Indian J. Plant Genet. Resour. 34(2): 206–215 (2021)
DOI 10.5958/0976-1926.2021.00019.X

RESEARCH ARTICLE

Genetic Resources of Genus *Allium* in India: Collection Status, Distribution and Diversity Mapping using GIS Tools

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The genetic resources of cultivated and wild *Allium* species collected from different states of the country have been discussed and analysed for distribution, diversity status and gaps. A total of 5,004 germplasm accessions have been collected during 1976-2020 by ICAR-NBPGR in collaboration with National Agricultural Research System (NARS) consisting 4,924 accessions of cultivated and 80 accessions of wild *Allium* species. Out of 5,004 accessions, 2,708 accessions have been conserved in National Genebank at ICAR-NBPGR, New Delhi. The cultivated alliums consist of 11 species, out of which nine species have been conserved (2,641 accessions). The wild *Allium* species comprise of 13 species out of which 11 species have been conserved (67 accessions). This study identified Western Himalaya as rich areas of diversity (H=1.491-2.0) for wild *Allium* species. Analysis indicated a significant gap for 21 wild taxa which are neither collected nor conserved in the genebank. Future thrust on explorations to be executed for collection of germplasm of these *Allium* species is discussed in this paper.

Key Words: *Allium* genetic resources, Diversity distribution mapping, Indian Himalayas, Wild *Allium* species

Introduction

The genus *Allium* L., one of the largest genera in the family Amaryllidaceae, has about 1,100 species distributed world-wide (The Plant List, 2020; Govaerts *et al.,* 2021). Mediterranean basin to Central Asia, and beyond is considered the centre of origin of *Allium* spp. which is the primary centre (Vavilov, 1926). Two main crops- onion (*Allium cepa* L.) and garlic (*A. sativum* L.) are commercially very important. About 40-45 species of *Allium* occur as cultivated and wild taxa from temperate to alpine regions of the Indian Himalaya. *Allium* species occurring in tropical areas are broadly distributed in different agro-ecological regions of India (Karthikeyan *et al.,* 1989; Pradheep *et al.,* 2014).

Allium species form an economically important group used as a vegetable, culinary salad, seasoning, spices and condiments, medicinal purposes and thus occupying an important place among the people of India (Verma *et al.,* 2008; Shah, 2014). In minor cultivated species *A. chinense* (lasan) and *A. tuberosum* are extensively grown as backyard cultigen in tribal dominated tracts of the Himalaya and other north-eastern states (Negi and Pant, 1992; Pandey *et al.,* 2008; Pandey *et al.,* 2019). *A. stracheyi* locally known as "*Faran"* grows wild in high altitude areas of Chamoli and Pithoragarh districts of Uttarakhand is declared as 'Vulnerable' and is used for seasoning purpose (Negi and Pant, 1992). Genetic resources of less-known *Allium*, their use and potential value have been discussed by some Indian workers (Negi and Pant, 1992; Pandey *et al.,* 2008; Shah, 2014; Pandey *et al.,* 2019).

ICAR-NBPGR has been carrying out explorations since 1976 in collaboration with crop-based institutes of the ICAR, State Agriculture University (SAUs) and Krishi Vigyan Kendras (KVKs). For alliums, the major collaborators were ICAR-Directorate of Onion and Garlic Research (ICAR-DOGR), Pune, Maharashtra; ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan (ICAR-VPKAS), Almora, Uttarakhand; ICAR-Central Institute of Temperate Horticulture (ICAR-CITH), Srinagar, Jammu and Kashmir; Mahatama Phule Krishi Vidyapeeth (MPKV), Rahuri, Maharashtra and National Horticulture Research and Development Foundation (NHRDF), New Delhi. These exploration missions have resulted in collection of diverse germplasm of several *Allium* species.

Crop wild relatives (CWR) of *Allium* have desirable traits/genes, which are generally not present in crops and recognized as a valuable resources; for crop improvement (Pandey *et al.,* 2019). Wild species, *Allium*

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roylei has provided genes resistant to powdery mildew and leaf blight to the *A. cepa* (Kofoet *et al.,* 1990; de Vries *et al.,* 1992; Khosa *et al.,* 2013). Molecular characterization performed by Khosa *et al.* (2013) for 10 indigenous *Allium* species, showed high transferability of different traits indicating their potential use in genetic transformation for crop improvement programmes. Germplasm characterization of Indian *Allium* especially those belonging to sub-genus *Cepa* deserve top priority for crop improvement (Pandey *et al.,* 2019).

The taxonomy of the genus *Allium* is poorly understood due to high polymorphism and wider adaptability to the habitats (de Vries *et al.,* 1992). Due to limited studies on taxonomy, morphology and eco-geography of wild taxa of *Allium* from the Indian region, species diversity remained uncollected and areas have remained unexplored. In present study geo-spatial tools and geographic information system (GIS) is used to analyze data of the collected and conserved germplasm of *Allium*. The aim is to assess the genus *Allium* particularly: (i) status of germplasm holding in national gene banks; and (ii) diversity mapping and identifying gaps in germplasm collection.

