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SPECIAL ARTICLE

Managing Agrobiodiversity of Indian Drylands for Climate-Change Adaptation

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Agrobiodiversity in drylands consisting of large number of field crops, horticultural crops, grasses, shrubs and multi-purpose trees plays a very critical role in providing food, fodder, nutritional and environmental security to the inhabitants of drylands. Despite several bio-physical constraints, the drylands support high human and livestock population with limited resources resulting in over-exploitation of the natural resources. Moreover, drylands are more vulnerable to global warming-mediated climate changes such as intense drought, sudden rainfall burst, high ambient temperature and appearance of new unforeseen diseases and pests. In addition to other technological interventions, the management of agro-biodiversity in drylands is expected to be a key factor for sustainability, food and fodder security and for improving livelihood in drylands.

Genetic resources of dryland species include local landraces, improved elite material, traditional cultivars, genetic stocks and wild relatives of coarse cereals (pearl millet, barley, sorghum, maize and small millets), legumes (chickpea, mungbean, mothbean, clusterbean), horticultural crops, grasses, shrubs, medicinal plants and multi-purpose trees. A large numberof exotic and indigenous germplasm accessions are conserved in National Gene Bank or Field Gene Banks at the ICAR-National Bureau of Plant Genetic Resources (NPBGR) and elsewhere across globe. Characterization of genetic resources using prescribed descriptors has largely indicated existence of large variation for phenotypic, phenological, nutritional and stress-adaptation traits among available germplasm.

Research conducted so far has indicated that the genetic resources from drylands hold a unique advantage as they have evolved over centuries by natural and human selection under drought, high temperature or saline conditions. They are better adapted to the local conditions and would contribute in enhancing the resilience at the farm level. These resources could be of immense importance especially as sources of native genes conditioning resistance to various biotic and abiotic stresses and also make unique study material to understand the mechanism of adaptation to abiotic stresses. They could also serve as an excellent genomic resource for isolation of candidate genes for tolerance to climatic and edaphic stresses for accelerating further genetic improvement. However, only a very small fraction of these accessions has been utilized so far because of operational difficulties in dealing with large number of germplasm accessions. The development of core and mini-core in recent past is expected to improve this situation. Formation of trait-specific gene pools is also likely to enhance the utilization of genetic resources to a greater extent.

There are multiple and complex challenges for agrobiodiversity in drylands due to habitat destruction, high grazing/browsing pressure, invasion of other species, unsustainable exploitation of natural resources and dilution of customary conservation practices. Critical assessment is needed for identifying geographical and trait-diversity gaps using GIS and other modern tools.

Additional explorations are needed in the regions where collection gaps have been indicated. *Ex situ* conservation of genetic resources from such regions and distribution of germplasm to the stakeholders on regular basis would remain very crucial especially in the present scenario of climate change. Developing e-resources with detailed information like passport data, characterization and evaluation data with respect to individual accessions would certainly help in enhancing the utilization of genetic resources to broaden crop genetic base which is very essential to reduce the chances of disease epidemics and to adapt to the effects of climate change.

Key Words: Agrobiodiversity, Arid and semi-arid regions, Climate change, Genetic resources and Indian drylands

Introduction

The drylands in India occupy about 80 million ha and are spread over arid, semi-arid and sub-humid climatic zones presenting nearly 56% of the net cultivated area. The drylands are characterized by low precipitation, highly variable rainfall patterns, high evapotranspiration

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rates, inadequatly available nutrients in majority of native soils, poor quality of ground water, severe land degradation, short growing period and low crop yields. Despite these bio-physical constraints, the drylands support high human and livestock population, which mostly depend on agriculture and allied activities with limited natural resources resulting in over-exploitation of the resources. Presently, degradation of natural resources (land, water and biodiversity), decreasing farm profitability and environmental pollution (soil and water) are threatening the sustainability of agricultural production in the drylands. Moreover, drylands are more vulnerable to global warming-mediated climate change reflected in the form of more intense drought, sudden rainfall burst, high ambient temperature and appearance of unforeseen diseases and pests. Along with other technological interventions, the management of agro-biodiversity in drylands is expected to be a key factor for sustainability, food and fodder security and for improving livelihood in drylands.

Drylands are critically important in terms of cultivation of landraces, traditional varieties and wild relatives of field crops in addition to huge variation in number of horticultural crops, grasses, shrubs, multi-purpose tress etc. With this background, an attempt has been made to assess the status of conservation, evaluation and utilization of genetic resources of drylands, and the role of agro-biodiversity in combating climate change in the Indian drylands.

Conservation

Plant genetic resources (PGR) of drylands consist of landraces, cultivars, genetic stocks, elite germplasm and, wild and weedy relatives of large number of cereals, legumes, horticultural crops, grasses, medicinal plants, shrubs and multi-purpose trees.

Cereals

The most important cereals in drylands include pearl millet [*Pennisetum glaucum* (L.) R.Br.], sorghum [*Sorghum bicolor* (L.) Moench.], maize (*Zea mays* L.), barley (*Hordeum vulgare* L.) and small millets consisting of six species viz., finger millet [*Eleusine coracana* (L.) Geaertn.], foxtail millet [*Setaria italica* (L.) P. Beauv.], little millet (*Panicum sumatrense* Roth ex Roem. & Schult.), kodo millet (*Paspalum scrobiculatum* L.), proso millet (*Panicum miliaceum* L.) and barnyard millet [*Echinochloa crusgalli* (L.) P. Beauv]. Efforts made at national and international levels have resulted in the collection and conservation of a large number of germplasm from different parts of the world providing the scientific community an access to a large pool of genetic resources to meet challenges in drylands. Details of germplasm accessions of cereals at ICAR-NBPGR, New Delhi is given in Table 1.

