which are highly palatable, are particularly vulnerable under sustained grazing pressure.

*Habitat loss and fragmentation*: Rapid infrastructure development has emerged as a major driver of habitat loss and fragmentation in Ladakh (Haq *et al.,* 2021; Gaur *et al.,* 2024b). Expansion of road networks, tourism facilities, military infrastructure, hydropower projects, and telecommunication installations has significantly altered the region's fragile landscapes. These developments often result in direct habitat removal, disruption of natural drainage systems, and increased human disturbance.

Fragmentation disproportionately affects WSWEP species with narrow habitat preferences or limited dispersal capacity, reducing population connectivity and genetic exchange. Valleys experiencing high tourism intensity, such as Indus and Nubra, face additional pressures from trampling, waste accumulation, and informal harvesting along trekking routes. Collectively, these factors contribute to the gradual erosion of foraging landscapes traditionally used by local communities (Haq *et al.,* 2021).

## Climate Change

Climate change poses a long-term and systemic threat to the distribution, phenology, and productivity of WSWEPs in Ladakh. Observed trends include rising mean temperatures, declining snow cover, altered precipitation regimes, and increased frequency of extreme weather events. These changes directly affect plant growth cycles, flowering and fruiting times, and water availability.

Climate models project that suitable habitats for several alpine and sub-alpine WSWEP species may shrink by 15-20% over the coming decades, particularly for taxa confined to narrow altitudinal ranges (Roy *et al.,* 2024; Hassan *et al.,* 2024). Earlier snowmelt and reduced glacial runoff may further limit soil moisture during the critical growing season, adversely affecting biomass production and nutrient composition.

In addition to direct physiological stress, climate change interacts synergistically with other threats such as overgrazing and habitat fragmentation, amplifying their impacts. Such cumulative pressures increase the risk of local extinctions and undermine the resilience of traditional food systems dependent on wild plant resources.

## Sustainable Utilization and Conservation Pathways

Ensuring the long-term availability of WSWEPs in Ladakh requires an integrated conservation approach that balances ecological sustainability with livelihood security and cultural continuity. Given the region's fragile ecosystems and strong dependence on natural resources, conservation strategies must be locally grounded, participatory, and adaptive.

*Community-based management and traditional knowledge*: Local communities in Ladakh possess extensive traditional knowledge related to the identification, harvesting, processing, and seasonal availability of WSWEPs (Rana *et al.,* 2012; Boesi, 2014; Gaur *et al.,* 2024a). This indigenous knowledge system has historically regulated resource use through customary norms, seasonal restrictions, and selective harvesting practices that minimized ecological impact. Revitalizing and formalizing such community-based management systems can significantly enhance conservation outcomes (Rana *et al.,* 2012; Boesi, 2014; Gaur, 2025).

Participatory resource governance models—such as village-level conservation committees, rotational harvesting schemes, and community-monitored grazing systems—can help regulate extraction intensity and timing. Incorporating elders, women, and pastoralists in decision-making processes ensures intergenerational knowledge transfer and strengthens local stewardship of edible plant resources (Rana *et al.,* 2012; Boesi, 2014). Leaves and young shoots constituted the most frequently utilized plant parts, followed by fruits, seeds, and underground organs. This pattern reflects both ease of access and sustainability, as selective leaf harvesting allows continued plant regeneration. Figure 3 presents growth and harvesting calendar of species.

*Sustainable harvesting and domestication potential*: Promoting sustainable harvesting protocols is essential to prevent population decline of ecologically and culturally important WSWEP species. Guidelines emphasizing partial harvesting, avoidance of uprooting, and post-seed collection can enhance regeneration

