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Spatial Distribution of Trait-specific Diversity in Indian Wheat Collections

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A total of 5,930 accessions of wheat were collected in collaboration with crop-based institutes of Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAUs) from diverse areas of the country during the period 1976-2013. Of these, 3,973 accessions were short-listed with details on state, district, village, collector number, latitude (N) and longitude (E) of the collection sites to understand the diversity distribution pattern. The geo-referenced map of collected diversity depicted that Himachal Pradesh and Uttarakhand states were extensively explored for *Triticum aestivum* and Karnataka, Gujarat and Madhya Pradesh for *T. turgidum* subsp. *durum*. Among the local landraces, drought tolerant Jautri local type from Madhya Pradesh; awnless types Lakh, Dhavati and Hansy from Uttarakhand; and non-shattering types Kankoo and Dharmauri from Himachal Pradesh were some notable collections. Besides, the priority areas for collection of cultivated species of wheat distributed in different agro-ecological regions were identified and discussed in the present communication.

Key Words: Diversity distribution, GIS, Landraces, Trait-specific germplasm

Introduction

Wheat is widely cultivated as a cash crop because of good unit area production. It grows well in a temperate climate even with a moderately short growing season. Wheat has more than 60% share of calories in human diet, together with rice and maize (Gill *et al.,* 2004). *Triticum aestivum* L. (bread wheat), *T. turgidum* L. subsp. *durum* (Desf.) Husn. (durum wheat) and *T. turgidum* L. subsp. *dicoccon* (Schrank) Thell. (emmer wheat) are three main species of wheat under cultivation in India. Among these, bread wheat is grown in about 95% area, durum wheat in 4% and emmer wheat in only 1% area (Gupta, 2004; Singh, 2006). *T. aestivum* has superior bread-making qualities, and traditionally dominates under cultivation in the north-western part of continent and the Ganges valley. *T. turgidum* subsp. *durum* is hardier, drought resistant, generally provides grittier flour and often traditionally used in grits, sweets, base for pizza, burger, etc. (Ambasta *et al.,* 1986). *T. turgidum* subsp. *dicoccon* has high fibre and antioxidant compound concentration, is particularly suitable for diabetes (Annapurna, 2000), also possesses high lysine content and minerals than bread and durum wheat (Zaharieva *et al.,* 2010).

In India, wheat is mainly grown in Punjab, Haryana, Gujarat, Rajasthan Uttar Pradesh, and West Bengal. Presently the wheat growing areas are experiencing the major impact of climate change and changes in cultivation pattern in the country; the cool period of crop growing duration is shrinking, while the threat of terminal heat stress is increasing (Rane *et al.,* 2000; Sharma *et al.,* 2002). The high temperature stress could be a significant factor in reducing yield and quality of wheat (Stone and Nicolas, 1995). Therefore, to combat biotic (yellow and brown rust, loose smut, etc.) and abiotic stresses (moisture stress at different stages, terminal heat, etc.), there is a need to collect trait-specific germplasm of landraces/ local cultivars as well as the wild *Triticeae* from areas of diversity (Gupta and Lakshmi Kant, 2012; Singh *et al.,* 2006).

Presently limited studies have been conducted on agro-ecological distribution pattern of *Triticum* spp. in India as compared to other crops. Geographical Information System (GIS) is an efficient tool that supports the analysis of exploration and collection, characterization and evaluation, genebank and herbarium databases to elucidate genetic, ecological and geographical distribution patterns of the crops and wild species (Hijmans and Spooner, 2001; Semwal, 2009). This tool has been used to analyse the data pertaining to management of plant genetic resources of various crops and crop wild relatives *viz.,* wild potato, wild *Vigna*, wild peanut, *Jatropha* and

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Brassica spp. (Hijmans *et al.*, 2000; Jarvis *et al.*, 2002; Dutta, 2008; Sunil *et al.*, 2009; Abraham *et al.*, 2010; Semwal *et al.*, 2013). Keeping this in view, DIVA-GIS software has been used in the present study to identify the high diversity rich and under-explored/ unexplored areas using passport data of collected germplasm.