Table 1. Germplasm accessions of dryland cereals at ICAR-NBPGR, New Delhi

Crop	Indigenous	Exotic	Total
Pearl millet	8006	830	8836
Sorghum	11938	9067	21005
Maize	8616	141	8757
Barley	5937	1149	7086
Foxtail millet	4500	81	4581
Finger millet	11075	109	11184
Little millet	2095	01	2096
Kodo millet	2372	01	2373
Barnyard millet	1923	08	1931
Proso Millet	998	0	998
Total	57460	11387	68847

Source: NBPGR, PGR Portal, 2019

Pearl millet: At global level, pearl millet germplasm collection consists of 65,447 accessions (FAO, 2010a) in more than 1750 gene banks of 46 countries (FAO, 2010b). Six large *ex-situ* holders are ICRISAT, India (33%); CNPMS, Brazil (11%); NBPGR, India (9%); ORSTOM, France (6%) and ICRISAT, Nairobi (4%). ICRISAT is holding 23,841 germplasm accessions which include 20,628 traditional cultivar/landraces, 2268 breeding material, 816 wild relatives and 129 advanced or improved cultivars from 50 countries (ICRISAT, 2019). Indigenous collections of ICAR-NBPGR are from 17 states and union territories (Yadav *et al*., 2017)

*Sorghum***:** Global germplasm collections of sorghum consist of 2,35,688 accessions (FAO, 2010a). Largest global collection of sorghum from 93 countries is conserved at ICRISAT, Patancheru (Upadhyaya *et al*., 2017). ICRISAT has a total of 41,023 accessions in the gene bank which include 35,632 landraces or traditional cultivars, 4841 breeding material, 461 wild relatives and 89 improved cultivars (GENESYS-PGR, 2019). China had also collected 12,836 accessions throughout the country and 10,414 of these have been registered and preserved in National Genetic Germplasm Resources Bank.

Indigenous collections in NBPGR are from 30 states and union territories with majority from Maharashtra (2,525), Andhra Pradesh (1,654), Madhya Pradesh

(1,224), and Karnataka (1,144). A total of 42,048 sorghum accessions have been stored in ICAR-IIMR Gene Bank, which are readily supplied to the AICRP centers for utilization. This collection includes landraces, mapping populations, breeding material, varieties, hybrids and parental lines of hybrids.

Maize: Global germplasm collection of maize consists of 3,27,932 accessions (FAO, 2010a). CIMMYT is working as a global repository of maize germplasm collection and is conserving 28,193 accessions from 64 countries. Apart from the germplasm collection, there is one primary maize bank especially for genes, the Maize Genetic Stock Centre. This centre has conserved and annotated the maize mutant stocks (nearly 80,000) and are available to maize geneticists.

Indigenous collection of 8,616 accessions in NBPGR are from 30 states and union territories with majority from Himachal Pradesh (976), Delhi (635), Mizoram (503), Andhra Pradesh (500), Uttarakhand (472) and, Jammu and Kashmir (400), whereas the exotic collections are from three countries mainly from Indonesia (97), Argentina (22) and Thailand (9). A detailed report on germplasm collection status, diversity mapping and gap analysis in India was recently published (Pandey *et al*., 2015)

*Barley***:** Global barley collection in different gene banks throughout the world are 4,66,531 (FAO, 2010a) stored in 49 gene banks across five continents. Among the national collections, highest collections are maintained in Canada (39,852) followed by USA (29,838), Brazil (29,227), UK (23,603) and Germany (22,106) (Anonymous, 2008). As a global collection centre, ICARDA has 32,790 accessions which include 18,935 traditional cultivar/ landraces, 8,458 breeding material, 2,392 wild and 46 wild relatives.

Indigenous collections in NBPGR are from 20 states and union territories with majority from Himachal Pradesh (1,177), Haryana (637), Uttarakhand (442) and Delhi (441). A total of 8,159 germplasm (both indigenous and exotic) are being maintained in medium-term storage facility at Karnal (IIWBR, 2019).

Small millets: Dwivedi *et al*. (2012) summarized the collection of cultivated and wild relatives of different small millets across the continents, in national and international gene banks. The major collection of germplasm accessions are stored in gene banks viz., foxtail millet at China, India, France and Japan; finger millets in India and African countries; proso millet in Russian Federation, China, Ukraine and India; barnyard millet in Japan and India; kodo millet in India and USA; and little millet in India (Upadhyaya *et al.,* 2016c; Vetriventhan *et al.,* 2016). ICRISAT is holding the global germplasm of small millets (Table 2).

Table 2. Small millet germplasm holdings at ICRISAT

Crop	Cultivated	Wild	Total
Finger millet	5880	204	6084
Foxtail millet	1488	54	1542
Little millet	473	-	473
Kodo millet	665	-	665
Proso millet	849	-	849
Barnyard millet	749	-	749
Total	10,104	258	10,362

Indigenous collection in ICAR-NBPGR for foxtail millet is from 26 states with maximum from Tamil Nadu (597) followed by Andhra Pradesh (506). The collection of finger millet is from 26 states with maximum from Uttarakhand (890) followed by Andhra Pradesh (852); little millet from 20 states with maximum from Andhra Pradesh (447) followed by Madhya Pradesh (250); kodo millet from 13 states with maximum from Madhya Pradesh (402); and barnyard from 18 states with maximum from Uttarakhand (186) (NBPGR, 2019). AICRP on small millets is maintaining germplasm at National Active Germplasm Site (NAGS) (AICRPSM, 2018).

