Legume Research, 41(5) 2018: 656-662
Print ISSN:0250-5371 / Online ISSN:0976-0571

AGRICULTURAL RESEARCH COMMUNICATION CENTRE
www.arccjournals.com/www.legumeresearch.in

Pigeonpea [*Cajanus cajan* (L.) Millsp.] and its wild spp. germplasm collection status, diversity distribution and trait-specific germplasm mapping using GIS tools in India

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Received: 14-09-2016 Accepted: 29-03-2017 DOI: 10.18805/LR-3778

ABSTRACT

A total of 2,456 germplasm accessions of pigeonpea (*Cajanus cajan*) and its wild spp. having essential geo-coordinates (latitude and longitude)/locality information were analysed for spatial and diversity distribution through GIS tools. Analysis of passport data revealed that maximum number of germplasm accessions are collected from the states of Madhya Pradesh (438 accessions) followed by Jharkhand (387), Andhra Pradesh (326), Telangana (253), Bihar (249), Gujarat (230), Uttar Pradesh (188) and Maharashtra (178). India being the centre of origin and diversity of this crop, collecting resulted in augmentation of 86 landraces from 14 states. Among wild relatives of pigeonpea, only *Cajanus scarabaeoides* (46) and *C. cajanifolius* (6) were augmented. GIS mapping of 107 selected trait-specific germplasm (with regard to eight important morpho-agronomic traits) identified few areas – Akola (Maharashtra) for pod bearing length; Srikakulam (Andhra Pradesh) for bold seed; and Banaskantha (Gujarat) for high pod number. Unexplored and underexplored areas as well as crop wild relatives belonging to genepool one and two are identified for future collection.

Key words: Pigeonpea, Collection, Conservation, Diversity Distribution, Trait-specific germplasm, GIS tools.

INTRODUCTION

Pigeonpea [*Cajanus cajan* (L.) Millsp.] belonging to family Fabaceae (subtribe Cajaninae, tribe Phaseoleae and subfamily Papilionoideae (Takhtajan, 2009) plays an important role in food and nutritional security in the Old World Tropics as this pulse crop is rich in protein (23-27%), minerals and vitamins (especially vitamin B). It is a widely adapted, hardy and drought tolerant crop which shows a large temporal variation (97-299 days) in maturity (Majumdar and Singh, 2005). Van der Maesen (1980) postulated that pigeonpea originated from *Cajanus cajanifolius* in India through selection for desirable traits like non-shattering pods and larger seeds, later spread to the Africa and Australia. Based on biosystematic studies, he merged all the species of *Atylosia* Wight & Arn. with *Cajanus* (Mallikarjuna *et al.* 2012; Van der Maesen, 1986). Genus *Cajanus* has 32 species in the world and 16 species in India including 3 endemic species *viz. C. cajanifolius, C. sericeus, C. villosus* (Singh *et al.*, 2015; Sanjappa, 1992; www.ildis.org). As per the revised concept of genepool proposed by Smartt (1990), *Cajanus cajanifolius* (Haines) Maesen was ranked in second order of primary genepool which is freely crossable with *C. cajan* and produces fertile hybrids. Nine other *Cajanus* species including five native ones [*C. acutifolius* (F.Muell.) Maesen, *C. albicans* (Wight & Arn.) Maesen, *C. lineatus* (Wight & Arn.) Maesen, *C. lanceolatus* (W.Fitzg.) Maesen, *C. latisepalus* Maesen, *C. reticulatus* (Dryand.) F.Muell., *C. sericeus* (Baker) Maesen, *C. scarabaeoides* (L.) Thouars, *C. trinervius* (DC.) Maesen] are cross-compatible with *C. cajan* to certain extent forming the secondary genepool, while remaining 21 species, do not cross with *C. cajan*, are placed in tertiary genepool (Remanandan, 1990). Pigeonpea is an often cross-pollinated crop with diploid chromosome number 2n=22, and a genome size of 858 Mbp (Greilhuber and Obermayer, 1998). Pigeonpea has unique place in Indian agriculture as India accounts for about 77% of its global production. It is the second most important pulse crop in this country next to chickpea, covering an area of about 4.42 m ha, and occupying 14.5% of total area under pulses (Singh *et al.* 2013; FAOSTAT, 2011). This crop is grown at altitudes ranging from 50 to 2000 m above sea level (Van der Maesen 1990) and even in moderate cold climatic conditions (18 to 24°C) in the country. The major areas of its cultivation come under the states of Uttar Pradesh, Madhya Pradesh, Maharashtra, Karnataka, Gujarat, Andhra Pradesh, Telangana and Bihar (Singh *et al.* 2013). These states also hold rich diversity in this native crop owing to favourable topographic and climatic situations as well as socio-economic conditions of farmers. In hilly areas of peninsular and north eastern India, often perennial forms are cultivated in backyards. Also vegetable type pigeonpea was reported from the north-eastern states of Nagaland (Pradheep *et al.* 2014),

