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Review Article

DIVERSITY IN PEARL MILLET [*PENNISETUM GLAUCUM* (L.) R. BR.] AND ITS MANAGEMENT

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ABSTRACT
Success in plant breeding depends largely on the extent of genetic variability available to a breeder. Pearl millet originated and domesticated in the Sudano-Sahelian Zone of West and Central Africa. Pearl millet germplasm has been extensively used in the development of pearl millet varieties. The greatest impact of germplasm utilization on pearl millet has been on the hybrid front. The pearl millet hybrid era in India started in 1962 with the introduction of the male-sterile line Tift 23A from Tifton, Georgia, USA. Five hybrids based on this line were released during 1965-69. The major thrust in pearl millet is to improve yield potential in fragile arid regions. Indian landraces provide excellent sources of early maturity, better tillering, and shorter height, while African sources, particularly those from the West African region, provide excellent sources of larger head volume and seed size, higher degrees of resistance to diseases, and better seed quality. The most useful germplasm that instilled desirable variability to breeding programs for earliness has come from *Iniadi*, a productive, bold seeded and early-maturing landrace from Benin, Burkina Faso, Ghana and Togo. During the 1920s and 1930s pearl millet germplasm was collected and maintained at Coimbatore and Niphad, during the 1960s at New Delhi. Since 1970s the responsibility to collect, maintain, conserve, document and distribute Pearl millet genetic resources is entrusted to ICRISAT. By the end of 2006, the genebank at ICRISAT had 21,594 accessions of pearl millet from 50 countries.

The genetic resources management has two important aspects – germplasm conservation and its optimum utilization in crop improvement. Germplasm can be conserved *in situ* by establishing 'reserves' or *ex situ* by assembling collections through exchange or exploration. Some of the constraints realized in optimum utilization of germplasm are lack of detailed evaluation of available germplasm accessions held in genebank. Also many wild and related species are difficult to maintain due to differences in their adaptability and seed biology/dormancy.

Although a large number of accessions have been assembled their management for effective use has become difficult. Therefore core germplasm collections and mini core germplasm collections have been developed in pearl millet. Lack of information on traits of economic importance is also the reason that plant breeders are using less basic germplasm in research. In this review challenges like Loss of genetic diversity due to monocultures following green revolution and climate change has also been discussed. Though a well-established mechanism for distribution of the genetic resources is already in place, satisfactory and sufficient feedback regarding utilization of germplasm is lacking and needs attention. Hence more catalogues regarding the potential value of the germplasm conserved should be published and widely circulated. Although databases have been developed, there is an urgent need for linking of these databases and creating a national database so that the information on passport data is easily available.
Key words: Pearl millet, *Pennisetum glaucum*, *Diversity, germplasm management*

INTRODUCTION
The Indian gene centre holds a prominent position among the 12 mega-gene centers of the world and is also one of the Vavilovian centers of origin and the diversity of crop plants. About 166 species of crops including 25 major and minor crops have originated and/or developed diversity in this part of the world.

Millets are small grained, annual, warm weather cereals of grass family that are adapted to harsher environments and diverse cultural and agro-climatic situations. The word millets was used to connote eight crops; Great millet (*Sorghum bicolor*), Pearl millet (*Pennisetum typhoides*), Finger millet (*Eleusine coracana*), Foxtail millet (*Setaria italica*), Proso millet (*Panicum miliaceum*), Little millet (*Panicum* *miliare*), Barnyard millet (*Echinochloa colona*) and Kodo millet (*Paspalum scrobiculatum*). Millet crops have been dominant components of rainfed agriculture on a regional basis in India. Western arid/semi-arid region including Rajasthan, Gujarat as well as Saurashtra region, possesses rich diversity for pearl millet, sorghum, wheat (drought and salinity tolerant types), guar, mothbean, cowpea, blackgram and mungbean. Following green revolution in India, introduction of high yielding/modern varieties in major crops (rice, wheat, maize and millets), many of the landraces and primitive cultivars have already vanished and some are on the verge of it, due to their abandonment by farmers. The remaining ones are genetically deteriorating gradually due to hybridization, selection or genetic drift. It is, therefore the immediate requirement to assess, collect and maintain them in suitable environments and conserve in National Gene Bank.