Legumes

The major legumes of drylands are chickpea (*Cicer arietinum* L.), mungbean [*Vigna radiata* (L.) Wilczek], clusterbean [*Cyamopsis tetragonoloba* (L.) Taub.] and mothbean [*Vigna aconitifolia* (Jacq.) Marechal]. Globally over 86,533 cultivated and 1032 wild germplasm accessions of chickpea are conserved in world gene banks. ICRISAT (20,267), International Centre for Agricultural Research in Dry Area (13,362) and NBPGR (15,084) have the major holdings of chickpea collections. Worldwide, a total of 43,027 mungbean accessions are held *ex situ* (Nair *et al*., 2012). ICRISAT holds 13,783 accessions of pigeonpea while more than 10,000 accessions are being maintained by the All India Coordinated Pigeonpea Improvement centers. Majority of clusterbean and mothbean germplasm collections are confined to Indian arid regions with some contribution from Pakistan in clusterbean. In India, NBPGR has been mandated for collection and conservation of germplasm (Table 3).

Table 3. Germplasm holdings of major legumes at ICAR-NBPGR, New Delhi

Crop	Landrace	Elite/breeding lines	Wild	Others	Total indigenous	Exotic	Total
Chickpea	4567	622	47	6765	12001	3083	15084
Pigeonpea	3715	1157	17	6132	11021	308	11329
Mungbean	887	146	13	2301	3347	405	3752
Mothbean	176	35	53	1195	1459	31	1490
Clusterbean	203	103	2	3659	3967	31	3998

Chickpea and pigeonpea germplasm have been collected from almost all parts of the country. Major areas of collections in clusterbean include Rajasthan (1,376), Haryana (243), Punjab (155) and Gujarat (105) while in mothbean the majority of collectioins have come from Rajasthan (541), Gujarat (167) and Haryana (78).

Grasses

Economy of the arid regions of drylands is closely linked to the raising of livestocks which mainly depend upon the native rangelands for their sustenance. About 106 species of grasses are found in western Rajasthan, though buffelgrass (*Cenchrus ciliaris* L.), birdwood grass (*Cenchrus setigerus* Vahl), sewan (*Lasiurus sindicus* Henr.), marvel grass [*Dichanthium annulatum* (Forsk) Stapf], blue panic (*Panicum antidotale* Retz.), murat (*Panicum turgidum* Forsk.) etc. are the main range grasses dominating the arid regions of drylands. Details of germplasm collections of grasses acquired mostly from arid regions of Rajasthan are given in Table 4.

Medicinal Plants and Shrubs

Drylands harbour a number of plants and shrubs that have a great relevance for medicinal purposes. Aloe [*Aloe vera* (L.) Webb. & Berth] is an important medicinal crop of arid and semi-arid regions of drylands and can withstand water scarcity. A total of 123 accessions of *A. vera*, have been collected and conserved from arid regions of Rajasthan and Gujarat. Guggual [*Commiphora wightii* (Arn.) Bhandari] is a commercially high-valued medicinal species as it yields oleo gum-resin of immense pharmacological importance. Only 19 collections of *C. wightii* are reported and deposited in NBPGR from ICAR-CAZRI, Jodhpur. Henna (*Lawsonia inermis* L.) is a hardy aromatic shrub capable of growing on diverse soil and climatic conditions. A total of 111 accessions from various states are with ICAR-NBPGR.

Shrubs like bawli (*Acacia jacquemontii* Benth.), phog (*Calligonum polygonoides* L.), kair [*Capparis decidua* (Forsk.) Edgew.], khara lana [*Haloxylon recurvum* (Moq.) Bunge ex Boiss.], lana [*H. salicornicum* (Moq.) Bunge ex Boiss.], kheep [*Leptadenia pyrotechnica* (Forsk.) Decne], bordi [*Ziziphus nummularia* (Burm.f.) Wight &Arn.] etc. have unique adaptability to harsh arid climatic conditions. During the last two decades, a wide range of unique germplasm have been collected from western Rajasthan and conserved in field gene banks of ICAR-CAZRI (Table 5).

Horticultural Crops

The drylands are suitable for growing many fruit species despite climatic constraints and limited irrigation facilities. These include ber (*Ziziphus mauritiana* Lam.), khejri [*Prosopis cineraria* (L.) Druce], peelu (*Salvadora oleoides* Decne.), pomegranate (*Punica granatum* L.), aonla (*Emblica officinalis* Gaertn.), date palm (*Phoenix dactylifera* L.), bael [*Aegle marmelos* (L.) Corr.], lasora (*Cordia myxa* L.), karonda (*Carissa carandas* L.), kair (*Capparis decidua*) etc. These fruit crops are very rich in nutraceuticals and can provide income security besides contributing to environmental amelioration. Great deal of variability exists in these species both at genotypic and phenotypic level as they are primarily propagated by seeds. The role of germplasm in the improvement of arid fruit crops has been well recognised and a large number of collections are maintained at different stations (Table 6).

Table 4. The number of germplasm collections of grasses in the field gene banks at ICAR-CAZRI, Jodhpur

Species	Number
Cenchrus ciliaris	85
Cenchrus setigerus	42
Cymbopogon jwarancusa	09
Lasiurus sindcus	111
Panicum antidotale	44
Panicum turgidum	01

Table 5. The number of germplasm collections of shrubs in the field gene banks

Species	No. of germplasm	Location of field gene bank
Acacia jacquemontii	26	ICAR-CAZRI, RRS, Bikaner
Calligonum polygonoides	32	ICAR-CAZRI, RRS, Bikaner
Capparis decidua	35	ICAR-CAZRI, RRS, Jaisalmer
Haloxylon salicornicum	55	ICAR-CAZRI, RRS, Bikaner
Haloxylon recurvum	2	ICAR-CAZRI, RRS, Bikaner