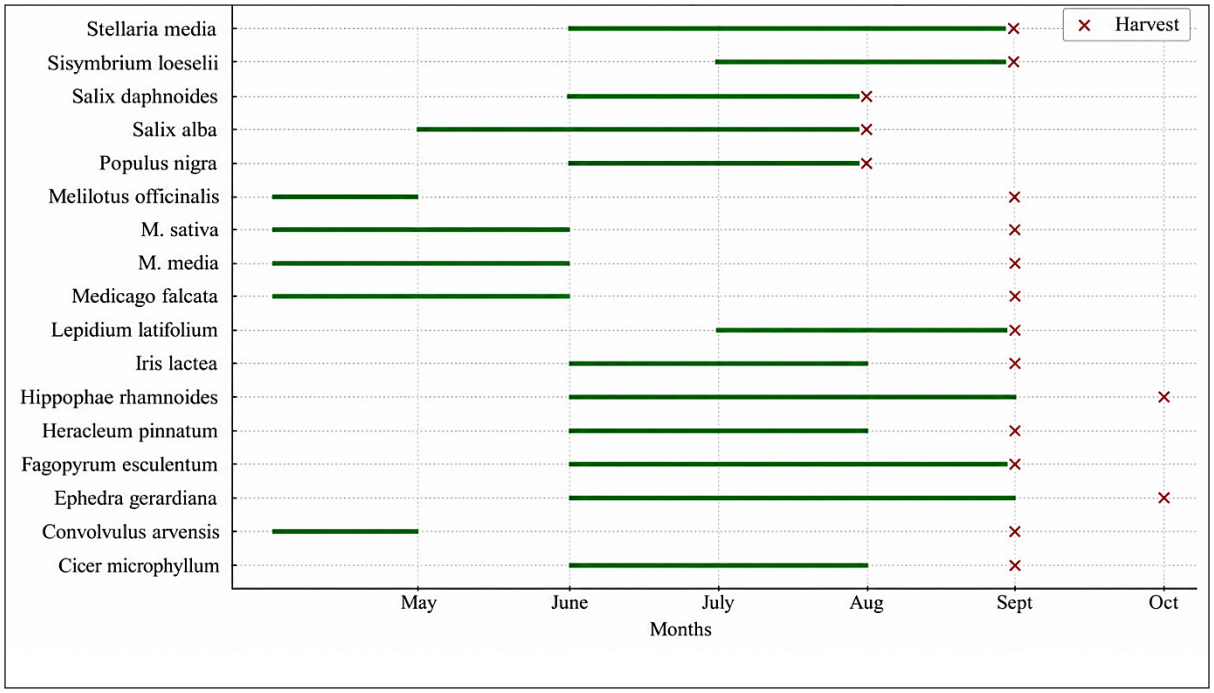


*Fig. 3. Growth and harvesting calendar of species.*

and population stability, particularly for slow-growing alpine taxa.

Several WSWEPs, including *Hippophae rhamnoides*, *Allium przewalskianum*, *Lepidium latifolium*, and *Medicago sativa*, show considerable potential for semi-domestication and integration into agroforestry or homestead systems. Cultivating such species in controlled environments can reduce pressure on wild populations while enhancing local food security and nutritional diversity. Pilot domestication initiatives have demonstrated improved yield stability and economic returns without compromising ecological integrity (Haq *et al.*, 2021).

*Policy integration and institutional support*: Effective conservation of WSWEPs requires alignment between local practices and regional policy frameworks. Inclusion of WSWEPs in biodiversity action plans, rangeland management policies, and climate adaptation strategies can provide formal recognition and institutional backing for conservation initiatives. Programs focusing on sustainable rangeland management, eco-restoration, and climate-resilient agriculture should explicitly integrate edible wild plant diversity.

Strengthening institutional support through research-extension linkages, seed banks, and demonstration plots can further facilitate sustainable utilization. Government agencies, research institutions, and non-governmental organizations must collaborate to document species diversity, assess conservation status, and develop location-specific management guidelines (Roy *et al.*, 2024).

*Awareness, value addition, and livelihood diversification*: Raising awareness about the nutritional, ecological, and cultural value of WSWEPs is critical for fostering conservation-oriented attitudes among both local communities and external stakeholders. Educational programs, food festivals, and school curricula can play an important role in revitalizing interest in traditional foods and sustainable harvesting practices.

Value addition through processing, packaging, and marketing of WSWEP-based products—such as dried greens, herbal teas, nutraceuticals, and traditional condiments—offers opportunities for livelihood diversification, particularly for women and marginal households. However, commercialization must be carefully regulated to ensure that increased demand does not lead to overexploitation of wild populations.

## Research Gaps and Future Directions

Despite growing recognition of WSWEPs, significant research gaps remain regarding their

population dynamics, nutritional composition, and response to environmental change. Long-term ecological monitoring, coupled with ethnobotanical and nutritional studies, is needed to inform evidence-based management strategies.

Future research should prioritize: (i) population ecology and regeneration dynamics of key WSWEP species (ii) climate sensitivity and adaptive traits (iii) sustainable harvest thresholds (iv) socio-economic valuation of ecosystem services

Addressing these gaps will strengthen conservation planning and enhance the role of WSWEPs in resilient food systems under changing climatic conditions.

## Global Relevance and Comparative Perspective

WSWEPs of Ladakh represent a distinctive yet globally relevant component of mountain food systems. Although shaped by extreme cold-desert conditions, the ecological functions, cultural values, and livelihood contributions of these species mirror patterns observed in other high-altitude and arid regions worldwide. Positioning Ladakh's WSWEPs within a global comparative framework highlights their broader significance for food security, biodiversity conservation, and climate adaptation.

## WSWEPs in Global Mountain and Arid Landscapes

Across mountain systems such as the Andes, Central Asian Highlands, Tibetan Plateau, and Ethiopian Highlands, wild edible plants continue to supplement household diets, particularly among indigenous and pastoral communities. Studies from these regions demonstrate that WSWEPs contribute essential micronutrients, dietary diversity, and resilience during periods of crop failure or climatic stress (Chongtham *et al.,* 2022; Hassan *et al.,* 2024).