STATUS

Success in plant breeding depends largely on the extent of genetic variability available to a breeder. Therefore collection, evaluation, utilization, and conservation of genetic resources assume considerable significance, especially in view of the rapid environmental degradation and exploitation of the available genetic wealth all over the world. Pearl millet [*Pennisetum glaucum* (L.) R. Br.] originated and was domesticated in what is now the Sudano-Sahelian Zone of West and Central Africa. Later it migrated to semi-arid areas of both South Asia and southern and eastern Africa at least a millennium ago. Although West Africa remains the center of maximum genetic diversity, there has been considerable evolution of the crop in its secondary centers of diversity, both due to the effects of climatic differences, and to conscious and creative human selection. As a result this crop is endowed with enormous genetic variability for yield components, adaptation, and quality traits. This variability has evolved as a result of natural selection for adaptation to diverse agro-ecological environments and with human selection for local preferences. Porteres (1976) attributed racial variation patterns in pearl millet to independent domestications and migrational events. The crop was introduced into India, which is a secondary center of diversity, through early human migration, (Purseglove 1976).

Germplasm collection: During the 1920s and 1930s pearl millet germplasm was collected and maintained at Coimbatore and Niphad, during the 1960s at New Delhi. After the drought of 1969-1974, threatened sorghum and pearl millet, collection and conservation of these crops were taken up by IBPGR in collaboration with ORSTOM, a French Organization For Scientific Research Overseas, *Institut Francais de Recherche Development en Cooperation*, and since 1970s the responsibility to collect, maintain, conserve, document and distribute Pearl millet genetic resources is entrusted to ICRISAT. In India, germplasm was collected in collaboration with scientists from the National Bureau of Plant Genetic Resources (NBPGR), All India Coordinated Pearl Millet Improvement Project (AICPMIP), Agricultural Universities, and other ICAR Institutes. The materials so collected were shared by ICRISAT, AICPMIP/NBPGR, and Agricultural Universities. By the end of 2006, the genebank at ICRISAT had 21,594 accessions of pearl millet from 50 countries, including 750 accessions belonging to 24 species of genus *Pennisetum*. This formed the single largest collection of pearl millet germplasm assembled at any one place in the world (Upadhyaya *et al.,* 2007).

Diversity in the collection

Assessment of diversity in 21,594 pearl millet accessions from 50 countries for 23 morphoagronomic traits revealed large variability for days to flowering (33 to 159 days), plant height (30 to 490 cm), tillers plant^{-1} (1 to 35), panicle length (5 to 135 cm), and 1000-seed weight (1.5 to 21.3 g). The phenotypic diversity index ranged from 0.427 (tiller number) to 0.772 (endosperm structure) with a mean of 0.528 (Upadhyaya *et al*., 2007).

Wild Relatives

Genus *Pennisetum* is polybasic with x=5,7,8, and 9. In the x=5 type, 2n=10 was observed in *P.ramosum* only. In the x=7 type, 2n=14 was observed in *P. glaucum, P. violaceum, P.mollissimum,* and *P. schweinfurthii* while 4x=28 was observed in *P. purpureum.* In the x=8 type, 2x=16, and 4x=32 were observed in *P. mezianum.* In the x=9 type, 2x=18 and 3x=27 were observed in *P. hohenackeri* and 3x=27 in *P. setaceum.* Tetraploid number 4x=36 was observed in *P. mecrorum, P. divisum, P. cenchroides, P.*

clandestinum, P.pedicellatum, and *P. orientate,* while 5*x=45* was observed in *P. villosum.* The species *P. squamulatum,* and *P. polystachyon* showed 6x=54 chromosomes, while the highest chromosome number (68) was observed in the species *P. macrostachyum* only. The species *P. schweinfurthii* is valued for its large grains and waxy coating, *P. purpureum* for forage and *P. clandestinum* as pasture, *P. setaceum* and *P.villosum* as ornamentals, and *P. hohenackeri* for thatching and rope making (ICRISAT 1988).