Materials and Methods

Wheat germplasm was assembled from different wheat growing regions of India through crop-specific and multi-crop explorations in collaborative mode with ICAR crop-based institutes/State Agricultural Universities/ Krishi Vigyan Kendras by Plant Exploration and Germplasm Collection Division of National Bureau of Plant Genetic Resources (NBPGR), New Delhi, India. Germplasm collection and conservation databases, plant collection reporters, NBPGR annual reports and other published literature were used for the analysis of passport and related information. Out of 5,930 assembled accessions of three different *Triticum* spp., a total of 3,973 accessions were short-listed with detailed information pertaining to state, district, village, collector number, latitude (N) and longitude (E) of the collection sites for the present study. In order to know the spatial distribution and assessment of diversity richness, DIVA-GIS version 7.3 was used for point to grid analysis using simple/circular neighborhood method (Hijmans *et al.*, 2001).

Results and Discussion

Mapping of Collected Diversity and Collection Sites

In the present study, 2,090 villages belonging to 213 districts and 22 states were surveyed and 5,930 accessions of *Triticum* germplasm were collected. By screening the passport data of collected germplasm, only 3,973 accessions comprising of *T. aestivum* (2,745 accessions), *T. turgidum* subsp. *dicoccon* (61 accessions), *T. turgidum* subsp. *durum* (1,167 accessions) could qualify the parameters to pool for further analysis.

The analysis of information has shown that majority of the accessions were assembled from seven states. A total of 732 accessions were assembled from 397 villages of 12 districts of Himachal Pradesh. Like-wise, 652 accessions from 326 villages of 44 districts in Madhya Pradesh; 612 accessions from 379 villages of 12 districts in Uttarakhand; 554 accessions from 305 villages of 25 districts in Rajasthan; 455 accessions from 195 villages in 14 districts of Karnataka; 375 accessions from 216 villages of 22 districts in Gujarat and 279 accessions from 84 villages of 12 districts in Jammu & Kashmir (Fig. 1 and Table 1).