Comparable to Ladakh, cold and arid mountain regions elsewhere rely heavily on perennial herbs, shrubs, and stress-tolerant annuals that are adapted to short growing seasons, high radiation, and nutrient-poor soils (Haq *et al.,* 2021; Akbar *et al.,* 2025). Species assemblages differ taxonomically but converge functionally, underscoring the universal ecological importance of wild edible flora in marginal environments.

## Food Security, Nutrition, and Climate Adaptation

Globally, WSWEPs are increasingly recognized as critical components of climate-resilient food systems. Their ability to thrive under extreme environmental conditions makes them particularly valuable in the context of rising temperatures, altered precipitation regimes, and increasing climate variability. Evidence from arid and semi-arid regions suggests that wild edible plants act as nutritional safety nets, buffering vulnerable populations against food insecurity and malnutrition.

In Ladakh, WSWEPs serve similar functions by supplementing cereal-based diets with vitamins, minerals, and bioactive compounds. This parallels findings from African drylands and Central Asian rangelands, where wild leafy greens and fruits contribute significantly to dietary quality and seasonal food availability (Haq *et al.,* 2021). Such comparisons reinforce the importance of conserving wild edible plant diversity as part of broader global strategies for nutritional security and climate adaptation.

## Indigenous Knowledge Systems and Cultural Parallels

Traditional knowledge associated with WSWEPs is a common feature across mountain societies worldwide. Indigenous communities have developed detailed understanding of plant phenology, habitat preferences, and sustainable harvesting practices, often embedded within cultural norms and belief systems. The ethnobotanical knowledge documented in Ladakh reflects similar adaptive strategies observed among Andean, Himalayan, and African highland communities, highlighting convergent human-environment interactions.

However, globalization, socio-economic change, and generational shifts threaten the continuity of this knowledge globally. Comparative studies emphasize that erosion of traditional ecological knowledge often precedes biodiversity loss, underscoring the need for integrated conservation approaches that value both biological and cultural diversity (Boesi, 2014).

## Lessons from Ladakh for Global Conservation and Policy

Ladakh offers valuable lessons for sustainable management of WSWEPs in fragile ecosystems. The close linkage between wild edible plants, pastoral systems, and cultural practices demonstrates the importance of integrating biodiversity conservation with livelihood strategies. Community-based resource management, seasonal harvesting norms, and multifunctional land use observed in Ladakh can inform conservation frameworks in other mountain and arid regions.

At a policy level, Ladakh's experience highlights the need to mainstream wild edible plants into food security planning, rangeland management, and climate adaptation policies. Recognizing WSWEPs as both ecological assets and cultural resources can strengthen global efforts to promote resilient and inclusive food systems under changing environmental conditions.

## Conclusions

Wild and semi-wild edible plants (WSWEPs) constitute an indispensable yet often underappreciated component of the high-altitude cold-desert ecosystem of Ladakh. This comprehensive review highlights their multifaceted roles in sustaining food security, nutritional diversity, ecological stability, and cultural identity in one of the world's most climatically extreme and fragile regions.

The diversity of WSWEPs documented across Ladakh reflects remarkable ecological adaptation to harsh environmental conditions, including low precipitation, extreme temperatures, and short growing seasons. These species not only supplement subsistence diets but also enhance ecosystem resilience through soil stabilization, nutrient cycling, biodiversity support, and rangeland functionality. Their close association with traditional food practices and indigenous knowledge systems underscores their cultural significance and long-standing role in human-environment interactions.

However, WSWEP resources are increasingly threatened by overharvesting, rangeland degradation, infrastructure expansion, and climate change. Without timely and coordinated interventions, these pressures may erode both biological diversity and traditional knowledge systems that have sustained mountain communities for generations. Addressing these challenges requires integrated conservation strategies that combine community-based management, sustainable harvesting practices, policy support, and scientific research.

This review emphasizes that conserving WSWEPs is not merely an ecological imperative but also a socio-economic and cultural necessity. By situating Ladakh's experience within a global context, the study demonstrates that lessons from cold-desert ecosystems can inform broader debates on climate-resilient food systems, sustainable rangeland management, and biodiversity conservation in arid and mountainous regions worldwide.

Future efforts should prioritize long-term ecological monitoring, nutritional and pharmacological validation, domestication potential, and policy integration of WSWEPs into regional development and climate adaptation frameworks. Recognizing and safeguarding these plant resources will be critical for strengthening resilience, food sovereignty, and sustainability in Ladakh and comparable fragile ecosystems across the globe.

## Competing Interests

The authors declare no competing interests.

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