Materials and Methods

Scrutiny of Passport Data and Geo-referencing

ICAR-National Bureau of Plant Genetic Resources has augmented *Allium* germplasm since its inception in 1976, from various parts of the country through crop-specific/ multi-crop explorations conducted in collaboration with crop-based institutes of ICAR, SAUs and KVKs. This resulted in collection of a total of 5,004 accessions from different parts of the country, which were used in this study (NBPGR Annual Reports 1976-2019; Plant Germplasm Reporters, 2002-2018). The germplasm locality site details (village/tehsil/district) were checked thoroughly and wherever geo-coordinates (latitude and longitude) were not available, same were assigned with the help of passport data, gazetteers and Google map.

Gap Analysis and Mapping of Diversity

After a thorough screening of passport/germplasm data, geo-referenced map was prepared using geo-coordinates, WGS84 datum and geographic projection systems. To know spatial distribution and assessment of wild *Allium* species richness, DIVA-GIS software is used for point-to-grid analysis using simple-circular neighbourhood method (Hijmans *et al.,* 2001). Wild *Allium* species diversity is calculated using the Shannon-Weaver diversity index (Magurran, 2004) -

$$H = -\sum [(ni/N) \ln (ni/N)]$$

H = Shannon diversity index, ni = individuals of a species, N = total individuals of all

Species, ln = natural log

The diversity assessment vis-à-vis germplasm collected/conserved, literature survey/reports (Pandey *et al.,* 2008; Verma *et al.,* 2008; ICAR-DOGR Annual Report, 2016-17) and notes mentioned in germplasm reporter and exploration reports, collection gaps were identified to meet the objectives particularly areas representing deficit collection and wild *Allium* species which were neither collected nor conserved in the gene banks.

Results and Discussions

A. Status of Germplasm Collection

(i) *Allium cepa*: A total of 2,847 accessions of *A. cepa* have been collected from 240 districts of 29 states of the country. Geo-referenced map and ICAR-NBPGR passport database showed that Maharashtra (1,016) followed by Uttar Pradesh (295), Telangana (142), Haryana (133), Gujarat (98), Madhya Pradesh (89), Rajasthan (68), Chhattisgarh (63), Karnataka (61), Himachal Pradesh (40), Jammu & Kashmir (39) and Uttarakhand (38) were fairly well collected states (Fig. 1a). Least accessions were collected from Bihar, Jharkhand, Sikkim (5 each) and West Bengal (4). The data revealed that in Maharashtra, the Nashik (152 accns.), Akola (130), Dhule (91), Jalgaon (78) and Pune (75) districts represent significant collections. Though onion is cultivated in almost 29 states in smaller scale (kitchen garden), but several local varieties (70) and two hybrids (Arka Kirtiman, Arka Lalima) which are very widely adapted to specific regions (parts of Maharashtra and Karnataka) are currently cultivated on larger scale in the country (Mahajan *et al.,* 2018).

The production of onion is maximum in Maharashtra state which has share of 38.06 percent followed by Madhya Pradesh (15.91), Karnataka (12.84), Bihar (5.33), Rajasthan (4.28), Andhra Pradesh (3.94) and Haryana (3.02) out of total onion production in the country (HSR, 2018) which is in line with germplasm collected and conserved from these states.

(ii) *Allium sativum*: Germplasm of *A. sativum* (1,912 accns.) has been assembled from 304 districts of 28 states of the country and diversity distribution mapped (Fig. 1, b). Mapping of assembled diversity has shown that Gujarat (237) followed by Maharashtra (218), Uttarakhand (195), Telangana (170), Rajasthan (140), Himachal Pradesh (120) and Uttar Pradesh (107) have good representation in total collections (Fig. 1,b) while Sikkim (11), Punjab (9), Mizoram (7), Andhra Pradesh (5), Bihar (5) and Kerala (4) have poor representation and least collections. Multiplier onion (*A. cepa* var. *aggregatum*) is mainly grown in Andhra Pradesh, Karnataka and Tamil Nadu and only 85 germplasm accessions were collected from these states. Overlaying of geo-referenced layer on the black soil region (mapped by Mandal *et al.,* 2015) of the country revealed that maximum collections were from this soil, which is the suitable for cultivation of both cultivated species (onion and garlic). Similar studies have also been conducted on *Brassica* species (Semwal *et al.,* 2013), *Cajanus cajan* (Semwal *et al.,* 2018), *Vigna mungo* (Abraham *et al.,* 2010) and wild *Solanum* (Hijmans *et al.,* 2000), etc. in different parts of the world and provided quite valuable information.