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Manipur and Tripura (Rathi, 2013). Landraces together with crop wild relatives (CWR) form an invaluable source of genes and gene complexes for yield, quality and several biotic and abiotic factors. Considering the high significance of pigeonpea in this country, the Indian Council of Agricultural Research (ICAR) started an All India Coordinated Pigeonpea Improvement Project in 1965. Under its umbrella, genetic improvement programme was simultaneously started at 30 research centres located in various agro-climatic zones of the country (Ramanujam and Singh, 1981). Out of 43 varieties released in the country, 30 are the mere selections from traditional cultivars/landraces. In view of changing climatic conditions, the collection of pigeonpea germplasm and its characterization, evaluation, conservation and utilization in crop improvement programmes assume greater significance.

Geographic information system (GIS) tools were frequently used for diversity mapping of different crops and their wild relatives. Utility of GIS tools especially DIVA-GIS software (Hijmans *et al.* 2001) in germplasm collection and diversity analysis has been widely recognized through various studies i.e. in beans (Ramirez-Villegas *et al.* 2010), in potato (Hijmans *et al.* 2001) and *Brassica* spp. (Semwal *et al.* 2013). In present study, passport data on collected germplasm of pigeonpea was analysed using above tools to map diversity-rich localities, to pinpoint sites holding trait-specific germplasm, and also to reveal the gaps in collected vs conserved germplasm vis-a-vis literature/documented information for future explorations.

MATERIALS AND METHODS

So far 2,967 accessions of pigeonpea were collected from more than 2,000 collection sites in different agro-ecological regions of the country (http://192.168.1.5/NBPGR/Search Passport.aspx; Annual Reports NBPGR, 1976-2014; Plant Germplasm Reporters, 2002-2014). This includes about 216 accessions assembled before the establishment of NBPGR (1952-75). Germplasm collections were made from diverse areas through crop specific and multi-crop explorations either independently or in collaborative mode with crop-based Institutes/State Agriculture Universities/Krishi Vigyan Kendras. Besides passport data, exploration reports were consulted for diversity related information originally observed by the collectors. The collection site details (village/tehsil/district) were checked thoroughly and wherever geographic coordinates were not available, same were assigned with the help of Google map/gazetteers. After rigorous screening, a total of 2,456 accessions having essential geographic details (latitude and longitude)/locality information were short-listed for diversity analysis. Geo-referenced maps were prepared using WGS84 datum and Everest projection systems. In order to know the spatial distribution and assessment of diversity, simple/circular neighbourhood method (grid analysis) in DIVA-GIS software version 7.5 was used (Hijmans *et al.* 2001). A grid of 1° x 1° cells (111.3 x 111.3 kms) was set for diversity mapping, as this analysis is pertained to large geographic area, i.e. at country level (Hijmans *et al.* 2001).

RESULTS AND DISCUSSION

Germplasm collection status: Pigeonpea germplasm was collected from 28 states (except Jammu & Kashmir) and also from Andaman & Nicobar Islands; this includes representation of 345 districts (out of total 686) throughout the country (Table 1). The geo-referenced map of 2,456 accessions showed that central India, peninsular region, Gangetic Plains and the western part had fair representation. Madhya Pradesh (438 accns.), Jharkhand (387) and Andhra Pradesh (326) accounts for the highest number of collected accessions (Table 1). Meagre collection status in the states of Haryana, Punjab, Manipur and Meghalaya implies that they fall under non-traditional area of its cultivation owing to less preference against high value/cash crops (wheat, rice, cotton, sugarcane) or availability of alternatives. Among its wild relatives, 46 accessions of *Cajanus scarabaeoides* were collected from eight states with maximum accessions from Maharashtra (9), Uttarakhand (8), Andhra Pradesh (7) and Odisha (6) while six accessions of *C. cajanifolius* from Odisha (3) and Andhra Pradesh (3).