Geographic Diversity and Adaptation

Considerable diversity was observed in the pearl millet germplasm which might have evolved to adapt to the diverse agroclimatic conditions in India. For example, very early maturing types with profuse nodal tillering were grown on the sand dunes of Haryana and Rajasthan, where soil moisture is a limiting factor. In contrast, the long-duration types of pearl millet are grown in the tribal areas of the Eastern Ghats. Desert types of Rajasthan and Gujarat have short cycle of 60 days and represent day neutral millets. The Chadi type from Rajasthan and Bhilodi of Gujarat represents desert types and Pittaganti type grown by hill tribes of the Eastern Ghats represent early types in India.

Pearl millet germplasm and variety development

Pearl millet germplasm has been extensively used in the development of pearl millet varieties. The variety development era can be divided into Pre-HYV period (before 1965) and Post HYV period (after 1965)

Pre HYV period: (Before 1965): Using mass selection Co 1 was developed in 1939, Co 2 in 1940, Co 3 in 1942, Jakhrana in 1950, Co 4 in 1953, Co 5 in 1954, RSK and RSJ in 1956 and S530 in 1965. Ghana, Pusa moti, Co 1 and S530 were developed from from African material (Harinarayana and Rai 1989), while others were developed from Indian landraces.

Post HYV period (after 1965): *Open Pollinated Varieties*: From World Composite from Nigeria, Popular variety WC-C 75 was developed in 1982. ICMS 7703 was developed in 1985 at ICRISAT by intercrossing seven partial inbreds derived from single-cross populations involving mostly breeding lines of Indian and African origin. RCB 2 resulted from half-sib selection from Indian landraces at Sukhadia University, Durgapura at Jaipur, PSB 8 (developed from 60 inbreds of Indian x Indian crosses), HC 4 (derived from 7 inbreds of Indian x African crosses. A commercially successful early maturing open-pollinated variety ICTP 8203 was developed in 1988 from landrace from Togo for cultivation in Maharashtra and Andhra Pradesh. A bold seeded early composite (BSEC) was developed from 'iniadi' landrace. From C3 cycle of BSEC, ICMV 221 was developed in 1993. This landrace has also been utilized in crossing with a smut resistant composite (SRC), for developing an open pollinated variety CZ-IC 923. This OPV was collaboratively developed by ICRISAT and CAZRI, Jodhpur, and released for cultivation in the north-western states (Manga, 2000). Later on another open pollinated variety CZP 9802 was developed by random mating 14 early maturing and high yielding full-sib progenies of a population that was developed from crosses involving early maturing and high tillering material from Rajasthan. This variety was notified for cultivation in 2003 for hyper arid (A_1 zone) areas of western Rajasthan, Gujarat and Haryana. Other open pollinated varieties developed are JBV-2 developed at Gwalior from Early Composite 91. HC 10 was developed in Hisar from early flowering and drought tolerant New Elite Composite (NELC), JBV 3 (GICKV 96752) was developed collaboratively by Gwalior and ICRISAT from cycle 3 of SRC II, while ICMV 155, a dual purpose variety was bred from 59 plants of NELC C4 selected at Patancheru.