(iii) *Other Less-known/ Minor Cultivated Species:* Among the less-known minor cultivated taxa namely- *A. ampeloprasum, A. cepa* var. *aggregatum, A. cepa* var. *viviparum, A. chinense, A. fistulosum, A. hookeri, A. porrum, Allium* × *proliferum* and *A. tuberosum* were collected from 19 states of the country (Table 1). Highest collections (>35%) were made in *A. cepa* var. *aggregatum* from Andhra Pradesh, Karnataka and Tamil Nadu. In *A. cepa* var. *viviparum* only four accessions were collected from Jammu & Kashmir. *A. tuberosum* is a widely distributed species in Himalayan region (1800-3000 m), and 13 accessions were collected from five states- Arunachal Pradesh, Jammu and Kashmir, Himachal Pradesh, Sikkim and Uttarakhand (Table 1).

(iv) Wild Allium Species: Data analysis revealed that out of 45 *Allium* species reported in the country (Kew Checklist, 2020; Pradheep *et al.,* 2014) the germplasm of only 13 wild *Allium* species were collected from different parts of the country (Table 2). Majority of the wild *Allium* species occur in high altitude regions of the Himalaya including cold desert of Himachal Pradesh, Ladakh and Uttarakhand (Fig. 3). Four economically important species namely *A. consanguineum, A. humile, A. przewalskianum* and *A. semenovii* were collected only from Pangi areas (3400 4600m) of Himachal Pradesh while *A. roylei* was collected from Jammu province especially Mendhar in Poonch; Gourwan in Reasi; Bani in Kathua; high altitude areas (1800-3500 m) of Malari in Chamoli, Milam valley in Pithoragarh district of Uttarakhand. Only three accessions of another economically important species – *A. stracheyi*, which is used as flavouring agent in high altitude areas of Uttarakhand (Chamoli- two accns. and Pithoragarh-one accn.), were collected. Collected diversity and literature revealed that temperate and high altitude areas of western and eastern Himalaya are the main habitats of wild *Allium* species diversity.

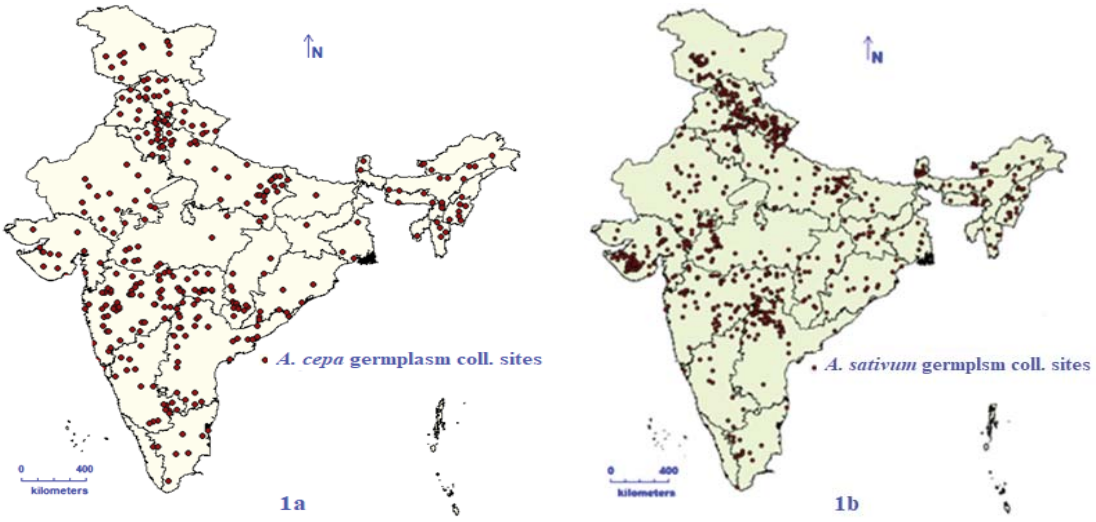

Fig. 1. Geo-referenced map of *A. cepa* (1a) and *A. sativum* (1b) germplasm collected from different states of India

Table 1. Status of *Allium* species indigenous collections (IC) from different states (1976-2020)

Cultivated species	Accessions[#] Collected	Wild species	Accessions[#]	Threatened status
A. cepa L. var. *cepa* L.	2,847	*A. carolinianum* DC.	25	
A. sativum L.	1,913	*A. auriculatum* Kunth	12	Endangered[$]
A. cepa var. *aggregatum* G.Don.	85	*A. griffithianum* Boiss.	11	
A. fistulosum L.	17	*A. wallichii* Kunth[#]	7	
A. tuberosum Rottler ex Spreng.*	13	*A. consanguineum* Kunth	6	
A. chinense G.Don	11	*A. przewalskianum* Regel[@]	5	
A. ampeloprasum L.	11	*A. humile* Kunth	5	
A. × *proliferum* (Moench) Schrad. ex Willd.	10	*A. stracheyi* Baker[@]	3	Vulnerable[$]
A. hookeri Thwaites*	10	*A. semenovii* Regel[@]	2	
A. cepa var. *viviparum* (Metz.) Alef.	4	*A. fasciculatum* Rendle	1	
A. porrum L.	3	*A. roylei* Stearn[#]	1	Endangered[$]
		A. prattii C.H.Wright	1	Rare[+]
		A. victorialis L.	1	
Total	4,924		80	

[#]ICAR-NBPGR Database *Also; wild occurring in India; @ also cultivated in kitchen garden, + Murti, 2001; $ Rao *et al.,* 2003

Table 2. *Ex-situ* conservation of cultivated and wild *Allium* species (IC) by ICAR-NBPGR.

