Wild edible plants used by the Indigenous communities of the Trans-Himalayan region of Ladakh, India

Zohra Batool, Sumeet Gairola

Correspondence

Zohra Batool[1,2], Sumeet Gairola[2,3]*

[1]Plant Sciences and Agrotechnology Division, CSIR- Indian Institute of Integrative Medicine, Canal Road, Jammu - 180 001, Jammu and Kashmir, India
[2]Academy of Scientific and Innovative Research (AcSIR), Ghaziabad, Uttar Pradesh, India
[3]Department of Botany and Microbiology, Hemwati Nandan Bahuguna Garhwal University, Srinagar Garhwal - 246 174, Uttarakhand, India

*Corresponding Author: sumeetgairola@gmail.com

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Research

Abstract

Background: Indigenous communities living in the cold-arid desert of Ladakh, located in the northernmost part of India in the Trans-Himalayan region, evolved traditional knowledge to identify, harvest, use, and manage wild edible plants (WEPs). WEPs are vital in meeting nutritional needs and surviving food scarcity during harsh winters. However, WEPs and related traditional knowledge in the region have declined recently due to multiple human, climatic, and environmental factors. Hence, the present study aimed to document traditional knowledge and diversity of WEPs, the current threat status of WEPs, identify species with maximum usage and quantify consensus among the informants in Ladakh.

Methods: The study was conducted in 12 villages of five regions, viz., Changthang, Kargil, Nubra, Leh, and Zanskar of Ladakh, between 2019 and 2022. 60 participants (35 men and 25 women) were interviewed using open and semi-structured questionnaires.

Results: Fifty-two wild edible plants belonging to 25 families and 40 genera were recorded as being used for edible purposes, with 288 use reports (UR). The most utilized species were *Thymus linearis* Benth. (UR=38), and *Capparis spinosa* L. (UR=31). The recorded species' cultural index (CI) ranged from 0.03 to 0.63. The highest informant consensus factor (ICF) was reported for the vegetable category (ICF=0.82), followed by traditional dishes and flavoring agents (ICF=0.80 each). Based on the IUCN Red List and North-Western Himalayan (NWH) database, recorded WEPs included one critically endangered, two endangered, and three vulnerable species.

Conclusions: The current study reported 52 wild edible plants of Ladakh, highlighting their rich diversity and importance in traditional cuisine. The findings of this study can be utilized in the future to identify individual nutritional value and antioxidant activities of species with high consensus and cultural significance.

Keywords: Wild edible plants; Ladakh; Traditional knowledge; Ethnobotany; Informant consensus factor

Background

Wild edible plant species (WEPs) have long been used as a source of food around the world. These WEPs include essential nutritional components such as carbohydrates, protein, fibers, and antioxidants (Jacinto-Azevedo *et al.* 2021). The Indigenous communities of Ladakh have employed WEPs since time immemorial (Batool *et al.* 2023). According to Gairola *et al.* (2014), the region has between 1250 and 1500 vascular plant species, of which just a few are edible. *Prunus armeniaca* L. and *Bunium persicum* B. Fedtsch are the most widely cultivated edible species in the Ladakh region (Batool *et al.* 2024). However, species like *Capparis spinosa* L.*, Carum carvi* L.*, Chenopodium album* L.*, Dysphania botrys* (L.) Mosyakin & Clemants*, Lactuca tatarica* C.A.Mey.*, Malva verticillata* L.*, Plantago major* L.*, Rumex patientia* L.*, Taraxacum officinale* F.H. Wigg., and *Urtica hyperborea* Jacquem. ex Wedd., only grow in the wild and are valued for their nutritional properties (Nirmala *et al.* 2022).

Wild edible species provide a good source of sustenance for far-flung residents, especially during the region's harsh and extended winter (Ballabh *et al.* 2007). For the winter season, the leafy portions of these plants are appropriately dried, packed, and stored in distinctive constructions locally called "*Sadong*," "*Tsothbang*," and "*Charches*" for preservation from frosting, rotting, and mechanical injuries (Ali *et al.* 2012; Batool *et al.* 2023). Most of these WEPs are located at an altitude of >3000 m asl and are predominately wild perennial herbs. Leaves, fruit, and shoots constitute > 50% of the most edible plant parts and are mainly consumed as vegetables, either cooked or boiled (Rana *et al.* 2012).

Some researchers have studied WEPs of the Union Territory of Ladakh (Ali *et al.* 2012; Angchok *et al.* 2009; Ballabh *et al.* 2007; Batool *et al.* 2024; Bhoyar *et al.* 2011; Boesi 2014; Dorjey 2025; Murugan *et al.* 2010; Rana *et al.* 2012). However, it is crucial to document WEPs with special reference to greater consensus among the local population and identify significant species based on regional cultural importance. The importance of these wild edible plants is enormous among the Indigenous communities of Ladakh, especially in light of the belief in traditional knowledge and the use of WEPs for nutritional and therapeutic purposes. The present study aimed to document traditional knowledge and diversity of WEPs, the current threat status of WEPs of Ladakh, identify species with maximum usage and quantify consensus among the informants in five regions of Ladakh, India, viz., Changthang, Kargil, Nubra, Leh, and Zanskar.

Materials and Methods

Study area

Union Territory of Ladakh, a cold desert tucked away in the Trans-Himalayan region of India, is popularly known as the "Land of Lamas" and as "Little Tibet," lies between 31°44’57” - 32°59’57” N latitude and 76°46’29” - 78°41’34” E longitude (Batool *et al.* 2022). The region has a unique topographical location, extreme climatic conditions, and short vegetative months, and it holds an important place in the mountain ecosystem (Batool *et al.* 2023; Gairola *et al.* 2014). Despite the hilly, dusted, mountainous terrain with minimal vegetation, the region is endowed with wild edible plants and high-value medicinal and aromatic plants.

The region's climatic condition witnesses extreme temperature fluctuations, ranging from 25℃ to 35℃ during summer and -25℃ to -35℃ in winter (Batool *et al.* 2023). The surrounding mountains of the region possess a barrier to the seasonal monsoon and receive meager precipitation of less than 100 mm/year (Negi 2002). During the harsh winter, the entire region is usually cut off from the rest of the country for a minimum of 4-5 months. The vegetative sessions in the region typically run for five to six months with only two crop rotations, and this is limited to only one crop in the Drass, Changthang, and Zanskar regions.