Hybrids and parents: The greatest impact of germplasm utilization on pearl millet has been on the hybrid front. The pearl millet hybrid era in India started in 1962 with the introduction of the male-sterile line Tift 23A from Tifton, Georgia, USA. Five hybrids based on this line were released during 1965-69. Of these, HB 3 released in 1968, was the most popular and was extensively cultivated. Its pollen parent J104 was derived from the Indian germplasm. Three hybrids were released in 1977. BJ 104 and BK 560 were based on male-sterile line 5141A and CJ 104 was based on 5054 A. Both BJ 104 and CJ 104 involve J 104 as pollen parent. The pollen parent of BK 560 (K560-230) was also developed from Indian germplasm. The nuclear genome of 5141A is also derived from Indian germplasm whereas that of 5054 A involves African germplasm. GHB 27 is based on 5141A and pollen parent J 2002 and GHB 32 is based on 5141 A and pollen parent J 1188. Both pollen parents are derived from Indian germplasm. MBH 110 is based on parental lines developed from materials bred at the Serere Research station, Uganda. Female parent of hybrid ICMH 451 (81A) is related to Tift23D2A1, and its pollen parent (ICMP 451) is a derivative of Late Composite developed at ICRISAT. GHB 30 is based on 5054A and J 2002 (derived from Indian germplasm). ICMH 423 is based on 841A (related to 5141A) and ICMP 423 (derived from Early Composite) developed at ICRISAT. MH 169 is based on 841A and D 23 (pollen parent is a downy mildew resistant selection from K 560-230). HHB 67 is based on 843A and H 77/833-2. This hybrid is highly popular in north western India, because of its extra early maturity. Its pollen parent is selected from a landrace from western Rajasthan. Similarly pollen parents of hybrids GHB 732 (J 2340), GHB 744 (J 2340), GHB 757 (J 2467), GHB 719 (J 2454), GHB 577 (J 2405), GHB 558 (J 2290), GHB 538 (J 2340) and GHB 526 (J 2372) have been derived from Indian germplasm. Early efforts between 1961 and1962 at Punjab Agricultural University, Ludhiana led to the development of two male- sterile lines (L66A, L67A). The cytoplasm of L66A (later named $L66A_2$) was derived from a genetic stock IP 189 originating from Malawi. The cytoplasm of L67A (later named $L67A_3$) was derived from a population of a natural cross involving an African germplasm. Another male-sterile line (PT 732A) developed at Tamil Nadu Agricultural University, Coimbatore, derives its cytoplasm from a landrace material from Andhra Pradesh and is claimed to be different from Tift23A1. Two male sterile lines CZMS 44A and CZMS 47A developed at CAZRI, Jodhpur had nuclear genome form local germplasm collected from Barmer (Pachpadra) of Rajasthan (Manga and Yadav, 1997). These male sterile lines have been found to be highly drought tolerant and have high degree of adaptation to harsh arid environment. Recently, several sources of cytoplasmic male-sterility (cms) have been identified in diverse germplasms. These are A4 cytoplasm transferred from a wild grassy subspecies, *P. glaucum* subspecies *monodii* (Hanna, 1989, 1996) and A5 cytoplasm (Rai 1995).