Multi-purpose Trees

The most important tree species in the drylands include khejri (*Prosopis cineraria*), kumat [*Acacia senegal* (L.) Willd.], rohida [*Tecomella undulata* (Sm) Seem.], meethajal (*Salvadora oleoides* Decne.) and kharajal (*S. persica* L.). Global collection of agroforestry tree species is mainly from India and African-Arab countries. The species like *P. cineraria* and *A. senegal* involve accessions from India, Oman, Yemen, Algeria, Mali, Pakistan, Ethiopia, Israel, Senegal, Sudan, Mali, Kenya, Tanzania and Niger. Though, no record for global collection of *T. undulata* and *Salvadora* species are available. India and Pakistan are the major contributors of *P. cineraria* germplasm with 9 and 11 accessions, respectively. Few accessions from Middle-East countries like Oman (4) and Yemen (2) were also recorded in global collection of *P. cineraria* whereas, collection of *A. senegal* was mainly from African and Asian countries *viz.* Sudan (13), Senegal (11), India (6), Niger (6), Pakistan (5) and Kenya (4).

Indigenous collections at ICAR-NBPGR include 48 accessions of *P. cineraria* mainly from Rajasthan and Gujarat and 340 accessions of *T. undulata*. Several accessions of *A. senegal* were collected from

Table 6. Conservation status and major diversity states of germplasm of different arid fruit crops

Crop	Conservation centres	Number of accessions	Conservation status	Major states of diversity
Punica granatum (Pomegranate)	NBPGR	360	Field gene bank	Maharashtra, Gujarat, Karnataka, Rajasthan, Tamil Nadu, H.P., U.P., J&K
	NRCP, Sholapur	375	Field gene bank	
	IIHR, Bangalore	203	Field gene bank	
	CIAH, Bikaner	154	Field gene bank	
	CAZRI, Jodhpur	28	Field gene bank	
	MPKV, Rahuri	170	Field gene bank	
Ziziphus mauritiana (Indian jujube, ber)	NBPGR	285	Field gene bank	Rajasthan, U.P., Haryana, Gujarat, M.P., A.P., Karnataka, Tamil Nadu, Maharastra
	CIAH, Bikaner	318	Field gene bank	
	CAZRI, Jodhpur	40	Field gene bank	
	HAU, Hisar	39	Field gene bank	
	PAU, Ludhiana	35	Field gene bank	
Aegle marmelos (Bael)	NBPGR	427	Cryo-bank (265) and field gene bank (162)	Jharkhand, U.P., Orissa, West Bengal, Rajasthan, Gujarat, Bihar, Chhattisgarh, H.P., A.P., M.P., Maharashtra, Kerla
	NDUAT, Faizabad	12	Field gene bank	
	CISH, Lucknow	54	Field gene bank	
	CIAH, Bikaner	17	Field gene bank	
	GBPUAT, PantNagar	10	Field gene bank	
	CAZRI, Jodhpur	8	Field gene bank	
Capparis decidua (Ker)	NBPGR	35	Cryobank (265)	Rajasthan, Gujarat
	CIAH, Bikaner	3	Field gene bank	
	CAZRI, Jodhpur	4	Field gene bank	
Cordia myxa (Lasora)	NBPGR	231	Cryobank (12), Field gene bank	Rajasthan, Haryana, H.P., Gujarat, Maharashtra, U.P., M.P., Jharkhand,Chhattisgarh
	CIAH, Bikaner	65	Field gene bank	
	CAZRI, Jodhpur	17	Field gene bank	
Emblica officinalis (Aonla)	NBPGR	51	Field gene bank	U.P., Gujarat, Rajasthan, M.P., Bihar, Tamil Nadu, Jharkhand Chhattisgarh
	NDUAT, Faizabad	22	Field gene bank	
	CIAH, Bikaner	50	Field gene bank	
	CAZRI, Jodhpur	8	Field gene bank	
Phoenix dactylifera (Date palm)	CIAH, Bikaner	61	Field gene bank	Gujarat, Rajasthan, Punjab
	RAU, Bikaner	35	Field gene bank	
	PAU, Research Station Abohar	31	Field gene bank	
	GAU, Research Station Mundra	24	Field gene bank	
	CAZRI, Jodhpur	23	Field gene bank	
Carissa Carandas (Karonda)	NBPGR	29	Field gene bank	Bihar, West Bengal, Chhattisgarh, Orissa, U.P., M.P., Jharkhand, Rajasthan, Gujarat, Maharashtra, Kerala, Karnataka, Haryana
	CIAH, Bikaner	8	Field gene bank	
	CAZRI, Jodhpur	5	Field gene bank	
	GBPUAT, Pantnagar	8	Field gene bank	

Updated from Malik SK, Rekha Choudhary, OP Dhariwal and DC Bhandari. 2018. Genetic resources of tropical and underutilized fruits in India. NBPGR, New Delhi. 168p.

different parts of country. However, no study on gap analysis of arid zone tree species has been done but on the basis of economic importance and conservation status, Ministry of Environment and Forests & Climate Change (MOEF & CC) has prioritized large number of forest tree species for conservation. Asia Pacific Forest Genetics Resource Programme and Food and Agriculture Organisation (FAO) had identified priority species for tree improvement and conservation programme. Lack of information on reproductive and population biology of many agroforestry trees along with the poor knowledge of gene pool diversity has led to lack of efforts for the conservation process. There is also limited knowledge on seed viability testing methods, maintenance of field gene banks, and susceptibility of genetic material to pest and pathogens.World Agroforestry Centre has over 500 accessions representing 120 agroforestry tree species, duplicated in a black box at the Svalbard Global Seed Vault, Norway.