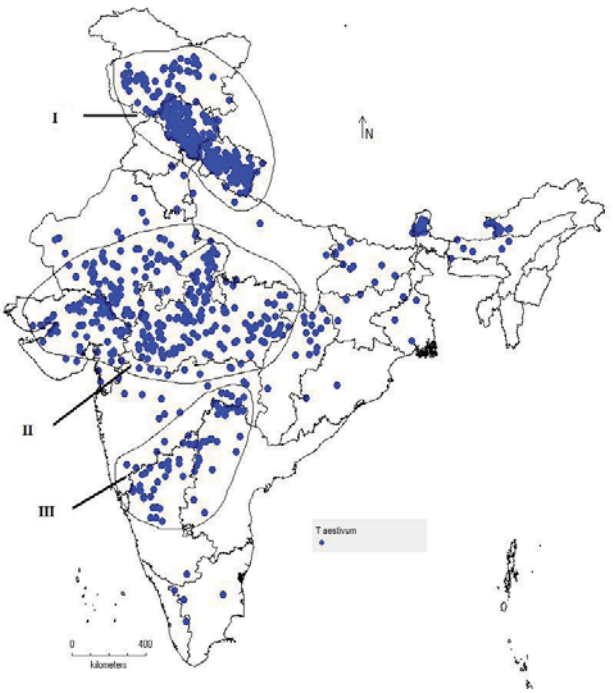

Fig. 1. Collection sites of *Triticum aestivum*

Keeping in view the diversity distribution pattern of *Triticum* species in different agro-ecological regions of the country, it was clearly observed that *T. aestivum* is under cultivation in 22 states but majority of accessions were collected from Himachal Pradesh (722) followed by Uttarakhand (611), Madhya Pradesh (377), Jammu & Kashmir (279), Rajasthan (260) and Gujarat (178) (Table 1). Analysis of the passport data indicated that *T. aestivum*, region I was extensively explored as compared to region II, whereas region III was meagerly explored (Fig. 1). For further collections, meagerly explored areas can be surveyed on priority basis. GIS mapping has successfully been used in identifying the areas of high diversity in *Phaseolus vulgaris* (Jones *et al.*, 1997), wild potato (Hijmans *et al.*, 2000), wild peanut (Jarvis *et al.*, 2002), mustard (Dutta, 2008), *Jatropha* (Sunil *et al.*, 2009), wild *Vigna* (Abraham *et al.*, 2010), eggplant (Gunjeet *et al.*, 2013) and rapeseed-mustard (Semwal *et al.*, 2013).

The emmer wheat is mainly grown in northern Karnataka, southern Maharashtra, the Saurashtra region of

Table 1. Species-wise accessions of wheat collected from different states

Species	State (accessions)	Total
Triticum aestivum	Andhra Pradesh (35), Arunachal Pradesh (48), Assam (18), Bihar (12) Chhattisgarh (19), Gujarat (178), Haryana (15), Himachal Pradesh (722), Jammu & Kashmir (279), Jharkhand (4), Karnataka (52), Kerala (1), Madhya Pradesh (377), Maharashtra (52), Manipur (1), Odisha (1), Rajasthan (260), Sikkim (48), Tamil Nadu (11), Uttarakhand (611), Uttar Pradesh (7), West Bengal (4)	2,755
T. turgidum subsp. *dicoccon*	Andhra Pradesh (1), Gujarat (11), Himachal Pradesh (2), Karnataka (31), Kerala (2), Madhya Pradesh (2), Maharashtra (4), Tamil Nadu (7), Uttarakhand (1)	61
T. turgidum subsp. *durum*	Andhra Pradesh (1), Gujarat (186), Haryana (4), Himachal Pradesh (8), Karnataka (372), Madhya Pradesh (281), Maharashtra (10), Rajasthan (294), Tamil Nadu (1)	1157
Total		3,973

coastal Gujarat, parts of Tamil Nadu and Andhra Pradesh (Hanchinal *et al.*, 2005). But presently it was seen under cultivation in about nine Indian states and from these 61 accessions could be assembled. Maximum number of accessions were collected from Karnataka (31) followed by Gujarat (11), Tamil Nadu (7), Maharashtra, Himachal Pradesh, Kerala, Madhya Pradesh, Uttarakhand and Andhra Pradesh (Table 1). The dry tracts of northwestern part of Karnataka were extensively explored (Fig. 2, encircled region I). Very few accessions were made from others areas of the country (Fig. 2 and Table 1).

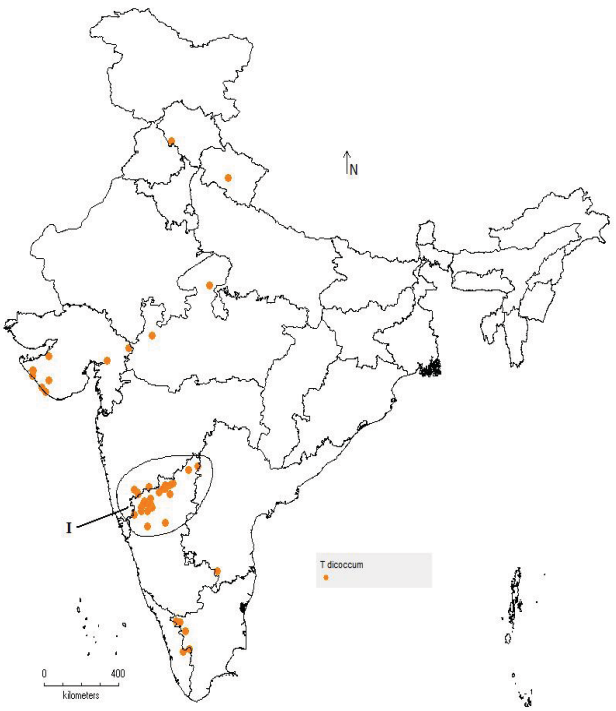

Fig. 2. Collection sites of *Triticum turgidum* subsp. *dicoccon*

Durum wheat is cultivated in a small portion of the total wheat grown area mainly under rainfed conditions in Madhya Pradesh, Gujarat, Karnataka, south Rajasthan, and Maharashtra, except in some irrigated areas of Gujarat. Efforts were made to collect 1,167 accessions in durum wheat from these states but majority of accessions were from northern Karnataka (372) followed by Rajasthan (294), Madhya Pradesh (281) and Gujarat (186) (Fig. 3 and Table 1).