Cult. Allium species	*Ex-situ* conservation methods				
	NGB	CB	IVR	FGB$	Total
A. cepa	991	9		606	1,606
A. sativum		134		779	913
A. fistulosum	16	3	1	6	26
A. chinense		11	9	3	23
*A. tuberosum**		7	4	18	29
*A. hookeri**		2	2	12	16
A. ampeloprasum		2		7	9
A. cepa var. *aggregatum*		1		3	4
*A. fasciculatum**			1	14	15
Sub-total	1,007	169	17	1,448	2,641
Wild *Allium* species					
A. przewalskianum#	1			19	20
A. griffithianum	2	1		8	11
A. carolinianum	3			5	8
A. stracheyi#	2			5	7
A. wallichii#		1		6	7
A. auriculatum	2	1		3	6
A. roylei#	1	1		1	3
A. humile	1			1	2
A. fasciculatum				1	1
A. prattii				1	1
A. victorialis	1				1
Sub-total	13	4		50	67
Total	1,020	173	17	1,498	2,708

NGB- national genebank; IVR- *in-vitro* repository; CB- cryo genebank; FGB- field genebank;
*also occurring in wild; [#]Also cultivated in kitchen garden [$]FGB at Bhowali, Uttarakhand and ICAR-Directorate of Onion and Garlic Research (ICAR-DOGR), Pune, Maharashtra.

B. Germplasm conserved Ex-situ

(i) ***Cultivated Allium species***: Among the two major *Allium* species, *A. sativum* (garlic) do not produce seeds hence it is conserved in field genebank and tissue culture repository. Out of the 24 species have been collected, only 11 produce seeds, while remaining non-seed producing or vegetatively propagated species are conserved in tissue culture repository, cryobank (CB)