Evaluation

Cereals

Almost full set of germplasm accessions of pearl millet for 23 morpho-agronomic traits have been evaluated for various phenotypic and phenological traits, and a huge variation has been observed for all traits (Yadav *et al*., 2017). Specific germplasm accessions have also been identified for use in resistance/tolerance to different biotic and abiotic stresses. Specific accessions have also been identified as a source of superior quality traits. Similarly, a total of 36,325 sorghum accessions have been characterized for important morpho-agronomic characters (Reddy *et al*., 2007). The range of variability available in cultivated races and their wild relatives is extensive, both for qualitative and quantitative traits. There was a wide range for qualitative traits like plant pigmentation from tan to pigmented, midrib colour from white to brown, panicle compactness and shape from very loose stiff branches to compact oval, glume colour from straw to black, glume fully covered to noncovered, grain colour from white to black, endosperm texture from completely starchy to completely corneous, threshability from freely threshable to difficult-to-thresh; grain lustre from lustrous to non-lustrous; and subcoat from presence or absence (Reddy *et al*., 2007). A total of 5,000 accessions maintained at IIMR, Hyderabad had also been characterized (Kudadjie, 2006; Elangovan *et al.,* 2007; Upadhyaya *et al*., 2008a; Durrishahwar *et al.,* 2012). The extent and pattern of genetic diversity within the world sorghum collections have also been investigated (Dje *et al*., 2000; Grenier *et al*., 2000; Casa *et al.,* 2005; Figueiredo *et al*., 2006, Upadhyaya *et al*., 2016b).

The entire set of accessions of barley maintained at IIWBR, Karnal has been evaluated for different biotic and biotic stresses as well as malting quality. A total of 21 genetic stocks have been registered in barley for disease resistance, quality traits, male sterility and altered botanical characters (IIWBR, 2019). Based on evaluation of 5,337 accessions including 2,801 indigenous and 2,536 exotic, germplasm was classified in different groups for various growth and qualitative traits (Sarkar *et al*., 2010).

The small millet germplasm accessions have been evaluated for morpho-agronomic traits (>10 traits) and there was large genetic variation in foxtail millet (Upadhyaya *et al*., 2008b), finger millet (Upadhyaya *et al*., 2006a), proso millet (Upadhyaya *et al*., 2011), barnyard, kodo and little millet (Upadhyaya *et al*., 2014a). The diversity in entire and core collections of small millets has been reviewed (Vetriventhan *et al*., 2016 and Upadhyaya *et al*., 2016b).

Legumes

Upadhyaya (2003) assessed the pattern of diversity in chickpea based on 21 traits from 16,820 accessions representing 43 countries. Based on geographical pattern of diversity, means for different agronomic traits differed significantly between regions and variances for all the traits among regions were heterogeneous. Majumder and Singh (2005) underlined that Indian sub-continent is the major area of genetic diversity in pigeonpea for a number of traits related to growth habit, duration, yield-contributing traits and resistance/tolerance to biotic stresses and abiotic stresses. Available germplasm accessions of legume crops have been evaluated (Kumar and Singh, 2009) and a large variation has been documented for most of the agronomic traits in chickpea (Archak *et al.,* 2016), pigeon pea (Dua *et al.,* 2007, 2009; Saxena, 2008), green gram (Bisht *et al.,* 1998), clusterbean (Dabas *et al.,* 1989; Dwivedi and Bhatnagar, 2002a) and mothbean (Dwivedi and Bhatnagar, 2002b).

Grasses

Variability in morphological and physiological characters in 10 strains of *Cenchrus setigerus* led to identification of strain 175 that was the most suitable for adaptation to arid zone owing to its higher forage yield, highest basal and crown diameters capacity for maximum tiller production, dark green leaf with longer and broader leaf blade and ability to sustain grazing pressure and to rejunivate (Chakravarty and Bhati, 1968). Wide genetic variation was observed in the characters contributing to forage yield, forage quality and underground biomass for *Cenchrus ciliaris*, *C. setigerus*, *Lasiurus sindicus* and *Dichanthium annulatum* (Yadav *et al*., 1980; Yadav, 1981; Yadav and Krishna, 1986; Rajora, 1998; Rajora *et al*., 2009). Genotypes of *C. ciliaris* exhibited significant variation with respect to earliness, plant height, tillering, leafiness and dry matter accumulation (Rajora, 1998; Rajora *et al.,* 2009). According to Dabadghao *et al.* (1963), *L. sindicus* exhibited maximum depth (4.03 m) of root penetration into the soil and also their horizontal spread, hence this is the most drought-resistant grass, because it can draw moisture from a broader horizon as compared to other arid zone grasses and remain alive under extreme arid condition.Wide range of variations was observed in the strains for fodder quality (Gupta *et al*., 1985).

Horticultural crops

Most of the present day commercial cultivars are selections from the variability generated by the germplasm collected/introduced in the past. Ber (*Ziziphus mauritiana*) which is commercially important has more than 300 varieties and this enormous diversity may be attributed to sexual propagation, heterozygosity, cross pollination and natural polyploidy. Khoshoo and Singh (1963) reported that segmental alloploidy also plays an important role in creation of variability in *Ziziphus* species. Pomegranate (*Punica granatum*) has a very narrow genetic variability with maximum variability occurring in Maharashtra, Karnataka, Tamil Nadu, Gujarat and Rajasthan. The genetic variability in aonla (*Emblica officinalis*) is widespread particularly in Uttar Pradesh (Pratapgarh), Gujarat, Rajasthan and Maharashtra with Banarasi, Francis, Banshi Red, Chakaiya, and Deshi being well-known old cultivars. Recent cultivars include NA6, NA7, NA10, Krishna, Kanchan, Anand-2 etc.. Evaluation of aonla cultivars in arid areas of Rajasthan revealed variation in growth attributes and physico-chemical parameters of fruits in different varieties (Meghwal and Azam, 2004). There are three major species of date palm grown in India viz., *Phoenix dactylifera*, *P. sylvestris* (L.) Roxb. and *P. canariensis* Chabaud. *P. Dactylifera* is grown commercially. Owing to superior quality edible fruits. At present, 35 date palm varieties are conserved at Date Palm Research Station, Bikaner, 19 cultivars at ICAR-CAZRI, Jodhpur, while only 5-6 varieties are recommended for commercial cultivation. In lasora (*Cordia myxa*), there are no well-defined cultivars, though great variation exists in size of fruits and their pulp content.