The Database also revealed that germplasm has been collected from diverse habitats such as plain fields, jhum

Table 1: Status of pigeonpea germplasm collected from top 20 states in India.

States	Accns collected	Accns in NGB	Districts (Total/Collected/ Represented in NGB)
Madhya Pradesh	438	235	51/40/32
Jharkhand	387	78	24/23/19
Andhra Pradesh	326	122	13/12/12
Telangana	253	22	10/10/6
Bihar	249	102	38/28/23
Gujarat	230	59	33/22/16
Uttar Pradesh	188	2	75/22/2
Maharashtra	178	91	36/28/26
Rajasthan	128	-	33/16/-
Karnataka	95	22	30/16/7
Chhattisgarh	86	39	27/11/9
Odisha	77	15	30/15/5
Tamil Nadu	68	-	32/18/-
Arunachal Pradesh	52	2	19/8/2
Kerala	44	10	14/11/7
Uttarakhand	39	11	13/8/8
Tripura	33	1	8/4/1
Mizoram	28	14	8/8/5
West Bengal	17	2	19/6/2
Assam	11	3	32/8/3
Others	40	12	-
	2,967	**855**	

Accns – accessions; NGB- National Gene Bank, ICAR-NBPGR

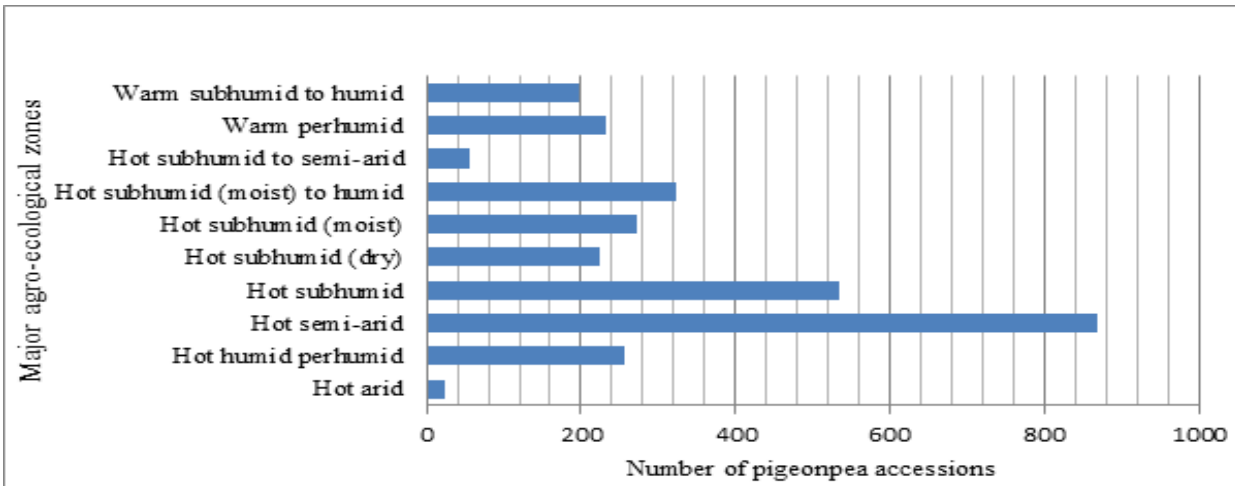

Fig 1: Pigeonpea germplasm collected from major agro-ecological regions of India.

areas, undulating terrains and backyards. The germplasm accessions were grouped according to ten major agro-ecological zones (Sehgal *et al.* 1990) to assess diversity distribution across the zones. Results revealed that maximum germplasm collections were made from hot semi-arid zone covering central, western and peninsular India (868 accn.) and hot sub-humid zone spreading in eastern part of central and eastern regions (535 accn.) while rest of the agro-ecological regions have comparatively lesser representation (Fig.1).

Germplasm conservation status: Out of a total 2,967 accessions, only 855 (29%) are conserved in national gene bank (NGB), of NBPGR. Maximum accessions were conserved from Madhya Pradesh (235) followed by Andhra Pradesh (122) and Bihar (102) (Table 1). While cent percent gap in collection vs conservation was noticed in states of Rajasthan, Tamil Nadu and Himachal Pradesh, large gaps (>70%) were also observed in Uttar Pradesh, Arunachal Pradesh, Tripura, West Bengal and Assam. Meagre conservation of pigeonpea germplasm at NGB may be attributed to reasons such as inadequate seed sample size (<4,000 seed), poor fruit setting under controlled pollination during seed multiplication (thus demanding repeated cycles of regeneration of this semi-perennial crop), high susceptibility to pests and diseases (especially storage pests) and poor quality seeds obtained from farm stores.