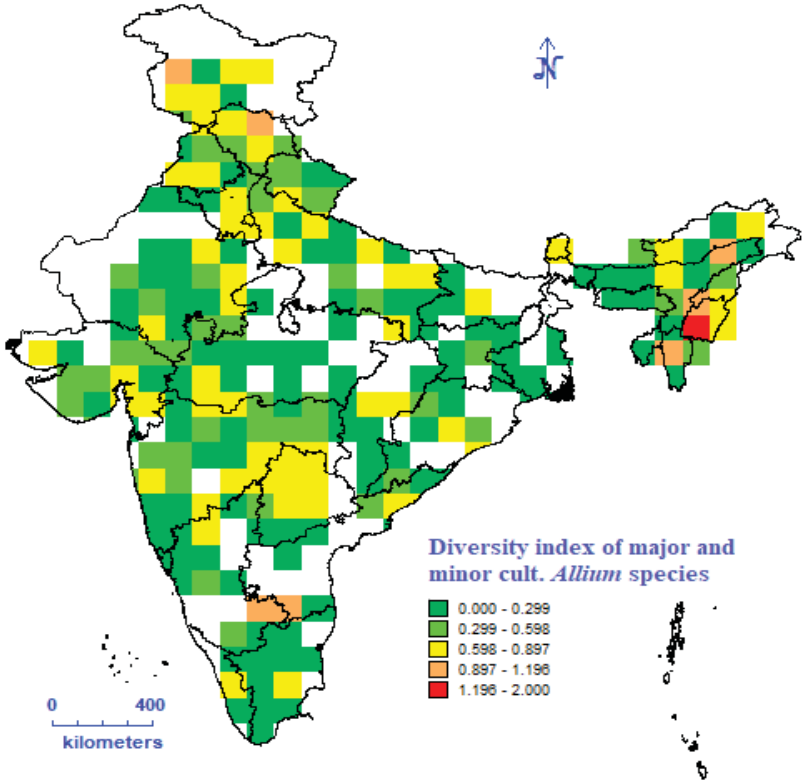

Fig. 2. Diversity index of major and minor cultivated *Allium* species

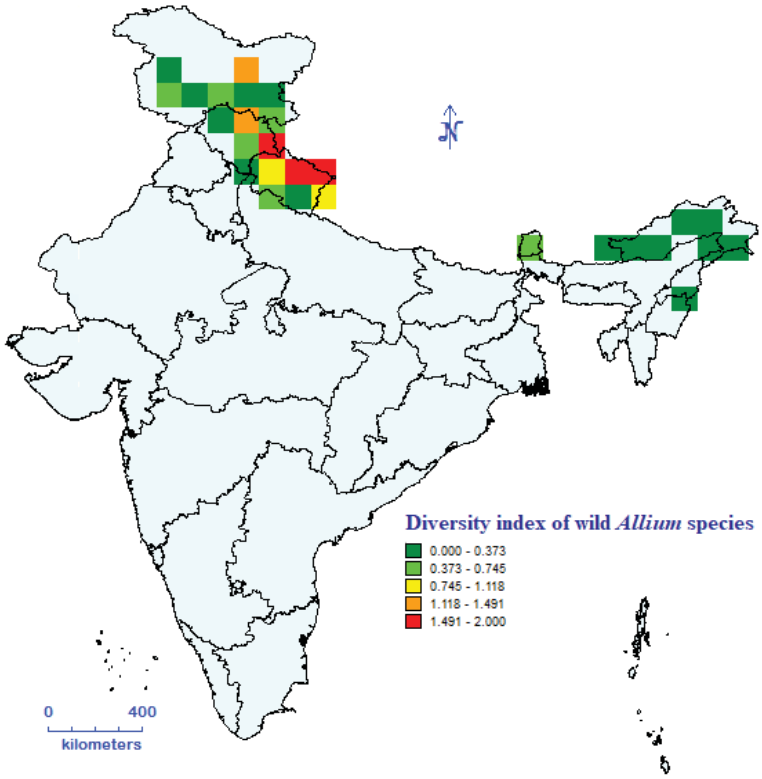

Fig. 3. Diversity index of wild *Allium* species

Table 3. Gaps and areas identified for collection of *Allium* species based on data from germplasm collected and conserved

Allium species (cult.)	Areas identified based on gaps in collections
A. cepa	Bihar (Chatra, Purnea, Sasaram, Samastipur, Vaishali districts), Jharkhand (Gumla, Garhwa, Hazaribagh, Ranchi), Tamil Nadu (Coimbatore, Cuddalore, Tiruchirappalli and Tirunelveli) and West Bengal (Darjeeling, Murshidabad, 24 South Parganas, West Medinipur)
A. sativum	Bihar (Nalanda, Nawada, Samastipur and Vaishali districts), Jharkhand (Garhwa, Gumla, Hazaribagh and Palamu), Tamil Nadu (Dindigul, Salem, and Tiruchirappalli) and West Bengal (Darjeeling, Murshidabad, West Medinipur)
A. cepa var. *aggregatum*	Andhra Pradesh (Chitoor, East and West Godavari, Kurnool, Ranga Reddy), Karnataka (Belgaum, Chikkabalapura, Dharwad, Medak, Mysore) and Tamil Nadu (Coimbatore, Cuddalore, Dindigul, Namakkal, Perambalur, Tiruppur, Tirunelveli, Thoothukudi, and Trichy)
Germplasm collected but not conserved	
A. porrum	Low altitude (1800-2800 m) areas (Kangra and Chamba) of Himachal Pradesh and Uttarakhand (low altitude areas of Chamoli and Pithoragarh districts)
Allium × *proliferum*	Jammu & Kashmir (Bandipura and Kupwara)
A. cepa var. *viviparum*	Anantnag, Bandipura, Kupwara and Parimpora village of Jammu and Kashmir and adjoining areas of Himachal Pradesh
A. consanguineum	High altitude (2800-4700 m) areas of Lahaul and Spiti, Kinnaur of Himachal Pradesh
A. semenovii	Pangi high altitude (3400-4600 m) areas of Himachal Pradesh
Species-wise least collection (in wild spp.)	
A. carolinianum	Hanupata, Khaltse, Lahaul areas of Ladakh (3700- 3950 m); Gilgit, Naltar lake, Kishenganga Valley (Jammu and Kashmir); High altitude areas (2400-4600 m) of Himachal Pradesh and Uttarakhand (Dasgupta, 2006)
A. humile	High altitude (2800-4700 m) areas of Himachal Pradesh (Chanchal pass, Chamba, Larot, Lahaul and Spiti, Kinnaur), Bashaur, high altitude areas of Gulmarg, Liddar Valley, Zojpal (Jammu and Kashmir), Hari Ki Dun (Uttarkashi district), high altitude areas of Pithoragarh Uttarakhand (Dasgupta, 2006; GBIF, 2021)
A. fasciculatum	Naku La, high altitude (1800-3500 m) areas of North Sikkim (Sikkim) (GBIF, 2021)
A. prattii	Tangu, Lachen and Tallum Sandong areas of Sikkim (GBIF, 2021)
A. roylei	Jammu province especially Mendhar in Poonch; Gourwan in Reasi; Bani in Kathua, Sanjhi, Chat Bhairoin temple (Jammu and Kashmir); high altitude (1800-3500 m) areas of Chamoli, Pithoragarh Rudraprayag districts of Uttarakhand (Dasgupta, 2006)
A. stracheyi	High altitude (2400-4600 m) Chamba, Kakcham hill slopes, Pangi, Lahaul and Spiti, Kinnaur areas of Himachal Pradesh and Lata, Gamshali, Niti, Valley of flowers (Chamoli district) (Dasgupta, 2006)
A. victorialis	Bal tal, Sonamarg areas of Jammu and Kashmir (GBIF, 2021)
A. wallichii	Banihal ridge of Jammu and Kashmir (Dasgupta, 2006), Chirbasa, Gangotri (Uttarkashi district), high altitude areas of Pithoragarh and Rudraprayag districts of Uttarakhand (Dasgupta, 2006) and Yakchi, Lachung and Islumbo sites (3000- 3300 m) of Sikkim (GBIF, 2021)
Areas representing deficit collection	
Arunachal Pradesh,	High altitude (1800-4600 m) areas of Dibang valley, Upper Siang and Tawang districts
Ladakh	Valley and remote areas of Leh, Kargil and Turtuk
Himachal Pradesh	Lahaul and Spiti, high altitude (1800-4200 m asl) areas of Kinnaur and adjoining areas
Jammu and Kashmir	High altitude (1800-3200 m) areas of Anantnag, Bandipura and Kupwara districts
Sikkim	High altitude (1800-4600 m) areas of West and North districts of Sikkim
Uttarakhand	Mana, Malari and Niti valley areas of Chamoli, Kedarnath valley of Rudraprayag, Dayara Bugyal and Nelong valley of Uttarakashi district, Milam valley of Pithoragarh district