In karonda (*Carissa carandas*), some promising types No. 13, 16, 12 and 3 have been identified at Rahuri, Maharashtra (Karale *et al.,* 1989). Phenotypic variability in Karonda was also observed in plant growth, fruit size, shape and colour of fruit at CAZRI, Jodhpur (Bankar and Prasad, 1992; Bankar *et al*., 1992; Meghwal *et al*., 2014a). Singh *et al*. (2007) studied the *in-situ* variability in morphological and fruit traits of *C. decidua* from arid and semi arid-regions. Mahla and Singh (2013) evaluated 45 accessions of *C. decidua* and observed a wide range of fruit diameter, fruit weight, number of seeds per fruit, root length, shoot length and root:shoot ratio. Characterization for fruit and seed characters as per IPGRI descriptors of 30 accessions of *C. decidua* was also done at NBPGR (Anonymous 2017). Pilu (*Salvadora oleoides*), grown naturally in arid areas, showed great variability in growth and quality attributes (Jindal *et al.,* 2006).

Medicinal plants

Of the 123 accessions of *Aloe vera*, collected from arid region, two broad groups were identified: bitter and non-bitter types having significantly different aloin content which ranged from 0.033 to 0.061% in non-bitter types and 6.76 to 12.43% in bitter types (Azam *et al*., 2009). Morphologically, of the 11 floral characters studied, eight characters of non-bitter *A. vera* were significantly different from those of bitter *A. vera* (Azam *et al*., 2012). Jindal *et al.* (2005) recorded considerable variation in morphology and seed traits in natural population of *Commiphora wightii*. Phenophytic observations of *Lawsonia inermis* indicated prevalence of two types of the yellow-flowered henna i.e '*desi'* and '*muralia'* type and both types exhibited diverse morphological and reproductive behavior (Singh *et al*., 2005a). Considerable variability in 'desi' henna has been observed in terms of plant height, canopy spread, leaf length and width, dry leaf yield and dye content of the plant. It is observed that *Lawsonia* from Sojat has more lawsone content than henna produced in other parts of country. Two superior henna germplasm *viz*., Sojat-8 and Sojat-22 were identified and multiplied at ICAR-CAZRI, RRS, Pali, Rajasthan. Evaluation of various accessions of *Cassia angustifolia* for morphological traits under rainfed conditions at Jodhpur and irrigated conditions at Bikaner, did not reveal any significant variation (Singh *et al*., 2005a).

Shrubs

There was a remarkable variability in shape and size of 70 accessions of *Calligonum polygonoides* collected from 50 diverse sites of western Rajasthan (Beniwal *et al*., 2005). Vyas *et al.* (2012) reported high level of genetic diversity among different collections of *C. polygonoides*, wherein 90.18% RAPD markers were polymorphic. However, the RAPD patterns were not systematic with respect to classification of sampling accords to regions which leads to an uncharacterized diversity in the dendogram. Wide variation was reported among 65 accessions of *Haloxylon salicornicum* for agro-morphological characters (Singh *et al.,* 2015a). Meghwal *et al.* (2014) examined 21 genotypes of *Haloxylon* species with 10 RAPD primers and four primers produced 28 scorable bands all of which were polymorphic.

Multi-purpose Trees

Characterization and evaluation of 16 accessions of *Prosopis cineraria* for various horticultural traits indicated huge morphological variation (Arshad *et al.,* 2006; Sivalingam *et al*., 2011).The variability in vegetative vigour of *P. cineraria* has also been reported by Mann and Saxena (1980), Muthana (1980) and Kaul *et al.,* (1991). Recent survey of khejri germplasm for desirable pod types for culinary purpose led to identification of two superior types which had longer pods and were thornless (Anonymous, 2008b). Thar Shobha is a selection from naturally occurring trees from Bikaner. Jindal *et al.* (1987) and Meena *et al*. (2015) assessed more than 100 accessions of *Tecomella undulata* from different regions and reported a wide variation in several morphological traits. Fast growing accessions of *Acacia senegal* were identified at ICAR-CAZRI, Jodhpur (Jindal *et al*., 2000). Fakuta *et al*. (2015) reported variation in the yield of gum in different accessions of *A. senegal* from Sudan and Sahel. *Salvadora oleoides* accessions collected from Gujarat and Rajasthan were evaluated for diversity in seed size, oil content, seed germination and juvenile traits (Jindal *et al*., 2006). Malik *et al*. (2010) also characterized the fruit and seed characters in 17 accessions of *Salvadora* spp. originating from Rajasthan and Haryana and identified useful accessions for specific traits.

Utilization

Selected genetic resources play a major role in crop improvement programmes. Over the years, systematic evaluation of germplasm accessions available in gene banks has led to the identification of several sources of phenotypic, quality and adaptation traits, and biotic and abiotic stress resistance in a number of species of drylands. Several genetic stocks have also been identified and used as sources of biotic and abiotic stress resistance/ tolerance (Dwivedi and Bhatnagar, 2002a; Kumar and Singh, 2009; Verma *et al*., 2015).