The flora of Ladakh falls under alpine and high alpine zones and is dominated by annual and perennial herbs, some of which are shunted shrubs and bushes (Ballabh *et al.* 2007). Most people are engaged in agricultural work and rearing livestock. Residents involved in agropastoral occupations benefit from cultivating and selling wild edible plants and other cultivatable fruits and vegetables in local markets. The agricultural and plant-related works, including the collection of WEPs in the region, are mainly male-dominated, while women are primarily occupied with household chores and livestock care (Batool *et al.* 2023).

According to the 2011 census (COI 2011), more than 75% of the population lives in rural areas. The average literary rate for males and females is 86% and 64%, respectively. The major ethnic groups of the region are Argon, Boto, Balti, Purigpa, Changpa, Brokpa, Changpa, Beda, and Mon (Batool *et al.* 2022; Bhasin 2005). Most people in Ladakh speak "*Ladakhi*" (a form of Tibetan language); however, there are some dialects that vary among different ethnic groups. Argon, Balti, and Boto speak Ladakhi and Zanskari; Purigpa speaks Purgi; Brokpa speaks Brokskat and Dardi; Changpa speaks Changskat; Mon and Beda can speak Ladakhi, Zanskari, and Purgi. The Argon ethnic group is mainly involved in business and trade, while the majority of the other ethnic groups are engaged in agricultural work and rearing livestock (Batool *et al.* 2023; Bhasin 2005).

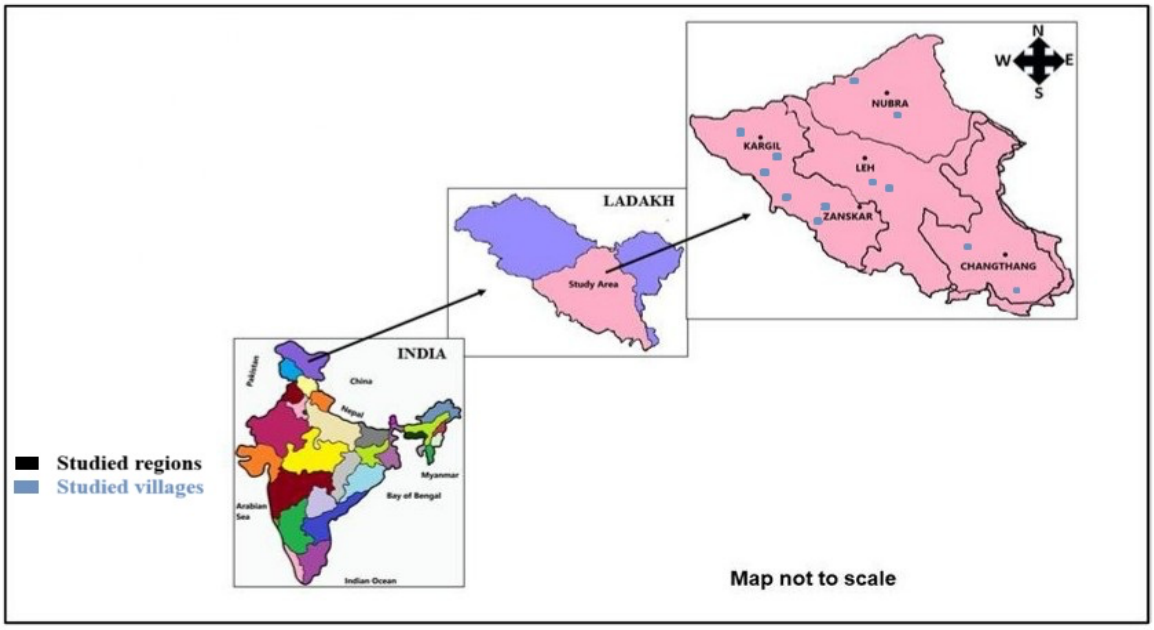

Figure 1. Map of the study area showing five regions of Ladakh

Data collection and plant identification

The ethnobotanical survey was conducted in 12 villages of five regions of Ladakh viz., Changthang (Nyoma, Korzok), Kargil (Minji, Sankoo, Panikhar, Suru), Nubra (Diskit, Thang), Leh (Thiksey, Choglamsar), and Zanskar (Padum, Sheela) between 2019 and 2022 (Fig. 1). The survey was conducted using open and semi-structured questionnaires from randomly selected local participants (Batool *et al.* 2023). The verbal participants' prior informed consent was obtained following CBD (Convention on Biological Diversity) guidelines, and they were fully informed of the purpose and scope of the investigation. The interview technique adopted in the current study encouraged participants' spontaneous participation and allowed them to elaborate on their traditional knowledge in a comprehensive manner (Batool *et al.* 2023). The local language, *Ladakhi,* spoken by one of the authors (Z.B), was used to conduct interviews. The code of ethics established by the International Society of Ethnobiology (2013) was strictly followed during the entire course of study. Sixty participants (35 males and 25 females) between the ages of 18 and 75 years participated in the study. The numbers of informants in each region were viz., Changthang (n=12), Kargil (n=18), Nubra (n=9), Leh (n=10), and Zanskar (n=11). Most participants (55%) were between the age of 45-75 years and were engaged in agricultural work (Table 1).

The authors of this paper taxonomically identified all the plant species collected during the present study. The Flora of Ladakh and regional herbaria viz., Herbarium of the University of Jammu, the University of Kashmir, and the Janaki Ammal Herbarium (RRLH), Council of Scientific and Industrial Research- Indian Institute of Integrative Medicine (CSIR-IIIM) Jammu, J&K, India were consulted for plant identification. For future reference, duly identified herbarium voucher specimens were deposited at the internationally recognized Janaki Ammal Herbarium (RRLH) at CSIR-IIIM, Jammu. The World Flora Online (www.worldfloraonline.org accessed in January 2024) was used to determine the currently accepted botanical names and author citations for the identified plant species.

Table 1. Demographic details of the participants

		No. of informants	Percentage
Gender	Male	35	58.3%
	Females	25	41.7%
Age groups	18-30 years	17	28.3%
	30-45 years	10	16.7%
	45-75 years	33	55.0%
Education level	Illiterate	30	50.0%
	Primary level	12	20.0%
	Secondary level	8	13.3%
	Graduate	10	16.7%
Occupation	Farmers	42	70.0%
	Faith healers	5	8.3%
	Government employee	3	5.0%
	Shopkeepers	10	16.7%

Data Analysis

The primary data of the present study was analyzed for Use Report (UR), Informant Consensus Factor (ICF), and Cultural Index (CI).

Use Report (UR)

A use report is a single record mentioning the use of a part of a plant by an informant (Tardío & Pardo-De-Santayana 2008).