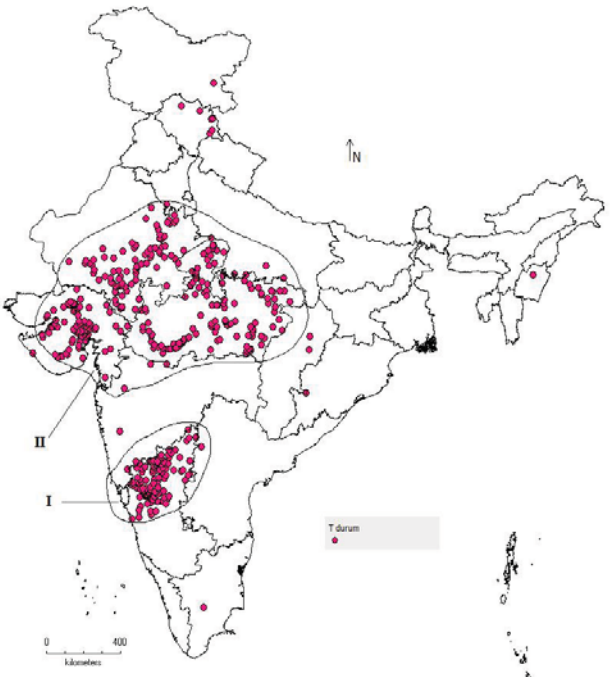

Fig. 3. Collection sites of *Triticum turgidum* subsp. *durum*

Mapping of collected diversity indicated that some of the diversity rich states viz., Himachal Pradesh, Jammu & Kashmir, Uttarakhand, Gujarat and Madhya Pradesh were extensively explored for collection of bread wheat germplasm. Similarly, Madhya Pradesh, Gujarat and Karnataka were explored extensively for collection of emmer and durum wheat. However, still

there is a scope for execution of specific explorations mainly for collection of trait-specific germplasm and wild species from under-explored/ un-explored areas in Tamil Nadu, Jharkhand, Kerala, Odisha, West Bengal and Uttar Pradesh keeping in view the availability of diverse germplasm.

Trait-specific Variability Collected

The crop landraces/local cultivars are geographically or ecologically distinctive populations, which are conspicuously diverse in their genetic composition both between populations and within them (Zeven, 1998). Wheat landraces/local cultivars have been largely displaced by high-yielding cultivars in many developing countries hence is rarely observed under cultivation due to their low yield potential and susceptibility to pests. However, landraces and old cultivars out-yield, and have better quality attributes than high-yielding cultivars under organic and low-input farming systems (Jaradat, 2011). During germplasm collection, rich variability was observed in landraces/local cultivars of wheat for different agro-morphological traits *viz.*, plant height, tiller number, ear head size, ear head types (lax/loose), awn colour (yellow, black, red or brown), awned and awnless types, grain size, grain colour (red, amber and white), shattering types, straw colour (yellow, dull yellow with brown tinge and shining yellow), etc. Different landraces/local cultivars collected from 13 states are listed in Table 2. Some of the notable landraces/local cultivars *viz.*, Kankoo and Dharmauri observed as highly non shattering types, tall and good for bread making collected from Sirmour district; tall with high tillering *viz.*, Dharnon, Shruin, Mundan, Daru and Bhangaru from rainfed areas of Mandi and Kullu districts; similarly other cultivars *viz.*, Bada kanak, Chhiti kankoo, Dharmodi, Lalpuri, Mandalum, Mundal kankoo, Shruin from Banjar, Sainj, Soja, Garsa and Parvati valleys and Mundri, Mundru, Kanku, Dharmodi, Kasyali from Hamirpur and Una districts of Himachal Pradesh (Anonymous, 1976-2012). According to Pal *et al.*, (2007) and Gupta and Lakshmi Kant, (2012), local cultivars *viz.*, Bharadoo, Chawera, Cheeuni, Desi mundal, Gazaria, Jael, Joth, Jhuladi, Kasieun, Kothek, Kothi, Kiawali, Lal kanak, Latar, Kalee bauri, Mundra, Marodum, Misri, Mundu, Paluwa, Ralieum, Rigaliya, Rundan, Trimudi are still under cultivation in different parts of Himachal Pradesh. Some of the landraces/ local cultivars *viz.*, Jael, Joth, Jhuladi, Kothek, Mundra and Rundan were assembled (Table 2).