and field genebank (FGB). Out of total 4,924 collected germplasm, only 2,641 accessions of cultivated *Allium* species including minor cultivated species are conserved in national gene bank, *in-vitro* repository (IVR), cryobank and field genebank (Table 2). Major part of that (1,335 accessions) comprising of *A. cepa* (584 accns.) and *A. sativum* (751 accns.) is conserved in the field gene bank at ICAR-DOGR, Pune, Maharashtra (ICAR-DOGR Annual Report, 2016-19).

(ii) *Wild Allium species:* Data analysis revealed that out of 34 wild *Allium* species reported in the country, germplasm of only 13 wild *Allium* species are conserved in gene bank, cryo genebank and field genebank (FGB) for utilization in future breeding programme of the country (Table 2). Maximum accessions are conserved in *A. przewalskianum* (20) and *A. griffithianum* (12). Meager conservation of wild germplasm in gene banks may be attributed to various reasons like niche-specificity,

Table 4. Wild *Allium* species not represented in genebanks and priority for collection

Wild *Allium* spp. and RET status	Distribution (altitudinal range)	References
A. atropurpureum L.	High altitude (2700-3400 m) areas of Himachal Pradesh (Lahaul and Spiti, Kinnaur), remote areas of Ladakh and Uttarakhand.	(Pandey *et al.,* 2008; Kew Checklist, 2020*)
A. atrosanguineum Schrenk var. *atrosanguineum*	Alampila, Gilgit and Nittar Valley (Jammu and Kashmir), remote and high altitude (2400-3100 m) areas of Himachal Pradesh	(Dasgupta, 2006; Pradheep *et al.,* 2014)
A. atrosanguineum Schrenk var. *fedschenkoanum* (Regel) G.H.Zhu & Turland	High altitude (3200-4400 m) areas of Himachal Pradesh and Jammu and Kashmir (Gilgit, Dras, Suru, Zanskar and Zojila)	(Murti, 2001; Pradheep *et al.,* 2014)
A. barsczewskii Lipsky	Kashmir Valley (Jammu and Kashmir),remote and high altitude (1900-3200 m) areas of Himachal Pradesh	(Dasgupta, 2006; Kew Checklist, 2020)
A. blandum Wall.	High altitude (2200-3600 m) areas of Himachal Pradesh, Jammu and Kashmir and Uttarakhand	(Kew Checklist, 2020)*
A. caesioides Wendelbo. Threatened	Rocky slopes from 2700-4000 m. areas of Lahual (Himachal Pradesh), Chenab Valley, Kashmir Valley and Gilgit (Jammu and Kashmir), Afghanistan and Pakistan	(Dasgupta, 2006; Pradheep *et al.,* 2014)
A. chitralicum F.T. Wang & Tang Rare	High altitude (2200-3400 m) areas of Kinnaur (Himachal Pradesh) and Gilgit (Jammu and Kashmir) and Ladakh	(Dasgupta, 2006; Murti, 2001)
A. chrysanthum Regel	Remote and high altitude areas (3700-4900 m) of Pangi (Himachal Pradesh) and Kashmir, Pajroti (Jammu and Kashmir)	(Dasgupta, 2006)
A. farctum Wendelbo.	High altitude (1900-3200 m) areas of Kalpa (Himachal Pradesh) and Jammu and Kashmir	(Dasgupta, 2006)
A. gilgiticum F.T. Wang & Tang Endangered	Remote and high altitude areas (2100-3100 m) of Gilgit, Kashmir (Jammu and Kashmir), Himachal Pradesh,. Endemic to Kashmir	(Dasgupta, 2006; Singh, 2017)
A. jacquemontii Kunth Threatened	High altitude areas (1100-3400 m) of Trilokinath (Himachal Pradesh), Rajaouri, Jammu, Kashmir (Jammu and Kashmir) and Zanskar Lahaul (Ladakh, threatened in Ladakh) and Tehri (Uttarakhand)	(Murti, 2001; Dasgupta, 2006; Pradheep *et al.,* 2014)
A. kokanicum Regel	Remote and high altitude (2200-3800 m) areas of Himachal Pradesh, Jammu and Kashmir and Uttarakhand	(Kew Checklist, 2020)*
A. loratum Baker Endangered	Remote and high altitude areas (2900-4100 m) of Himachal Pradesh, Chenab Valley, Kishtwar (Jammu and Kashmir), Nubra, Zanskar (Ladakh) and Bhaironghati (Tehri Garhwal). Uttarakhand	(Murti, 2001; Rao *et al.,* 2003; Dasgupta, 2006; Singh, 2017)
A. macleanii H.Lev.	Chenab Valley, Chamba, Kilar, Pangi (Himachal Pradesh), Kishtwar (Jammu and Kashmir).	(Dasgupta, 2006; Kew Checklist, 2020)
A. macranthum Baker Threatened	High altitude (3700-4300 m) areas of North and West districts, Lachen and Senthang (Sikkim), Tawang (Arunachal Pradesh)	(Dasgupta, 2006; Pradheep *et al.,* 2014)
A. mairei Baker	High altitude areas (2300-3200 m) of Tawang and Dichu gorge (Arunachal Pradesh) and other places in NEH	(Dasgupta, 2006)
A. oreoprasum Schrenk	Hanupata, Khaltse of Ladakh and high altitude (3700- 3900 m) areas of Jammu and Kashmir ; Zalung, Karpo pass (Himalayas)	(Dasgupta, 2006)
A. phariense Rendle Threatened	Remote and high altitude (3200-4600 m) areas of Arunachal Pradesh and other places in NEH	(Pradheep *et al.,* 2014; Kew Checklist, 2020)
A. schrenkii Regel	Remote areas (2900-4800 m) of Ladakh; Losar, Spiti and Kangra (Himachal Pradesh)	(Orrell, 2021)
A. sikkimense Baker	High altitude (3500-5200 m) areas particularly on open grassy hill sides, Cholamo, Lhonak, Naku Chu, Lachen and Tangu areas of Sikkim	(Dasgupta, 2006; GBIF, 2021)
A. spicatum (Prain) N. Friesen syn. *Milula spicata* Prain Threatened	High altitude (2900-4500 m) areas of Chamoli, Bageshwar and Pithoragarh districts of Uttarakhand	(Govaerts, 2011; Pradheep *et al.,* 2014; Kew Checklist, 2020)