Informant Consensus Factor (ICF)

To understand the homogeneity of collected information about a plant in a particular category, the Informant Consensus Factor (ICF) was calculated using the following equation (Trotter & Logan 2019).

$$\mathrm{ICF} = \frac{\mathrm{N_{ur}} - \mathrm{N_t}}{\mathrm{N_{ur}} - 1}$$

N_{ur} is the total use reports for a specific use category, and N_t is the total number of species used in that category. ICF values are between 0-1, and a value close to one indicates higher consensus among the informants, and a value close to zero indicates minimal consensus for the share of information among the informants.

To assess ICF, the uses of the recorded WEPs were classified into eight different edible categories, viz., traditional dishes, chutney, spice, vegetable, juice, flavoring agent, flour, and local tea.

Cultural Index (CI)

The data was also analyzed to understand the Cultural Index (CI) using the following equation (Tardío & Pardo-De-Santayana 2008).

$$\mathrm{CI} = \sum_{u=u_1}^{u_{nc}} . \sum_{\mathrm{i}=\mathrm{i}_1}^{\mathrm{i_n}} \mathrm{UR}_{\frac{\mathrm{ui}}{\mathrm{N}}}$$

The Cultural Importance Index (CI) was calculated by adding the percentage of informants who cited each usage category for a given species. CI shows the variety of plant uses and the degree to which information sources are recognized for each category (Tardío & Pardo-De-Santayana 2008). NC is the total number of use categories, and N is the total number of informants who participated in the study.

This index is meant to quantify the importance of a plant species to indigenous inhabitants of Ladakh.

Current Threat Status

The threat status of the recorded plants was assessed using the IUCN (International Union for Conservation of Nature) Red List database and the North-Western Himalayan (NWH) region database (Kala 2005). This analysis would aid in prioritizing the strategies for the conservation and sustainable utilization of these important resources (Batool *et al.* 2023).

Results

Diversity of wild edible plants

In the present study, 52 wild edible plant species belonging to 25 families and 40 genera were recorded, with a total of 288 use reports (UR) (Table 2). The most dominant families used by the Indigenous communities of Ladakh were Brassicaceae (8 spp.), followed by Polygonaceae (6 spp.), and Asteraceae (4 spp.) (Fig. 2). Most of the species were herbs (Fig. 3). Leaves were the most edible plants (42%), followed by tender shoots (19%), mature shoots (15%), stems (9%), and fruits (7%) (Fig. 4). In the current study, the maximum number of species were used as vegetables (23 spp.), followed by traditional dishes (21 spp.) and Chutney (5 spp.) (Table 2). Of 52 recorded plants, most of the species were reported from the Kargil region (n=39), followed by Nubra (n=28), and the least in the Changthang region (n=14) (Table 2). The majority of the plant species and their uses in traditional meals were reported by males aged 45-75 years, primarily engaged in agricultural activities, as illustrated in Table 1.

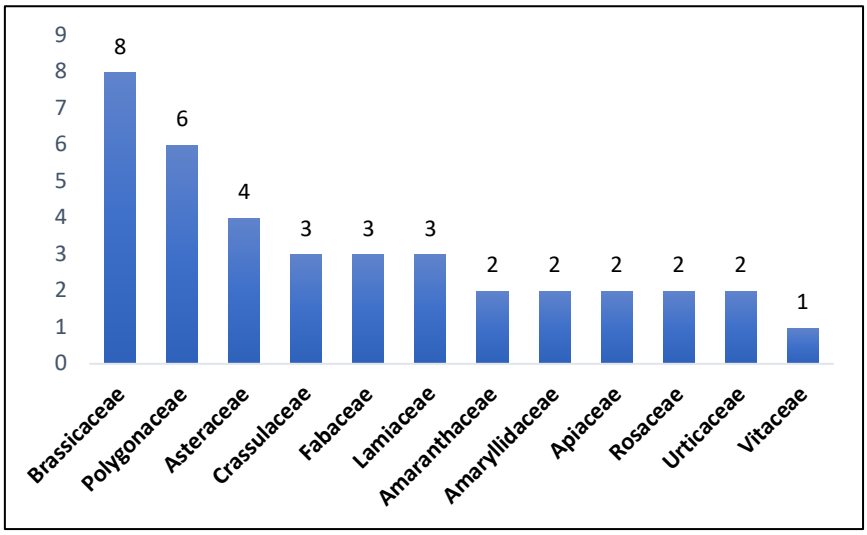

Figure 2. The most represented families of WEPs used by the indigenous people of Ladakh

Most cited species

The most cited species used for edible purposes by the Indigenous communities of Ladakh based on the highest use report (UR) was *Thymus linearis* Benth. (UR=38), followed by *Capparis spinosa* (UR=31), *Mentha longifolia* (L.) L. (UR=28), *Urtica hyperborea* (UR=26), *Carum carvi* (UR=25), and *Lepidium latifolium* L. (UR=24), as presented in Table 2. The highest use report was recorded for vegetables (UR=121), followed by traditional dishes (UR=99), and the least for local flour (UR=4).

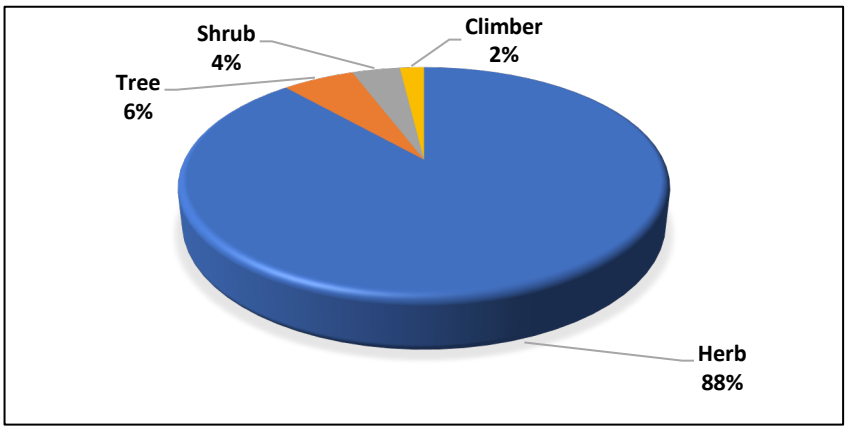

Figure 3. Percentage representation of plant habits of WEPs used by the indigenous people of Ladakh