In Uttarakhand, good variability was observed in bread wheat (*T. aestivum*) for traits like grain colour (deep amber to light amber white) and grain size, while tillering was shy (3-4) and awned types were more common. Landraces/ local cultivars in awnless types *viz.*, Lakha, Dhavati, Hansy and Donya were collected from Bageshwar districts. Safed mundri and Lal mundri considered as drought-tolerant; Jhusia, Kishva and Churi known for high yield potential; and Bhuri mundiya for high biomass were some notable collections from Uttarakhand. Among these, Mundiya landrace has been

Table 2. List of some landraces/local cultivars collected from different states

State	Landraces/Local cultivars
Andhra Pradesh	Erragoduma, Goduma, Godumalu, Goduma vadlu, Katta koduma, Machhu godumalu, Neeti godumalu and Tella goduma
Arunachal Pradesh	Buku, Feuk, Fu, Fugiri, Kangla, Kho, Koh, Nai and Rambu
Assam	Bhutia gom, Molllah gom and Ranto wheat
Gujarat	Dukhani ghau
Himachal Pradesh	Amreek gandham, Baasthi gehun, Bangla kalyan, Bariharu, Brehar, Haans, Jael, Jiri kanak, Joth, Jhuldi, Jhurti, Kali bhauri, Kali and Safed dharmodi, Kankoo, Kashmal, Keshwali, Kishaal, Kothek, Lamtara, Mundra, Rindyu, Rundan, Serohan and Sherwan
Jammu & Kashmir	Kashur kanak, Moond kanuk, Tro and Toe
Karnataka	Beligodi, Goi, Jawari kadli, Kolavi sadak, Lokapur sadak, Moolagodhi, Neeragodhi and Ravagodhi
Madhya Pradesh	Gajri, Jautri, Hasia gehun, Jalalia, Kali muchh gehun, Kacchi pissi, Kariya-sukra, Kathia gehun, Kathia, Kali pissi, Karodpati gehun, Lajya gehun, Lal kathi, Lal pissi, Mundi lal and Safed mundi
Maharashtra	Khapali gahun
Rajasthan	Gehun katha
Sikkim	Ghaow, Knoo, Menchak and Semia
Tamil Nadu	Ettagodhi, Gothumai, Mullu gothum and Sambagodhumai,
Uttarakhand	Bareek lal, Bhotia gehun, Bona, Chanosi, Chini, Churiya gehu, Cheuri, Dabdi gehun, Dapati gehun, Daulatkhani, Dhol churia, Dhudia, Dogla gehun, Donia, Dug gehun, Gerua, Gharia, Ghegua, Jhusal gehun, Jhausa, Jiswal gahun, Juinsi Ninsa, Jusia gehun, Kisala, Kontha Gainhu, Lakha Gainhu, Lal mishri, Lal sungari, Laldandi gehun, Lal kishwa, Lal mundiya, Messa, Munara, Munda, Mundania, Muneri, Munnar, Palthi gehun, Radh, Raje gehun, Ratta, Ryat gehun, Safed mundri, Safed mundiya, Setta, Syatgehun, Tank, Thaenkna, Thangi and Thull