Systematic evaluation of pearl millet germplasm led to the identification of accessions for specific traits including abiotic stress tolerance, biotic stress tolerance and nutritional traits (Yadav *et al*., 2017). In general, Indian pearl millet landraces have mainly contributed for earliness, high tillering, high harvest index and local adaptation (Yadav and Bidinger, 2007), whereas African material has been a good source of high head volume, large seed size and disease resistance (Kumar and Appa Rao, 1987). Several germplasm accessions have been used directly as cultivars after a few cycles of mass selection (Rai *et al*., 1990; Yadav, 2004; Upadhyaya *et al*., 2007; Yadav and Rai, 2013).

Sorghum germplasm accessions have also been identified for different traits like earliness, resistance to diseases and insect-pests (Prom *et al.,* 2007; Prom *et al*., 2011; Erpelding, 2011). Several sorghum germplasm accessions have been directly released as cultivars in 17 countries (Reddy *et al.,* 2006; Upadhyay*et al*., 2014b).

Kaul *et al*. (2018) evaluated maize accessions (registered at NBPGR for specific traits) for tolerance to various diseases, insects, early maturity, medium maturity, high tryptophan content, QPM (quality maize protein) etc. In small millets, germplasm accessions have been identified as source for specific traits by various researchers (Vetriventhan *et al*., 2016; Upadhyaya *et al*., 2016b).

In pomegranate, varieties like Muskat, Bassein Seedless, Dholka, Jalore Seedless and Jodhpuri Red are the traditional cultivars derived from local material. Selections P-23 and P-26 from Muskat, Ganesh from Alandi, G-137 from Ganesh, IIHR selection from Basein seedless and Yercaud-1 (Sayed *et al*., 1985) have been made. The cultivar Mridula has been developed at Rahuri, from the open-pollinated progeny raised from the F_1 population, derived from Ganesh × Gul-e-Shah

Red (Anonymous, 1994). It has red arils with very soft seeds. At Hisar, Shirin Anar and Russian seedlings possessed resistance to bacterial leaf (Singh and Rana, 1993). Evaluation of nine pomegranate cultivars under arid conditions of Jodhpur revealed significant variation in plant growth, fruit yield and physico-chemical properties of fruits (Prasad and Banker, 2000). The pomegranate orchard in Jalore and Jodhpur district in western Rajasthan have spread through seed propagation with lot of variability (Vashistha *et al*., 2003). Presently, Bhagwa is the most popular variety occupying maximum area under cultivation in India. It has been released by MPKV, Rahuri, Maharashtra by selection from F_2 progeny of the cross between Ganesh × Gul-e-Shah Red. It is a high yielder with an average fruit yield of 20-25 kg/plant. Due to bigger fruit size, sweet and glossy red rind with bold deep red arils, it fetches a very good price in the market and has a heavy demand for export. The fruit matures in about 170-180 days.

Long term evaluation of lasora (*Cordia myxa*) germplasm at ICAR-CAZRI, Jodhpur led to identification of five high yielding genotypes i.e. CZCM-2011, CZCM-2012, CZCM-2021, CZCM-2025 and CZCM-2062. The accession CZCM-2025 has been released as Maru Samridhi from CAZRI with fruit yield more than 100 kg per plant. Evaluation of karonda (*Carissa carandas*) germplasm over a period of eight years for fruit yield and other desirable attributes, led to identification of the accessions *viz*., CZCC-2011, CZCC-2022 and CZCC-2031 for hot arid zone. Subsequently, one of the accessions, (CZCC-2011) was released as Maru Gaurav, an improved high yielding variety from ICAR-CAZRI Jodhpur. The variety Thar Kamal has been released recently from ICAR-CIAH, Bikaner (Singh *et al*., 2015b) while Pant Manohar, Pant Suverna and Pant Sudarshan were released earlier from GBPUAT, Pantnagar.

Despite collection and conservation of large number of germplasm accessions, only fraction of these resources have been utilized in genetic improvement programmes across the world. Formation of trait-specific gene pools, core and mini core collections are likely to enhance the utilization of genetic resources to a greater degree. The core collection (10% of entire collection) and mini-core collection (10% of core collection or 1% of entire collection) of many drylands field crops have been established which may enhannce the utilization of germplasm (Grenier *et al*., 2001; Upadhyaya *et al.,* 2006a, 2006b; Bhattacharjee *et al*., 2007 Upadhyaya *et al.,* 2008b; Upadhyaya *et al*., 2009; Yong-Bi Fu and Horbach 2012; Vančetović *et al*., 2015).

Access to Germplasm Collections

The ICAR-NBPGR, New Delhi is the nodal agency for supply of plant germplasm, within India to researchers under the material transfer agreement. The bureau also facilitates import of germplasm from the countries having treaty as per convention of biological diversity act. As per agreement with the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), CGIAR centres like ICRISAT, ICARDA, CIMMYT supply germplasm free of cost to global research community using the Standard Material Transfer Agreement (SMTA) to strengthen breeding programmes. Various systems are in place to retrieve information on many aspects of germplasm collections, such as PGR portal of ICAR-NBPGR, Genebank Information Management System (GIMS) at ICRISAT, GRIN-Global used at USDA ARS and SINGER at CGIAR centers.

Effect of Climate Change on Dryland Agro-biodiversity

Climate has been the main motivating force in the nature for evolution of biological systems. Climate change, happening at a much faster rate in terms of frequency and extent of extreme of weathers, floods and droughts, might have negative impact on agrobiodiversity. This may threaten the livelihood of dryland inhabitants, which is closely intertwined with the diversity cherished by them since long. Climate change will affect the plant species with respect to their distribution, reproduction timings, length of growing seasons etc. Thus, it will modify the topography of plant or crop suitability. Moreover it will affect the crop wild relatives, which are an important component of agrobiodiversity. Climate change will significantly reduce the suitable areas of some of the crops like wheat and oats. However, suitable areas for some of the dryland crops like pearl millet and small millets are likely to increase.