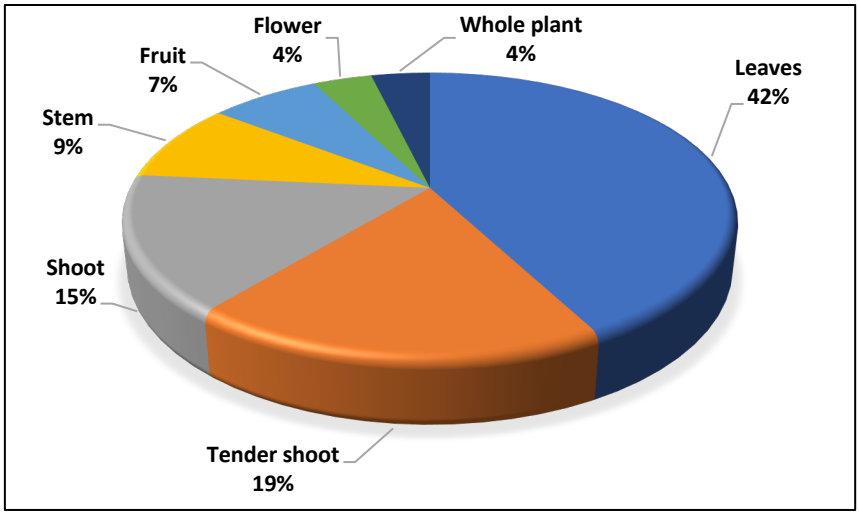

Figure 4. Percentages of different plant parts of WEPs used by the indigenous people of Ladakh

Table 2. Wild edible plants consumed by indigenous communities of Ladakh

Family/ Botanical Name/ Voucher Number [RRLH-]	Local name	Growth form	Edible part	Food use	IUCN/NWH*	UR**	CI***	Regions****
Amaranthaceae								
Chenopodium album L. [RRLH-25400]	Snue	Herb	Leaf	Traditional dishes, Chutney	NL	20	0.33	K, Z
Dysphania botrys (L.) Mosyakin & Clemants [RRLH-25622]	Hama, Snue	Herb	Leaf	Traditional dishes, Chutney	NL	21	0.35	N
Amaryllidaceae								
Allium carolinianum DC. [RRLH-24147]	Kangmar	Herb	Leaf	Spice	EN	4	0.07	K. N
Allium przewalskianum Regel [RRLH-25556]	Skotse, Phoron	Herb	Leaf	Traditional dishes	NL	15	0.25	L, K,
Allium sativum L. [RRLH-24056]	Sgogpa, Gogpa	Herb	Bulb	Spice	NL	8	0.13	K, L, Z
Apiaceae								
Carum carvi L. [RRLH-25618]	Kumbulik, Kosnyot	Herb	Leaf, Stem, Seed	Vegetable, Spice	LC	25	0.42	K, N, C, Z, L
Daucus carota L. [RRLH-26677]	Walafru	Herb	Tape-root	Vegetable	LC	10	0.17	K
Asteraceae								
Cichorium intybus L. [RRLH-24049]	Shianthi	Herb	Tender shoot	Vegetable	LC	20	0.33	K, Z, N
Lactuca sativa L. [RRLH-26694]	Ldums	Herb	Leaf	Vegetable, Chutney	NL	5	0.08	N, L
Lactuca tatarica C.A.Mey. [RRLH-24316]	Skyabs	Herb	Leaf	Vegetable	LC	12	0.20	K, C, L
Taraxacum officinale F.H.Wigg. [RRLH-24055]	Khorma	Herb	Leaf	Vegetable	LC	22	0.37	K, A, Z
Boraginaceae								
Arnebia euchroma I.M.Johnst. [RRLH-24086]	Demok	Herb	Flower	Flavoring agent	EN	2	0.03	K, Z, N, L, C
Brassicaceae								
Brassica napus L. Syn- *Brassica napus* var. *napobrassica* (L.) Rchb.	Samulak	Herb	Tuber	Vegetable	DD	7	0.12	K, L, N

[RRLH-26666]								
Brassica cretica Lam.	Phul-Gobi	Herb	Flower	Vegetable	DD	5	0.08	K, L, N, Z
Syn- *Brassica oleracea* var. *botrytis* L.								
[RRLH-27060]								
Brassica oleracea L.	Band-Gobi	Herb	Leaf	Vegetable	DD	5	0.08	Z
Syn- *Brassica oleracea* var. *capitata* L.								
[RRLH-27061]								
Brassica oleracea L.	Kadam	Herb	Leaf, Stem	Vegetable	DD	5	0.08	Z
Syn- *Brassica oleracea* var. *gongylodes* L.								
[RRLH-26667]								
Brassica rapa L.	Mulak,	Herb	Swollen tuber	Vegetable	DD	9	0.15	K, Z, L, N, C
[RRLH-26668]	Nyungma							
Capsella bursa-pastoris Medik.	Sokapa	Herb	Leaf	Vegetable	LC	11	0.18	K
[RRLH-26649]								
Lepidium latifolium L.	Shangsho	Herb	Leaf	Vegetable	LC	24	0.40	K, Z, L, N, C
[RRLH-25423]								
Raphanus raphanistrum subsp. *sativus* (L.) Domin	Labook	Herb	Swollen root	Vegetable	NL	5	0.08	Z
[RRLH-26710]								
Campanulaceae								
Codonopsis clematidea C.B.Clarke	Phag-phag	Herb	Root	Traditional dishes	NL	2	0.03	K, N
Capparaceae								
Capparis spinosa L.	Kabra	Herb	Leaf, Fruit	Traditional dishes	LC	31	0.52	N, C, L
[RRLH-25409]								
Caryophyllaceae								
Silene vulgaris (Moench) Garcke	Luguru	Herb	Leaf	Vegetable	LC	8	0.15	K
[RRLH-25624]								
Crassulaceae								
Rhodiola heterodonta (Hook. f. & Thomson) Boriss.	Shrolo	Herb	Tender leaf, Tender shoot	Traditional dishes	NL	19	0.32	Z
[RRLH-24054]								
Rhodiola imbricata Edgew.	Shrolo-karpo	Herb	Tender leaf, Tender shoot	Traditional dishes	NL	21	0.35	Z, C, L
[RRLH-27035]								
Rhodiola tibetica (Hook. f. & Thomson) Fu	Shrolo	Herb	Tender leaf, Tender shoot	Traditional dishes, Chutney	NL	6	0.10	C, N
[RRLH-25632]								
Elaeagnaceae								
Hippophae rhamnoides L.	Tsokskur	Shrub	Fruit	Juice	NL	17	0.28	K, L, N, Z, C