reported to be suitable both for drought and higher biomass production (Mehta *et al.,* 2009). Some other potential landraces *viz.*, Naphal is known for softness and good quality biscuit making; Lal gehun for tastier chapati; Rata for good dalia and better fodder quality and Bhati for excellent fodder for livestock were also collected from parts of Uttarakhand. Vivekanand Parvatiya Krishi Anusandhan Shala (VPKAS), Almora has also registered a landrace 'Tank' from Uttarakhand is known for long awns and small grains, which is not damaged by monkeys (Gupta *et al.,* 2009). Some of the local landraces/local cultivars *viz.*, Chanosi, Chini, Chotia safed, Chyud, Dapti, Dhang, Dhaulia, Dualatkhani, Dudgyn, Doldakhani, Dudh, Geruwa, Intor, Kanyari, Kavjhusi, Lal misri, Lalnoi, Mangraje, Munda gehun, Munar, Naulia, Pothi, Safed jhusia, Safed misri, Setta and Thull collected are also popular in the different pockets of hills of Uttarakhand (Mehta *et al.,* 2009).

Kharchia landrace, known for salinity tolerance is largely cultivated in saline areas of Barmer and Jalore districts of Rajasthan has been utilized for the purpose. The farmers in Sirohi, Pali, Nagaur, Churu and Jhunjhunu districts of Rajasthan use brackish water reserved in wells for irrigation of wheat fields. The landraces/ local cultivars *viz.*, Bajia, Contoli gehun, Chapadia, Deshi lal, Desi safed, Dhoiti, Dhola gehun, Mangsi, Pissi, Rata, Safed kanak and Pili kanak collected from these areas could be important source to utilize as salinity tolerant germplasm. Some other notable landraces/ local cultivars *viz.*, Dholia, Kharchia, Katta, Katbajya, Moti and Teria with long ear heads were also collected from Southeast Rajasthan. Likewise, Vajya, Lal gehun, Kharchia, Sachiya and Bundiya gehun in bread wheat; Popatiya and Putra gehun in emmer wheat and Kathia, Futel, Bansi, Arnej katha, Bhatiya desi, Dant khani and Poona giri in durum wheat were collected from salinity and drought affected districts of Gujarat (Ahmedabad, Amreli, Banaskantha, Bhavnagar, Jamnagar, Junagarh, Kachchh, Porbandar and Rajkot) and Rajasthan (Barmer, Jalore, Jodhpur, Pali and Sirohi) (Anonymous, 1976-2012).

In durum wheat, a medium tall variety Kathia collected from Madhya Pradesh was distinct from local landraces. It appeared in two forms (ear head colour) on maturity, one with reddish-brown ear heads and the other with whitish-yellow ear heads, extensively grown in Chhatarpur, Damoh, Dewas, Khargone, Raisen, Rewa, Satna, Shahdol and Sidhi districts of Madhya Pradesh (Arora and Koppar, 1979). A long culmed trait of landrace/ local cultivar Jautri identified as drought tolerant was collected from dry tracts of Madhya Pradesh. Some other notable landraces/ local cultivars *viz.*, Beligodi, Goi, Jawari kadli, Kolavi sadak, Lokapur sadak, Moolagodhi, Neeragodhi and Ravagodhi grown during *kharif* season in Karnataka exhibiting variability in plant height, tillers per plant, straw colour (yellow, dull yellow with brown tinge and shining yellow), ear length and grain colour (red/deep amber) were also collected.