The gene bank at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, (genesys-pgr.org) has the largest germplasm collections (over 13,771 accns.) of *Cajanus* species from 74 countries, about two-third of the same from India only. It includes 555 accns. of its wild relatives representing six genera and 57 species (ICRISAT, 2015; Upadhyaya *et al.* 2007). In NGB, NBPGR, a total of 11, 234 acc. of pigeonpea germplasm were conserved, including 1,045 exotic collections and out of them 5,748 acc. are repatriated materials from ICRISAT (Singh *et al.* 2013).

Diversity distribution mapping: Collection data showed that pigeonpea is under cultivation from 50 to 2000 m altitude MSL (Fig. 2). Some typical high altitude areas from where collections made includes Giriya Mansoona-altitude 1,850m (Rudraprayag) and Urgam-altitude 2,000m (Chamoli) of Uttarakhand state, those collections may prove to be potential source for cold tolerance. Also some interesting collections were made from coastal parts -- Velukkara, Thrissur (Kerala), Rajavomangi, East Godavari (Andhra Pradesh) and Palibandha, Ganjam (Odisha). With regard to climate, maximum diversity was found in areas having average temperature of 20 to 35^{0}C during growing season and 1000 to 1500 mm rainfall. Apart from commercial cultivation, pigeonpea was also observed under cultivation in home/ kitchen gardens and backyards in tribal dominated pockets for self-consumption by local people. Diversity map (Fig. 2)

Fig 2: Geo-referenced map of pigeonpea germplasm collected.

revealed that some diversity-rich areas viz. Parts of eastern plains (eastern Uttar Pradesh and Bihar); western parts of central India (Madhya Pradesh, Maharashtra and Gujarat) and peninsular region (Andhra Pradesh) were extensively explored for germplasm collection. Predominant soil types in these areas are red and black/ red and lateritic/ red and yellow/ alluvial soils. Hot humid climate of these regions also favoured its cultivation, on the other hand, in northern areas of India this crop is prone to fusarium wilt disease as well as frost (Majumder and Singh, 2005).

Diversity in landraces: Pigeonpea, being an indigenous crop, it has adapted to varying climatic conditions; selections for desirable types at local/regional level have led to evolution of a good number of landraces across the country. A total of 366 accessions involving 86 (named) landraces were collected from 14 states of the country. Some of the prominent named landraces include *Kandulu, Peddakandi, Rahar Mah, Aghani Arhar, Kala Jatahi, Khar Thuvar, Gullalli local, Katki Rahar, Laltuar, Raharchoti* and *Tumorcadi*. All 86 landraces are conserved in NGB. Maximum number of germplasm accessions under named landraces are conserved from Andhra Pradesh (131 acc. of 19 landraces conserved) followed by Madhya Pradesh (137/ 17) Bihar (47/10), Karnataka (9/8) and Maharashtra (26/8). Only one landrace has been conserved from each of the states of Assam, Chhattisgarh, Manipur, Kerala, Uttarakhand and West Bengal.

The Exploration and Germplasm Collection Database revealed that collected germplasm possesses variation with respect to crop duration (annual/ semi-perennial/ perennial), maturity behaviour (synchronous/ asynchronous), growth

Table 2: Promising accessions among trait-specific germplasm and their source areas.

Traits (value)	Accessions*	Locality (number of accessions)
Plant height (<162 cm)	IC56054	Akola, Maharashtra (1)
Pod bearing length (>64 cm)	IC15707	Pakur, Jharkhand (1)
	IC56060	Banaskantha, Gujarat (1)
	IC28199	Akola, Maharashtra (1)
Long pod (>4.5 cm)	IC348314, IC348323, IC406843	Hyderabad, Telangana (3)
	IC489990	Banaskantha, Gujarat (1)
	IC489968	Sitapur, Uttar Pradesh (1)
High pod number (>138 pod per plant)	IC525788	Muzaffarpur, Bihar (1)
	IC423669	Hyderabad, Telangana (1)
High yield (>106 g/plant) annual type	IC 33755	Sangli, Maharashtra (1)
	IC47233, IC525685	Kurnool, Andhra Pradesh (2)
	IC525662, IC527709	Hyderabad, Telangana (2)
	IC369011	Ranchi, Jharkhand (1)
	IC368997	Dharwad, Karnataka (1)
High shelling % (>80)	IC441500	Srikakulam, Andhra Pradesh (1)
Bold seed (>5 mm diam.)	IC441500, IC489810	Srikakulam, Andhra Pradesh (2)
	IC56068	Akola, Maharashtra (1)
Protein content (>20.95%)	IC407060	Seraikella Kharsawan Jharkhand (1)
	IC407505, IC525515	Jalna, Akola, Maharashtra (2)
	IC73321, IC552858	Ambikapur, Gwalior, Madhya Pradesh (2)