[RRLH-26920]								
Fabaceae								
Chesneya cuneata (Benth.) Ali [RRLH-26961]	Bigangbu	Herb	Fruit	Vegetable	NL	9	0.15	K, N. L
Cicer microphyllum Benth. [RRLH-24072]	Sari	Herb	Fruit	Traditional dishes	NL	7	0.12	K, N
Lathyrus sativus L. [RRLH-26695]	Ranma	Herb	Fruit	Vegetable, Traditional dishes	LC	4	0.07	K, Z
Juglandaceae								
Juglans regia L. [RRLH-26691]	Starga	Tree	Fruit	Traditional dishes	LC	9	0.15	N
Lamiaceae								
Elsholtzia densa Benth. [RRLH-24062]	Smutu	Herb	Leaf	Vegetable	NL	5	0.08	K
Mentha longifolia (L.) L. [RRLH-24039]	Phololing	Herb	Leaf	Chutney, Flavoring agent	LC	28	0.47	K, C, L, Z, N
Thymus linearis Benth. [RRLH-24055]	Tumburu	Herb	Mature Shoot	Flavoring agent	CR	38	0.63	Z, L, N
Liliaceae								
Tulipa clusiana Redouté [RRLH-24083]	Kapi-tsong, Mayo	Herb	Bulb	Flavoring agent, Traditional dishes	NL	9	0.15	K
Malvaceae								
Malva verticillata L. [RRLH-24738]	Shochilik	Herb	Leaf	Vegetable	NL	11	0.18	K
Papaveraceae								
Corydalis govaniana Wall. [RRLH-25799]	Makshang	Herb	Leaf	Traditional dishes	NL	2	0.03	K, N, L, C
Plantaginaceae								
Plantago major L. [RRLH-24295]	Karatse	Herb	Tender shoot	Vegetable	LC	19	0.32	K, C
Polygonaceae								
Fagopyrum esculentum Moench [RRLH-26679]	Bro	Herb	Seed	Traditional dishes, Flour	NL	14	0.23	K, N
Oxyria digyna Hill [RRLH-25488]	Lamanchu	Herb	Leaf	Vegetable	NL	8	0.13	K

Rheum spiciforme Royle [RRLH-25437]	Lachu	Herb	Stem, Root	Traditional dishes, Flour	VU	9	0.15	K, N, C
Rheum australe D.Don [RRLH-24335]	Lachu	Herb	Stem	Traditional dishes	VU	10	0.17	K, Z
Rumex acetosa L. [RRLH-24313]	Be-skurmo	Herb	Leaf	Traditional dishes	NL	6	0.10	K
Rumex patientia L. [RRLH-24322]	Shoma	Herb	Tender leaf	Vegetable	NL	21	0.35	K, L, Z, N
Ranunculaceae								
Ranunculus hirtellus Royle [RRLH-24331]	Spang-ner	Herb	Whole plant	Spice	VU	5	0.08	K, Z
Rosaceae								
Prunus armeniaca L. [RRLH-24741]	Chuli	Tree	Fruit, Seed	Traditional dishes, Juice	NL	23	0.38	K, L, N
Rosa webbiana Wall. ex Royle [RRLH-26735]	Siah marpo	Shrub	Fruit, Root	Traditional dishes, Local tea	NL	6	0.10	Z, L, C
Salicaceae								
Salix alba L. [RRLH-24739]	Malchang	Tree	Bark	Local tea	LC	5	0.08	K, N, L
Solanaceae								
Solanum tuberosum L. [RRLH-24339]	Aloo	Herb	Rhizome	Vegetable	NL	14	0.23	K, L, N, Z
Urticaceae								
Urtica hyperborea Jacquem. ex Wedd. [RRLH-26991]	Rdoastot	Herb	Leaf	Traditional dishes	NL	26	0.43	K, N, C, L
Urtica dioica L. [RRLH-25639]	Rdoastot	Herb	Leaf	Traditional dishes	LC	16	0.25	K
Vitaceae								
Vitis vinifera L. [RRLH-26729]	Rgun	Climber	Fruit	Juice	LC	8	0.13	N

Legends:

IUCN*: CR-Critically Endangered, EN-Endangered, VU-Vulnerable, LC-Least concerned, NL-Not listed, DD- Data deficient; **NWH**: North-Western Himalayan; **UR****: Use-report; **CI*****: Cultural index; **Regions*****: K-Kargil, N-Nubra, C-Changthang, Z-Zanskar, L-Leh

Informant Consensus Factor (ICF)

The present study reported 288 use reports for eight different edible categories. The Informant Conesus Factor values ranged from 0.67 to 0.82. The vegetable category reported the highest ICF value (ICF=0.82), with 23 spp. and 121 UR. This was followed by traditional dishes and flavoring agents' categories (ICF=0.80 each), with 21 spp. and 99 UR and four spp. and 16 UR, respectively (Table 3).

Table 3. Informant Consensus Factor (ICF) for various food categories of WEPs

Categories (Food use)	Nur	Nt	ICF
Chutney (Sauce)	19	5	0.78
Flavoring agents	16	4	0.80
Traditional dishes	99	21	0.80
Local tea	5	2	0.75
Local Flour	4	2	0.67
Spices	14	4	0.77
Vegetables	121	23	0.82
Juice	10	3	0.78

Cultural Index (CI)

Our study's Cultural Index values of WEPs ranged from 0.03 to 0.63 (Table 2). The species with the highest CI value was *Thymus linearis* (0.63), followed by *Capparis spinosa* (0.52), *Mentha longifolia* (0.47), and least by *Corydalis govaniana* Wall. (0.03) (Table 2). In addition to nutritional and flavorful benefits, the species with the highest CI values provide a significant amount of health-related benefits, especially during the winter months when the region faces extreme weather conditions, causing food scarcity.

Vegetables

23 species consumed by the indigenous communities of Ladakh as vegetables constituted 40.60% of total CI. Of the 23 spp., the leaves of 13 spp. (56.50% of the total) were used to prepare vegetables. The important species used as vegetables based on the CI values were *Carum carvi* (UR=25; CI=0.42), followed by *Lepidium latifolium* (UR=24; CI=0.40), *Taraxacum officinale* (UR=22; CI=0.37), and *Rumex patientia* (UR=21; CI=0.35) (Table 2). The bulk of the species were utilized as vegetables only, although several species had multiple uses. For example, the leaves and stems of *C. carvi* were eaten as vegetables, while the seeds were utilized as spices. *Lactuca sativa* leaves were used to prepare vegetables and chutneys (sauces). Indigenous people of the region mainly preferred to eat these vegetables in local traditional cuisines such as *Tagi*, *Paba*, *Khulak*, and *Kaptsey*. However, in recent years, it has been observed that they also prefer to consume them with white rice as well.