*Kew Checklist, 2020 (accessed on 30.12.2020); http://wcsp.science.kew.org/prepareChecklist.do;jsessionid;

http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:77068854-1

lack of *ex-situ* conservation protocols, rapid loss of viability, poor performance/non-suitability to climatic conditions of field gene bank at Pune and Bhowali. Asynchronous maturity and seed shattering pose great problems in collecting their sufficient number of seed for conservation and regeneration.

Out of 80 accessions, only 67 accessions of wild *Allium* species are conserved (Table 2) in national

genebank, *in-vitro* repository, cryobank and field genebank. Among these, maximum accessions (50) are conserved in the FGB at ICAR-NBPGR, Regional Station, Bhowali, Uttarakhand. Besides these, the ICAR- Directorate of Onion and Garlic Research (ICAR-DOGR), Pune, Maharashtra reported that 139 accessions of 17 wild *Allium* species were conserved in their FGB (ICAR-DOGR Annual Report, 2016-17).

C. *Diversity Mapping of Cultivated Species*

GIS-based grid mapping technique has proved to analyze species richness, assessment of variability and occurrence of trait-specific germplasm (Ramirez-Villegas *et al.*, 2010; Semwal *et al*., 2018). The GIS mapping using diversity indices have identified species rich areas in collected accessions of different cultivated species with different colour grids and Shannon diversity (H) values. In cultivated *Allium* species, dark red coloured grids (H= 1.196-2.00) represent regions with high diversity/more number of species (*A. cepa. A. sativum, A. ampeloprasum*, *A. chinense, A. hookeri* and *A. tuberosum)* collected from these sites; yellow to orange colour (H=0.00-0.598) areas represent regions with occurrence of moderate number of species (*A. proliferum, A. porrum, A. cepa* var. *aggregatum, A. cepa var. viviparum*), while dark green to light green (H=0.00-0.598) areas represent regions with occurrence of minimum species (*A. fistulosum*, *A. cepa, A. sativum*) from these collection sites (Fig. 2). In a map of country level like India, which has 3.28 million km^2 areas, it is very difficult to identify diversity hot-spots, this technique has identified high/low diversity areas in a very short time for ease of understanding of researchers and explorers to plan further collection. The geo-referenced map of collected diversity also indicated that parts of western plains (mainly Gujarat and Maharashtra); western Himalaya (Himachal Pradesh and Uttarakhand) and Telangana had extensive collections for major cultivated species.