*Compiled from several sources like (Annual reports NBPGR, 1976-2014; Singh *et al.,* 2013; Dua *et al.,* 2007)

Table 3: Prioritized CWR of pigeonpea and the areas to be explored (Modified from Remanandan, 1990; Van der Maesan, 1986).

Species	Genepool status	Areas to be explored
Cajanus cajanifolius (Haines) Maesen	GP_1	Bastar region of Chhattisgarh; Eastern Ghats of northern Andhra Pradesh and southern Odisha
Cajanus albicans (Wight & Arn.) Maesen	GP_2	Tropical dry deciduous forests in southern Western Ghats and Eastern Ghats (in states of Tamil Nadu, Kerala, Karnataka, Andhra Pradesh and Odisha)
Cajanus lineatus (Wight & Arn.) Maesen	GP_2	Tropical dry or moist forests in Western Ghats (all states) and Nilgiris in Tamil Nadu
Cajanus scarabaeoides (L.) Thouars	GP_2	Widely distributed (upto 1500 m MSL) in India. Priority should be given to central and eastern India (Madhya Pradesh, Chhattisgarh, Jharkhand, Bihar), south India (Tamil Nadu, Kerala, Karnataka), Assam, Uttar Pradesh and West Bengal
Cajanus sericeus (Baker) Maesen	GP_2	Dry deciduous forests in Maharashtra, Gujarat, Karnataka and Eastern Ghats (Odisha and Andhra Pradesh)
Cajanus trinervius (DC.) Maesen	GP_2	High hills of Kerala and Tamil Nadu

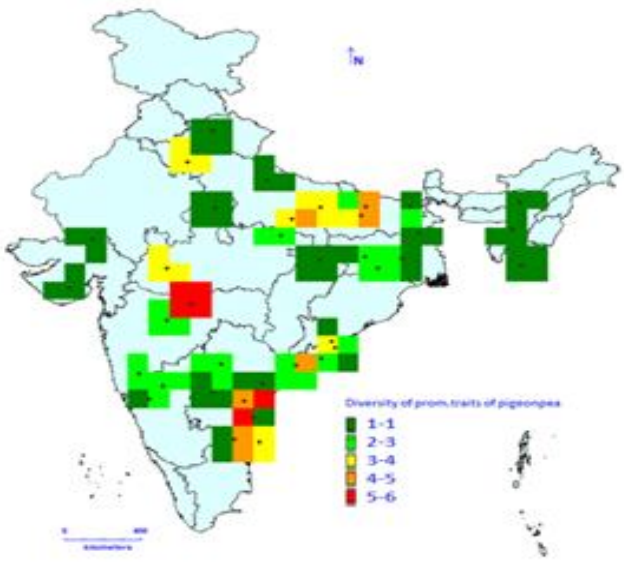

Fig 3: Grid map of promising and trait-specific germplasm collections of pigeonpea.

habit (erect and compact/ semi-spreading/ spreading or plant type), pod and seed size, and seed coat colour (white/ cream/ orange/ light brown/ grey or dark grey (Majumdar and Singh, 2005; Remanandan, 1990). Variability in these and other parameters of the pigeonpea collections from India has been reported by others (Singh *et al.* 2014). Perennial forms are collected from hilly tracts of peninsular and north eastern India, while vegetable types (use of immature pod) from north-eastern states of Nagaland, Manipur and Tripura. Mehra and Arora (1982) also reported vegetable types from tribal areas of Karnataka (Bellary, Mysuru and Raichur) and Maharashtra, and have noticed very long pods, with 7-8 seeds per pod.