Traditional dishes

In the present study, 21 spp. with a total use report of 99, were documented for their uses as traditional dishes. These species were well-known for being used as a main ingredient in preparing traditional dishes. Some of the popular traditional dishes of the region were *Tagi, Kaptsey, Khulak, Paba, Tangthur, Zathuk, Thukpa, Skyu, Timok, Gur Gur Chia,* and *Chhurpe*. The important species used in the preparation of traditional dishes by the Indigenous communities of Ladakh were *C. spinosa* (UR=31; CI=0.52), followed by *U. hyperborea* (UR=26; CI=0.43), *Prunus armeniaca* (UR=23; CI=0.38), and *Rhodiola imbricata* Edgew. (UR=21; CI=0.35) (Table 2).

Chutney (Sauce)

Of the recorded 52 spp., five WEPs were reported in the preparation of chutneys (Table 2). Leaves of *Chenopodium album* L., *Dysphania botrys*, *Lactuca sativa, Rhodiola tibetica*, and *Mentha longifolia* were used in the preparation of different types of chutneys and local dish *Tangthur* after they were pulverized in mortar and pestle with the inclusion of curd or milk in addition to salt and spices (Table 2).

Spices and flavoring agents

In the current study, four species viz., *Allium carolinianum* DC. (leaf) (UR=4), *Allium sativum* L. (bulb) (UR=8), *C. carvi* L. (seed) (UR=25), and *Ranunculus hirtellus* Royle (whole plant) (UR=5) were reported to be used in vegetables and traditional foods such as *Tangthur, Zathuk, Thukpa, Timok* as species and condiments (Table 2).

Juice, Flour, and Local tea

Of 52 spp., eight species were documented for their uses in juice, flour, and local tea. The fruits of *Hippophae rhamnoides* L., *Prunus armeniaca* L., and *Vitis vinifera* L. were recognized for juice production. The seeds of *Fagopyrum esculentum* Moench and the root of *Rheum spiciforme* Royle were used to make flour for local delicacies such as *Paba*, *Thukpa*, *Tangthuk*, and *Zathuk*. Throughout the year, the root of *Rosa webbiana* Wall. ex Royle and the bark of *Salix alba* L. were also dried to make local tea (Table 2).

Threat status of WEPs

The recorded 52 spp. included some of the threatened species of Ladakh (Table 2). According to the International Union for Conservation of Nature (IUCN) Red List of Threatened Species and NWH database, six plant species were listed in different threatened categories, viz., critically endangered (CR) (1 spp.), endangered (EN) (2 spp.), and vulnerable (VU) (3 spp.) (Table 2). The most threatened species belonging to CR and EN categories were *Thymus linearis*, *Arnebia euchroma*, and *Allium carolinianum*.

Discussion

The traditional diet culture of the indigenous inhabitants of Ladakh is considerably more than merely meeting their nutritional needs. It represents their ongoing belief in their traditional knowledge, community gathering, and support at various religious and cultural occasions using their native cuisines. The extreme climate, low precipitation, and constant hypoxic conditions not only enhance the endurance of these wild edible plants to harsh biotic and abiotic conditions but also load these plants with abundant amounts of antioxidants (Batool *et al.* 2024). This study discussed the relevance of 52 wild edible plants and the traditional knowledge of the indigenous communities in the region for their uses for various dietary needs. Male informants over the age of 45 provided the majority of ethnobotanical information, owing to their involvement in agricultural work and their daily interaction with plants (Batool *et al.* 2023). The use of dominant families (Brassicaceae, Polygonaceae, and Asteraceae) as (WEPs) was consistent with previous studies conducted in Ladakh (Murugan *et al.* 2010; Rana *et al.* 2012). Apart from Rosaceae, Polygonaceae and Asteraceae were also dominant among Indigenous inhabitants of the Paddar valley of Jammu Division, India (Singh *et al.* 2021), Kupwara district of Jammu and Kashmir, India (Mir 2014), Gaddi and Sippi tribes in Doda district, India (Singh *et al.* 2023), lesser Himalayas, Pakistan (Abbasi *et al.* 2013), and the Kurram district, Northwestern Pakistan (Hussain *et al.* 2023). The leaves and other edible parts of plants of the Brassicaceae family can be stored in unique storage areas locally known as "*Sadong*," "*Tsothbang*," and "*Charches*" for extended winter use when there is usually a shortage of vegetables in the entire region (Batool *et al.* 2024). The usage of leaves as edible parts in most WEPs was also reported in previous studies conducted in Ladakh and neighboring Himalayan regions (Bhatia *et al.* 2018; Rana *et al.* 2012; Singh *et al.* 2021).

The dominance of herbs usage as wild edible species by the residents of the present study was in line with other previous studies conducted in Ladakh (Rana *et al.* 2012) and other neighboring Himalayan regions (Samant & Dhar 1997; Singh *et al.* 2021; Thakur *et al.* 2017). Herbs can abundantly grow in soils with poor nutrition, which is favored by the topographical and climatic conditions of the study area (Batool *et al.* 2022).

Thymus linearis, locally known as *Tumburu,* with the highest use report (UR=38) in the present study, constitutes an important WEP of the region. The leaves, flowers, and stems of *T. linearis* have been identified as flavoring agents in previous studies from Ladakh (Boesi 2014; Rana *et al.* 2012) and the neighboring Himalayan region (Hussain *et al.* 2023). However, the use of shoot for a similar purpose was reported for the first time in the current study. Apart from using as a condiment, dried root and aerial parts of *T. linearis* were also taken as tea by the Indigenous communities of the Kupwara district of Jammu & Kashmir, India (Mir 2014), and Pakistan (Ijaz *et al.* 2022; Pieroni *et al.* 2017) respectively. The seeds of *T. linearis* were also used as a spice by the local inhabitants of Uttarakhand living around the Kedarnath Wildlife Sanctuary (KWLS) (Agarwal & Chandra 2019). The Northwestern Himalayan database listed this species as critically endangered (Kala 2005). As a result, its preservation through *in-situ* and *ex-situ* methods, as well as cultivation, is critical.

Capparis spinosa was a valuable and popular edible perennial shrub known locally as *Kabra.* For millennia, locals have devoured the species' leaves and buds to prepare *Kabratsotma* - a local Ladakhi dish (Dorjey 2015; Nirmala *et al.* 2022). Ladakh's indigenous inhabitants cherish eating "*Kabra Tsotma*" with either *Tagi*, *Kaptsey,* or *Paba*. The leaves and fruits of this plant are also sun-dried and stored for winter consumption in Ladakh (Dorjey 2015). However, among the Italian Indigenous communities, *C. spinosa* is well known for its use in pasta sauce, pizza, fish, and meat, secondary to its peculiar aroma (Sher and Alyemeni 2010). In addition, the burned ash of the root of *C. spinosa* has been used as a source of salt in Indigenous systems (Chevalier 1996). Batool *et al.* (2024) evaluated the nutraceutical and antioxidant activities of *C. spinosa*

from Ladakh and reported substantial amounts of carbohydrates (29.28 mg/g dw), protein (18.52 mg/g dw), glucose (275.46 ng/g dw), vitamin C (41.41 mg/g dw), total phenolic content (28.59 mg GAE/g) and total flavonoid content (43.84 mg QE/g) in *C. spinosa*.