D. *Diversity Mapping of Wild Allium Species*

Similar to cultivated species, geospatial software (DIVA-GIS) was used to generate diversity map of wild species to demarcate areas vis-à-vis species richness. Dark red colour (H= 1.491-2.0) grid on the map is showing maximum number of wild *Allium* species (*A. humile, A. roylei, A, stracheyi* and *A. wallichii*) collections from the high altitude areas of Uttarakhand and Himachal Pradesh. The second species-rich (*A. humile, A. roylei*) area has comparatively low value (H=1.118 -1.491) of Shannon diversity depicted with orange colour grid, displayed in Leh region of Ladakh and northern region of Himachal Pradesh (Fig. 3). This revealed that high altitude areas/districts of Himachal Pradesh and Uttarakhand adjoining to the border areas would form the target for future exploration and collection through fine grid survey. Diversity map has also showed that most of the wild *Allium* species are distributed in high altitude areas of Arunachal Pradesh, Himachal Pradesh, Jammu and Kashmir, Ladakh, Sikkim and Uttarakhand. Most of these species have meager representation in the NBPGR collections.

Based on high Shannon diversity value (H=1.491-2.0) for the Western Himalaya region, literature survey (sites surveyed and visited) and availability of maximum number of species in Malari-Niti valley (a part of Nanda Devi Biosphere Reserve) may be a probable *in-situ* conservation site for wild *Allium* species. Similar site for *Citrus* spp. was located and established as citrus gene sanctuary in Garo hills, Meghalaya by ICAR during 1981 based on availability of maximum citrus species represented in that area for *in-situ* conservation (Singh, 1981). Alpine meadows (locally known as *Bugyals*) in Himalayas are home to the several tuberous plant species including *Alliums*. Hence, there is a need for extensive survey of temperate, sub-alpine and alpine regions of Himalayas for this purpose.

E. *Gaps in Germplasm Collection and Conservation*

Based on germplasm collections data of cultivated and wild *Allium* species, their distribution, diversity mapping through GIS grid method, inputs from floristic and relevant literature, the gaps were identified with detail description of distribution and altitudinal range (Table 3).

F. *Gaps in Collection-germplasm of Wild Allium Species not Represented in Genebank*

Analysis has revealed that twenty one wild *Allium* species are not represented in any of the gene banks (table 4) and need to be explored and collecting on priority. Majority of these species have origin in Central Asia, extended to Iran, Afghanistan, Pakistan and Himalayas in India. Reports on availability of these species in Western Himalayas (WH), eastern Himalaya (EH)/ north-eastern hill (NEH) region are scanty, mostly mentioned by explorers, botanists and others on floristic surveys, which generally have not collected for the purpose of

germplasm conservation and use. These reports have insufficient information on their locations, altitudinal range, frequency and population density. In most of the cases, their distribution is reported like WH, EH or Himalayas, which covers 5 lakh km^2 (about 16.2% of country's total geographical area) in three states in WH and seven states in NEH including Sikkim. Hence, it is very difficult to pin-point their specific locations. There is drastic loss in habitat and species composition in past decades due to increase in frequency of erratic rainfall and cloud burst in Himachal Pradesh and Uttarakhand would be affecting their niche habitat and population. Climate change is adversely affecting all the temperate species of the Himalayas. Now it is an urgent need to conduct *Allium* specific explorations in Himalayan region and report their current status on availability as well as rare, endangered and threatened (RET) status of these twenty one species.

Conclusions

Significant amount of germplasm samples of cultivated *Allium* species have been assembled from all over the country, still there are gaps in lesser cultivated areas and different agro-ecological zones. *Allium cepa* being cross pollinated crop, a large variability developed naturally through introgression and honey bee pollination, while collection gaps exist in wild and less-known *Alliums* in the Himalayan region. *Allium* species as revealed through diversity mapping using GIS tools, the following conclusions are:

- Prioritized and unattended taxa need to be explored to collect and conserve on priority
- Prioritization of sites/ areas for collecting wild *Allium* species through specific exploration mission.
- Identification of areas/sites suitable for *Allium* gene sanctuary to facilitate *in-situ* conservation, multiplication, evaluation studies of collected germplasm.
- Need to study the reproductive biology of rare/ endangered taxa- *A. stracheyi, A. wallichii, A. auriculatum, A. humile* and *A. roylei*.
- Multiplication and development of protocols for conservation in cryo/in-vitro repository of *A. przewalskianum, A. stracheyi, A. wallichii* and *A. auriculatum.*

Acknowledgments

The authors are thankful to the Director, ICAR-National Bureau of Plant Genetic Resources, New Delhi for the facilities and encouragement provided to undertake this study. Authors also thank Head, Division of Conservation and Officer-In charge, TCCU, ICAR-NBPGR, New Delhi for providing conservation status and Dr. K Pradheep, ICAR-NBPGR Regional Station Thrissur, Kerala for providing valuable inputs on status of wild *Allium* species in India.

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