Mapping of trait-specific germplasm: A total of 107 trait-specific germplasm have been grid-mapped for eight economically important traits–short plant height, high pod bearing length, high pod number, long pod, bold seed, high shelling percent, high yield and protein content (Singh *et al.* 2014). Promising accessions identified for these traits by the Bureau (Annual reports NBPGR, 1976-2014; Dua *et al.* 2007) along with their source areas are given in table 2. The red/ orange-coloured grids (4-6 traits) in figure 3 show the presence of maximum desirable traits in particular grid area. This resulted in the identification of areas – south-eastern Andhra Pradesh, north-eastern Maharashtra and north-western Bihar for likelihood presence of maximum number of desirable traits (Table 2, Fig. 3). Further mapping through fine grid method, identified few specific areas like Akola (Maharashtra) for pod bearing length; Srikakulam (Andhra Pradesh) for bold seed and Banaskantha (Gujarat) for high pod number. Other traits showed random distribution across the above identified regions.

Gaps identified: In view of the diversity assessment vis-a-vis germplasm collected/conserved, literature survey/reports (Singh *et al.* 2013; Varshney *et al.* 2012; Dua *et al.* 2007; Majumdar and Singh, 2005; Smartt, 1990; Van der Maesan, 1986) and personal communications with crop experts, the following areas have been identified for future exploration and collection of pigeonpea germplasm.

- **Landraces**: Priority shall be given in following areas **Maharashtra:** districts of Nandurbar, Dhule and Jalgaon in northern parts; Latur and Osmanabad in Marathwada region; Buldhana, Bhandara, Chandrapur, Nagpur, Gondia and Wardha districts in Vidharba region. *Andhra Pradesh*: districts of Prakasam, Guntur, Krishna, East Godavari and West Godavari. *Assam*: districts of Chirang, Kokrajhar, Baksa, Nalbari, Barpeta, Lakhimpur, Dhemaji, Dibrugarh and Tinsukia; *Arunachal Pradesh*: foothills of East Kameng, West Kameng, Papum Pare and Lohit districts. Exploration of perennial types should be given due emphasis in North Eastern Hill regions, particularly Manipur, Nagaland and Arunachal Pradesh.

- There is a need to revisit already collected areas in states of Tamil Nadu (Coimbatore, Erode, Nilgiris, Pudukkottai, Tirunelveli, Virudhunagar, Salem, Tiruvannamalai), Rajasthan (Baran, Chittaurgarh, Dholpur), Himachal Pradesh (Bilaspur, Sirmaur), Uttar Pradesh (Ballia, Hamirpur, Unnao, Mirzapur, Ghazipur and Gorakhpur) and West Bengal (Purulia, West Medinipur and 24 South Parganas), as nil to meagre germplasm collected from these districts have been conserved in NGB.

- Explorations for trait-specific germplasm can be focused in fine-grid manner in south-eastern Andhra Pradesh, north-eastern Maharashtra and north-western Bihar.

- Exploration and germplasm collection database showed very poor collection status of CWR of pigeonpea. Smartt (1990) and Van der Maesen (1986) reported tremendous variability in related wild species also. In this regard, priority may be given to those CWR falling in primary and secondary genepool of pigeonpea (see Table 3). It is suggested to conduct specific exploration trips to collect germplasm of *Cajanus cajanifolius*, the progenitor of pigeonpea.

CONCLUSION

The pigeonpea is fairly cultivated throughout the country except in areas having extreme climatic conditions i.e. hot and temperate climates and arid zones. A major quantity of pigeonpea germplasm has been collected from almost all its areas of cultivation vis-a-vis diversity-rich areas in the country, with highest collections from tribal dominated central, eastern and south-eastern India. A significant number of collections (10,189 acc.) are conserved in NGB, however, most of them are repatriated ones (5,748 acc.) from ICRISAT, Hyderabad; such germplasm hardly have locality information in place. Grid-mapping of trait-specific germplasm identified - the south eastern coastal Andhra Pradesh, north-eastern Maharashtra and north-western Bihar for maximum

diversity in eight promising traits. Also most suitable localities for specific desirable traits have been identified. Collection gaps indicated underexplored/ unexplored areas such as parts of northern Western Ghats, Eastern Ghats of Andhra Pradesh and North-Eastern Hill region (perennial type) necessitating focused collection in the near future. There exists vast information on various sources of biotic and abiotic stress tolerance in indigenous collections (Varshney *et al*. 2012; Majumdar and Singh, 2005), that can help in devising specific exploration programmes for stress-tolerance breeding at fine-grid level.

ACKNOWLEDGEMENT

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 other scientists and staff of Plant Exploration and Germplasm Collection Division, who generously helped in compiling information and all the explorers who have collected germplasm and associated information, which formed the base for this analysis.

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