Mentha longifolia, locally known as *Phololing*, was another important species with the highest use report. The Indigenous communities of Ladakh use the aromatic leaves of this plant to prepare chutneys. Dorjey (2015) documented the same application in one of the previous studies from Ladakh. Dorjey (2015) reported that *M. longifolia* is also used to make *Phololong-Thangthur*, a traditional cuisine that pairs well with *Taki* (bread) and *Khulak* (a barley-based dish). In Ladakh, the plant is well-known for its consumption as species, sauces, and herbal tea (Nirmala *et al.* 2022).

Carum carvi is high in protein, carbohydrates, vitamins C and E, and minerals such as calcium, magnesium, copper, and iron (Nirmala *et al.* 2022). As far as the traditional dishes are concerned, *C. carvi* is the main ingredient in the preparation of *Tenten*, which is typically cooked during the Buddhist festival *Losar* (the start of the new year) (Dorjey 2015). *C. carvi* seeds are widely used in spice and condiments production in Ladakh, the surrounding Himalayan region, and around the world (Bhatia *et al.* 2018; Dorjey 2015; Murugan *et al.* 2010; Raghuvanshi *et al.* 2021). It has a wide range of distribution and has been reported in eight different regions of Ladakh (Kargil, Shargole, Nubra, Aryan Valley, Changthang, Drass, Zanskar, and Leh) (Batool *et al.* 2023).

Lepidium latifolium, also known as *Shangsho*, and its leaves are well known for making the local dish *Shangsho chonma*. This vegetable is cooked by boiling the leaves first, then immersing them in cold water. This procedure helps to reduce bitterness from the leaves (Murugan *et al.* 2010). Fried leaves of *L. latifolium* are also served with the bulb of *Allium przewalskianum* in the traditional dish *Paba* (Murugan *et al.* 2010). Similar usage was also reported for the Indigenous communities of Lithang County, China (Boesi 2014). The plant is an excellent source of glucosinolates, and its leaves are high in unsaturated fatty acids, especially linoleic acid, higher glucose, crude protein, and a higher nitrogen-to-sulfur ratio (Kaur *et al.* 2013). Higher content of phenol (27-50 mg GAE/g dry weight) and flavonoid (37-76 mg quercetin equivalents per g dry weight) make the species an excellent source of antioxidants (Kaur *et al.* 2013).

Taraxacum officinale or Dandelion leaves are commonly used to cook vegetables in Ladakh culture. The most typical way to consume the leaves is in boiled form, although they can also be fried with the seed of *Carum carvi*. Several previous studies from Ladakh and the neighboring Himalayan region have found similar applications (Boesi 2014; Rana *et al.* 2012). *T. officinale* young leaves are popular salad ingredients in France and Vietnam, and the plant's leaves and roots are known to be used as herbal tea, while the roasted seed can be used to prepare coffee (Lis & Olas 2019). Escudero *et al.* (2003) reported moisture, protein, total carbohydrate, and total dietary fiber content in the leaves of *T. officinale* to be 91.5g/100g, 15.8 g/100g, 58.4 g/100g, and 47.8 g/100g, respectively.

Urtica hyperborea, commonly known as stinging nettle, is an important wild edible species utilized by locals to prepare traditional dishes such as *Thangthur*, chutney for *Thukpa* (a sort of noodles), and *Paba* (barley's flour-based cuisine) along with other delicacies such as *Zathuk* and different forms of *Thukpa*. Raghuvanshi *et al.* (2021) also reported similar uses of the species from Ladakh. Boesi (2014) and Rana *et al.* (2012) reported using *U. hyperborea* shoots and tender leaves to prepare soups. The Indigenous communities of Yadong Valley, Tibet, China, have also reported using the plant's leaves as vegetables (Guo *et al.* 2022). Previous authors from Ladakh (Angchok *et al.*2009; Hussain *et al.* 2022; Navchoo & Buth 1990) and Yadong River Valley, Tibet, China (Guo *et al.* 2022) have found similar findings. During winter, rural residents prefer to take *Zathuk* with another local dish, such as *Paba* (Angchok *et al.* 2009). The combination of these native cuisines is well known to raise body heat and provide significant energy throughout the winters when temperatures drop drastically. Other species of *Urtica,* such as *U. dioica* L., *U. ardens* Link, and *U. urens* L., are well-known wild edible species in Ladakh and nearby Himalayan regions (Bhatia *et al.* 2018; Guo *et al.* 2022; Rana *et al.* 2012). Batool *et al.* (2024) and Xavier *et al.* (2011) identified *U. hyperborea* as a strong source of antioxidants and free radical scavengers. Batool *et al.* (2024) reported the total phenol and flavonoid contents in *U. hyperborea* as 53.25 mg GAE/g dry weight and 47.80 mg QE/g dry weight, respectively.

The species mentioned above were some of the species with the highest CI values in the present studies. Besides meeting the region's dietary demands, these plants offer various medicinal uses for both humans and livestock (Batool *et al.* 2022, 2023). The CI of WEPSs in the neighboring state of Jammu & Kashmir was also in a comparable range, particularly for the Indigenous people of Udhampur, as reported by Bhatia *et al.* (2018). The species with the highest Informant Consensus Factor (ICF) in the present study were popular among the Indigenous communities of Ladakh to prepare various vegetables (*Chonma*) such as *Shangso, Kabra,* and *Ldum,* along with other traditional cuisines such as *Thangthur, Phaba,* and *Phololing*

Chamyk (Murugun *et al.* 2010). Previous studies in different regions of Ladakh have also revealed higher ICF values for ethnobotanical plants (Batool *et al.* 2023). The same can be said for research conducted in surrounding Himalayan regions (Bhatia *et al.* 2018; Kumar *et al.* 2015; Rao *et al.* 2015; Singh *et al.* 2021). High ICF values imply an adequate flow of traditional knowledge among the regions' participants as well as a reasonable consensus on how to use the plant species for that group (Batool *et al.* 2022; Sharma *et al.* 2014).