Role of Agrobiodiversity in Imparting Adaptation to Climate Change

Agrobiodiversity holds potential solution for adaptation to climate change. Adaptive traits of dryland organisms will be of immense value in coping with climate change. Larger genepool of various arid crops will facilitate breeding of genotypes better adapted to shifts in climatic conditions. Crop species such as pearl millet, mothbean, clusterbean, forage grasses (*Lasiurus, Cenchrus,* *Cymbopogon*) can provide invaluable genes imparting tolerance to abiotic stresses. Woody perennial species having wide range of adaptability need greater attention in climate change scenario. Genera like *Acacia, Ziziphus, Cordia, Grewia, Indigofera, Crotalaria, Maytenus, Balanites* etc. need greater attention. Moreover, genetic resources from arid rangelands would play a significant role as valuable source of diverse genetic material needed for rehabilitation and improvement of degraded arid rangelands to the level of a multitiered silvi-pastoral systems.

Threats to Drylands Agrobiodiversity

The agrobiodiversity of drylands is facing serious threat due to climatic and anthropogenic factors. Habitat destruction/change in land use pattern is one of the major threats to dryland agrobiodiversity. Conversion of key grasslands in hot arid areas into cropping is threatening the existence of native grasslands particularly *Lasiurus sindicus* and *Panicum turgidum* grasslands. Conversion of *P. turgidum* dominated grasslands into croplands in Jaisalmer district is a great loss to natural habitat of *Caralluma edulis* which is one of the threatened species of great Indian Thar Desert.

Grazing intensity of small and large ruminants in arid and semi-arid regions is 3-5 times higher than what can be called as sustainable in these regions. Increased livestock population is leading to deterioration in composition of forage species. There is a significant loss of diversity in key palatable species.

Unsustainable practices are leading to exhaustion of genetic stocks and erosion of biodiversity. Non-scientific methods of gum and resins collection in certain shrubs of drylands are causing a decline in population of certain species. For example, loss of diversity and plant population in guggal (*Commiphora wightii*), in Jaisalmer district, is a major concern due to its overexploitation for oleo-gum resin. Further, unsustainable harvesting practices particularly in those medicinal plants which have underground and reproductive parts is also a serious concern in important species like *Ceropegia, Urginea* and *Dipcadi* in western Rajasthan. Large scale root digging for fuel wood in key species like Phog (*Calligonum polygonoides*) in western Rajasthan has threatened this important rangeland shrub of Thar Desert.

Species like *Prosopis juliflora* in drylands of Rajasthan and Gujarat, *Lantana camara, Parthenium hysterophorus* in semi-arid regions are the problematic invasive species. Proliferation of *Prosopis juliflora* in Kutch region of Gujarat and Gajner century of Bikaner, Rajasthan is threatening the habitat of indigenous Banni grasslands and *Heliotropium rariflorum,* respectively.

Dilution of traditional management practices is also an important factor for loss of biodiversity**.** Traditional management of *Orans* (sacred groves), *Gauchars* (common grazing lands), *Agors* (catchment areas for water harvesting) in western Rajasthan that were harbouring agro-biodiversity are the best examples which are losing their relevance in current scenario.

Afforestation with inappropriate woody perennial (replacing native species with exotic ones) is also one of the threats to biodiversity as it affects the ecosystem services at local scale.

Measures for Conservation of Dryland Agro-biodiversity

Tremendous efforts have been made towards *ex situ* conservation of agrobiodiversity from drylands. However, desired attention has not been paid for *in situ* conservation of genetic resources of drylands. Farmers need to be incentivised for preservation of agrobiodiversity in their agricultural fields. Planting of locally adapted multipurpose shrubs and woody perennials on farm boundaries is one example of conserving biodiversity and also from climate change mitigation point of view. Dryland farmers cultivating traditional landraces of crops and rearing native breeds need to be suitably recognized and rewarded.

Certain traditional farming systems and specific habitats do play a very critical role in conservation of genetic resources. For instance, saline depressions (Playas) or lakes are scattered throughout drylands in Rajasthan. Significant *ranns* may be seen in the district of Barmer, Bikaner, Jaisalmer, Jodhpur and Nagaur where several important halophytes are abundantly found. Another good example comes from runoff farming system (*Khadins*) in western Rajasthan that plays an important role in on-farm conservation of agro-biodiversity of traditional varieties of crops like pearl millet, clusterbean, wheat, chickpea, mustard and indigenous trees on bunds.

Communities play a great role in management of genetic resources in drylands agro-ecosystems. There is a greater need to capacity building and raising awareness among the drylands farmers for promotion and conservation of agrobiodiversity.

Conclusion

Agrobiodiversity in drylands has undoubtedly played an extremely critical role in achieving food and fodder security, in addition to raising the resilience to climatic stresses of drylands. However, the agro-biodiversity is facing several complex challenges due to global warming-mediated climate changes and due to several anthropogenic factors like habitat destruction, high grazing/browsing pressure, unsustainable exploitation of natural resources and dilution of customary conservation practices. This situation calls for several interventions at scientific and policy fronts to conserve the genetic diversity. Genetic resources of drylands are potential sources of native genes conditioning resistance to various biotic and abiotic stresses, present unique study material to understand the mechanism of adaptation to abiotic stresses and are likely to serve as an excellent genomic resource for isolation of candidate genes for tolerance to climatic and edaphic stresses for accelerating further genetic improvement. Because of these reasons, enormous efforts have been made, in the past, to collect and conserve them. Given that agrobiodiversity is dyanamic in nature, continuous explorations are needed in the regions where collection gaps have been indicated, taking help of GIS and other modern tools. *Ex situ* conservation efforts are to be strengthend and e-resources to be developed to enhance the utilization of genetic resources in order to broaden crop genetic base which is very essential to mitigate the effects of climate change.

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