Future Thrust

The gaps identified during exploration and collection of *Triticum* species indicated that representation of germplasm collections from Uttar Pradesh, Punjab and Haryana states was meager because landraces/ local cultivars have been replaced by high yielding hybrid varieties that narrowed down the genetic base in the area. In such situation, collection of landraces/primitive cultivars which have been grown by the farmers for thousands years in such areas can be of great help. Moreover, collection of wild Triticeae needs to be made to broaden the genetic base. Broadly all wheat growing states have been surveyed and assembled the diversity. However, based on gaps identified in the collection and genebank holdings, trait-specific and unique germplasm need to be assembled. Traits recorded in the field by the collectors need further validation through field evaluation studies. Keeping in view the diversity assessment of wheat *vis-à-vis* germplasm collected from diverse localities, thrust would be laid on the following:

- Cultivated species with important traits identified for abiotic stresses with their presence in respective priority areas *viz.*, intensive survey for heat tolerance in arid tracts of Rajasthan, Gujarat, Madhya Pradesh and Karnataka and for cold tolerance in Nilgiri hills of Tamil Nadu, Ladakh region of Jammu and Kashmir and Lahaul and Spiti of Himachal Pradesh.
- Collection of trait-specific landraces/local cultivars from areas prone to flood, drought, salinity, heat, cold and its detailed evaluation for validation of traits.
- Collection of wild and weedy relatives of wheat (wild *Triticaceae* such as species of *Aegilops*, *Elymus* and *Eremopyrum*) distributed mainly in western/ north-western Himalaya to enhance the genetic base of the wheat.

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References

Abraham B, V Kamala, N Sivaraj, N Sunil, SR Pandravada, M Vanaja and KS Varaprasad (2010) DIVA-GIS approaches for diversity assessment of pod characteristics in black gram (*Vigna mungo* L. Hepper). *Curr. Sci.* **98**: 616-619.

Ambasta SP, K Ramachandran, K Kashyapa and R Chand (eds) (1986) *The Useful Plants of India.* Publications and Information Directorate, CSIR, New Delhi.

Annapurna K (2000) *Comparative Study on Protein and Storage Quality of Supplemented Uppuma of dicoccum and durum Wheat*. MSc Thesis, University of Agricultural Sciences, Dharwad, Karnataka, India.

Anonymous (1976-2012) Annual Reports of *National Bureau of Plant Genetic Resources (NBPGR)*, 1976-2012, NBPGR, New Delhi, India.

Arora RK and MN Koppar (1979) *Collection of Local Wheat Germplasm from Madhya Pradesh.* National Bureau of Plant Genetic Resources (NBPGR), New Delhi.

Dutta S (2008) Remote sensing applications to agriculture with special reference to mustard. In: A Kumar, JS Chauhan and C Chattopadhyay (eds) *Sustainable Production of Oilseeds Rapeseed-mustard Technology*. Agrotech Publishing Academy, Udaipur, Rajasthan, pp 495-500.

Gill BS, R Appels, AM Botha-Oberholster, CR Buell, JL Bennetzen, B Chalhoub, F Chumley, J Dvorak, M Iwanaga, B Keller, W Li, WR McCombie, Y Ogihara, F Quetier and T Sasaki (2004) A Workshop Report on Wheat Genome Sequencing: International Genome Research on Wheat Consortium. *Genetics* **168**:1087-1096.

Gunjeet, N Sivaraj, V Kamla, KK Gangopadhyay, S Pandey, SK Tiwari, NS Panwar, BL Meena and M Dutta (2013) Diversity analysis in eggplant germplasm in India using DIVA-GIS approach. *Indian J. Hort.* **70**: 519-525.

Gupta A, L Kant, V Mahajan, S Saha and HS Gupta (2009) 'Tank': local land race of wheat for protection of wheat field against monkey raids–an indigenous technological knowledge. *Curr. Sci.* **96**: 467-468.

Gupta RK (2004) Quality of Indian wheat and infrastructure for analysis. In: AK Joshi, R Chand, B Arun and G Singh (eds) *A Compendium of the Training Program on Wheat Improvement in Eastern and Warmer Regions of India: Conventional and Non-conventional Approaches.* NATP project, (ICAR), Banaras Hindu University, Varanasi, Uttar Pradesh, (26–30 December, 2003).

Gupta HS and Lakshmi Kant (2012) Wheat improvement in northern hills of India. *Agri. Res.* **1**: 100-116.