Besides leaves, fruits of four species viz., *Cicer microphyllum* Benth. (UR=7; CI=0.12), *Lathyrus sativus* L. (UR=4; CI=0.07), *Juglans regia* L. (UR=9; CI= 0.15), and *Prunus armeniaca* L. (UR=23; CI=0.38) were also used in the preparation of local dishes. Except for *C. microphyllum*, all of the other three species are found both in the wild and in cultivated conditions. These species' fruits are also dried and preserved in special storage structures for winter use. Shepherds and children in the remote region of Ladakh prefer to eat the uncooked seeds and the flowers of *C. microphyllum* to enhance their physical strength (Ballabh *et al.* 2007). The Indigenous people of Tibet, China, and the Balti community of Baltistan, Pakistan, eat the fruits and whole plants of *C. microphyllum* raw and as vegetables (Abbas *et al.* 2016; Guo *et al.* 2022).

The leaves mixture of *Chenopodium album*, *Dysphania botrys*, *Lactuca sativa, Rhodiola tibetica*, and *Mentha longifolia* can be served with rice or other traditional dishes like *Tagi, Kaptsey, Khulak,* or *Paba*. Previous studies in Ladakh (Dorjey 2015), Udhampur district, Jammu & Kashmir (Bhatia *et al.* 2018), and Paddar Valley, Jammu & Kashmir (Singh *et al.* 2021) have also documented the use of *M. longifolia* leaves in chutney making. The leaves of *C. album* have been reported for their rich contents of protein, essential amino acids such as lysine, leucine, and isoleucine, and a significant amount of calcium (11,000 IU/100g) (Poonia & Upadhayay 2015). Batool *et al.* (2024) quantified the nutritional and antioxidant activities of *C. album* leaves from Ladakh and documented various parameters, including carbohydrates (16.67 mg/g dw), glucose (215.31 ng/g dw), protein (21.35 mg/g dw), vitamin C (38.09 mg/g dw), DPPH (34.66 E_{50} mg/ml dw), ABTS (204.94 mmol Trolox/g dw), and FRAP (103.37 mmol Fe^{2+} 100/g dw).

Allium carolinianum, A. sativum, *Carum carvi*, and *Ranunculus hirtellus* are important species used both in Ladakh and other Himalayan regions as spices (Boesi 2014; Dorjey *et al.*2012; Hussain *et al.* 2023; Pieroni *et al.* 2017). Apart from their use as spices, these plants are highly recommended to treat various human and livestock ailments in Ladakh and nearby Himalayan regions (Angmo *et al.* 2012; Ballabh & Chaurasia 2007; Batool *et al.* 2022, 2023; Bhatia *et al.* 2018). Aside from the species mentioned above, four other notable species have been documented for their aromatic qualities and use as flavoring agents. The shoot of *Thymus linearis* (UR=38), leaves of *Mentha longifolia* (UR=28), bulb of *Tulipa clusiana* Redouté (UR=9), and flower of *Arnebia euchroma* (UR=2) are used as flavoring agents in local dishes viz., *Tsotma, Thukpa, Skyu,* and *Timok* along with other vegetables like carrot, and cabbage. The tribal inhabitants of Takhte-e-Sulaiman Hills in Pakistan's northwest tribal area drink tea made from *T. linearis* leaves (Pieroni *et al.* 2017). On the other hand, ethnic Tibetan communities used *T. linearis* leaves and stems to prepare condiments (Boesi 2014). *C. carvi* leaves are high in carbohydrates (29.54 mg/g), glucose (231.23 ng/g), protein (20.63 mg/g), vitamin C (34.06 mg/g), and antioxidant components such as total phenolic and flavonoid contents of 17.80 mg GAE/g and 45.75 mg QE/g, respectively (Batool *et al.* 2024).

The fruits of *Hippophae rhamnoides*, *Prunus armeniaca*, and *Vitis vinifera* are well-known in the region for juices. The National Agricultural and Marketing Federation (NAFED) has introduced the fruit juice of *H. rhamnoides* or Seabuckthorn in the local, regional, and national markets as "*Ladakh Berry*" (Nirmala *et al.* 2022). Besides juices of the species mentioned above, fresh and dry fruits are also valuable and contribute to the socio-economic standing of the residents. There is a lot of potential for the development of value-added products from these plants, which needs to be explored further.

In the cold-arid region of Ladakh, species in the wild habitat face threats either through natural calamities, unscientific exploration, overgrazing, infrastructure development, uprooting for fuels, etc. (Batool *et al.* 2023; Kumar *et al.* 2011). Similar scenarios have been documented in other parts of the Himalayan regions (Malik *et al.* 2015).

Conclusion and recommendations

The dietary needs of Ladakh's indigenous communities are supplemented in large parts by WEPs. They make these WEPs increasingly more important in meeting the region's nutritional needs. The current study documented 52 spp. and highlighted the enriched ethnobotanical knowledge of the Ladakh region. In addition, this study revealed a high level of homogeneity of information provided by the informants through the ICF, along with insight into key species for the Indigenous population using the CI. These WEPs are particularly valuable to Ladakh's traditional communities due to their nutritional advantages. However, many species are also prone to widespread exploitation for non-nutritional and non-medicinal uses, which stresses

their existence in natural habitats. Local communities have been using these WEPs on a sustainable basis without disturbing their natural populations. They understand the value of these WEPs and the importance of their conservation. However, due to modernization, younger generations are losing touch with this traditional knowledge. It is critical to motivate the younger generation and impart traditional knowledge to them. Therefore, the local communities should be involved in the conservation of these important WEPs, and local community-based organizations should be formed to protect these WEPs in their wild habitats. The majority of the study participants were unaware of the current threat status of these vital plants. In this regard, it's pertinent to educate them about the nutritional and therapeutic benefits of these plants. There is also a need for proper conservation training through workshops and seminars, as well as encouragement to cultivate these valuable resources. The ethnobotanical data of the current study could be used in the future for phytochemical (phenolic and flavonoid contents including antioxidants) and nutritive studies (macro- and micro-nutrients) to identify novel plants with high antioxidant and nutritive values to meet the residents' nutritional requirements throughout the year.

Declarations

List of abbreviations: C Changthang **CI** Cultural index **CR** Critically Endangered **CSIR** Council of Scientific & Industrial Research **DD** Data deficient **EN** Endangered **ICF** Informant consensus factor **IUCN** International Union for Conservation of Nature **K** Kargil **L** Leh **LC** Least concerned **NL** Not listed **NWH** North-Western Himalayan **N** Nubra **Z** Zanskar **UR** Use-report **VU** Vulnerable

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