Hanchinal RR, BN Patil, LK Kalappanavar, KK Math, HC Lohittashwa, SA Desai and BY Nirmala (2005) *Fifty Years of Wheat Research in Karnataka*, AICRP on Wheat, University of Agricultural Sciences, Dharwad, Karnataka, pp 1-2.

Hijmans RJ, KA Garrett, Z Huaman, DP Zhang, M Schreuder and M Bonierbale (2000) Assessing the geographic representativeness of genebank collections: the case of Bolivian wild potatoes. *Conserv. Biol.* **14**: 1755-1765.

Hijmans RJ, L Guarino, M Cruz and E Rojas (2001) Computer tools for spatial analysis of plant genetic resources data: 1. DIVA-GIS. *Plant Genet. Resour. Newsl.* **127**: 15-19.

Hijmans RJ and DM Spooner (2001) Geographic distribution of wild potato species. *Am. J. Bot.* **88**: 2101-2112.

Jaradat AA (2011) Wheat Landraces: Genetic Resources for Sustenance and Sustainability USDA-ARS 803, Iowa, USA.

Jarvis A, L Guarino, D Williams, K Williams, I Vargas and G Hyman (2002) Spatial analysis of wild peanut distributions and the implications for plant genetic resources conservation. *Plant Genet. Resour. Newsl.* **131**: 29-35.

Jones PG, SE Beebe, J Tohme and NW Galway (1997) The use of geographical information systems in biodiversity exploration and conservation. *Biodiv. Conserv.* **6**: 947-58.

Mehta PS, KC Muneem and KS Negi (2009) Traditional wheat (*Triticum aestivum* L.) genetic resources for subsistence in district Pauri of Uttarakhand. *Indian J. Plant Genet. Resour.* **22**: 70-73.

Pal D, S Kumar and JC Rana (2007) Collection and characterization of wheat germplasm from North-west Himalaya. *Indian J. Plant Genet. Resour.* **20**: 170-173.

Rane J, J Shoran and S Nagarajan (2000) Heat stress environments and impact on wheat productivity in India: guestimate of losses. *Indian Wheat Newsl.* **6**: 5-6.

Semwal DP (2009) Geographic information system (GIS): A tool for the ecological modelling, *The Botanica* **57**: 42-45.

Semwal DP, DC Bhandari, KC Bhatt and Ranbir Singh (2013) Diversity distribution pattern in collected germplasm of rapeseed-mustard using GIS in India. *Indian J. Plant Genet. Resour.* **26**: 76-81.

Sharma SN, VK Bhatnagar, MS Mann, US Shekhawat and RS Sain (2002) Maximization of wheat yields with a unique variety in warmer areas. *Wheat Inform. Ser.* **95**: 11-16.

Singh SK, S Kundu, Dinesh Kumar, K Srinivasan, D Mohan and S Nagrajan (2006) Wheat. In: BS Dhillon, S Saxena, A Agarwal, RK Tyagi (eds) *Plant Genetic Resources: Foodgrain Crops*. Narosa Publishing House, New Delhi, India, pp 58-89.

Stone PJ and ME Nicolas (1995) Effect of timing of heat stress during grain filling on two wheat varieties differing in heat tolerance. I. Grain growth. *Aust. J. Plant Physiol.* **22**: 927-934.

Sunil N, N Sivaraj, K Anitha, B Abraham, Vinod Kumar, E Sudhir, M Vanaja and KS Varaprasad (2009) Analysis of diversity and distribution of *Jatropha curcas* L. germplasm using geographic information system (DIVA-GIS). *Genet. Resour. Crop Evol.* **56**: 115-119.

Zaharieva M, NG Ayana, A Al Hakimi, SC Misra and P Monneveux (2010) Cultivated emmer wheat (*Triticum dicoccon* Schrank), an old crop with promising future: a review. *Genet. Resour. Crop Evol.* **57**: 937-962.

Zeven AC (1998) Landraces: a review of definitions and classifications. *Euphytica* **104**: 127-139.