Landraces

Landraces are primitive varieties, which have been evolved without systematic and sustained plant breeding efforts. They possess novel genes for adaptation, disease resistance and other agronomically important traits (Ceccarelli 1994). Pearl millet, because of its tolerance to high temperature and better ability to withstand drought and to grow even in low soil fertility conditions, it is best suited for arid and semi-arid regions of the country. The major thrust is to improve yield potential in fragile arid regions. This may be achieved either through direct selection of landraces/germplasm lines or by developing populations/hybrids that are adapted to such environments and provide higher yield of both grain and fodder. Indian landraces provide excellent sources of early maturity, better tillering, and shorter height. In contrast, African sources, particularly those from the West African region, provide excellent sources of larger head volume and seed size, higher degrees of resistance to diseases, and better seed quality. Use of the African germplasm in almost all Indian National programs has substantially contributed to the diversification of the genetic base of breeding programs. Two large-seeded male-sterile lines (863A, ICMA 88004) with high hybrid yield potential and downy mildew resistance were developed directly from a landrace originating from Togo. The most useful germplasm that instilled desirable variability to breeding programs for earliness has come from *Iniadi*, a productive, bold seeded and early-maturing landrace from Benin, Burkina Faso, Ghana and Togo. Evaluation of landraces of pearl millet collected from Rajasthan revealed a high degree of variation. The landrace accessions identified for earliness were SR 15, SR 17 and SR 54. The Chadi landrace from Rajasthan and Bhilodi of Gujarat represent desert types, and the Pittaganti type, grown by the hill tribes of the Eastern Ghats, represents a unique early type in India (Anand Kumar and Appa Rao 1987). Landraces SR 40, SR 121 and SR 33 were the best for tallness; SR 75, SR 74 and Desi Chothina for high productive tillering; and Sulkania and Jhakrana for long panicles. Landraces Dhodsar (Sunda Ram), Jhakrana (ex-situ), Sulkania (ex-situ) and SR 54 were identified for long sheath length, the blade length and width contributing directly to the production as well as quality of the fodder. Evaluation of core collection accessions indicated a wider range for all the traits studied. Accessions IP 4066, IP 9496 and IP 9426 were promising for earliness at Jaipur. Very high variability was observed for plant height and accessions IP 3616, IP 19190, IP 19405, IP 13150 and IP 5452 were identified as very tall. These accessions may be used as parents to develop potential pearl millet forage hybrids/population. Accessions IP 13645, IP 15273 and IP 17493 had high productive tillering when evaluated at Mandor. The number of total tillers per plant is also an important trait that contributes to high biomass. Accessions found to have high total tillering were IP 6148 and IP 15257 at Mandor. Accessions IP 5447, IP 10273 and IP 12848 at Mandor and IP 10456 at Jaipur were promising for panicle length; IP 7935 and IP 5396 at Mandor and IP 18797 and IP 15917 at Jaipur were promising for panicle thickness. Anand Kumar and Appa Rao (1987) reported that panicle length varied from 4 cm in oasis millets to 200 cm in Zongo of Niger. Panicle density was recorded on a 1–9 scale and varied from 1 (very loose) to 9 (very compact); accessions IP 14100 and IP 8350 at Mandor, and IP 14160 at Jaipur were identified as very compact. The grain size of accessions varied considerably and accessions IP 11893, IP 19160, IP 10705 and IP 14160 were found promising at Jaipur. Anand Kumar and Appa Rao (1987) reported grain size up to 19 g 1000^{-1} grain in accessions from Ghana and Togo. Accessions IP 15304, IP 3616 and IP 6125 at Mandor, IP 13885 and IP 6146 at Jaipur, and IP 6897 at Jamnagar were identified as promising for green fodder potential and IP 17350 and IP 3150 at Mandor and IP 17945 and IP 7095 at Jaipur were identified as promising for grain yield potential. Accessions IP 16131, IP 22281 and IP 15817 at Mandor and IP 17945 and IP 7095 at Jaipur were identified as promising for overall plant aspect (Khairwal et al., 2007). Wide genetic variability for salinity tolerance has been reported in pearl millet (Dua and Bhattacharya 1988; Ashraf and McNeilly 1992; Chopra and Chopra 1997). Another study of 169 landraces collected from 18 districts of Rajasthan during the crop seasons of 1999–2003, revealed that it should be possible to select landraces from different regions with various combinations of morphological traits. Bristles were more frequently observed in landraces from western Rajasthan. Nodal tillering provides developmental plasticity to landraces and is an important component of adaptation mechanism to the harsh growing environments (van Oosterom et al. 2003). These were found to be slightly higher in western Rajasthan landraces. An assessment of genetic diversity within and between pearl millet landraces using RFLP probes revealed high within-accession variability (30.9%), but the variability between accessions was significantly higher (69.1%) than that within the accessions (Bhattacharjee Ranjana et al., 2002).

In Haryana, an important pearl millet growing state, primitive cultivars are still grown in isolated/ remote areas, especially on sand dunes around Loharu , Narnaul , Chiriya , and other areas. A primitive type called "*bajri*" grows to a height of about 125 cm, and produces many very thin stems with sequential maturity of spikes. A dual-purpose form called "dholsari" is grown around Choudhari-ki-Nangal for grain and fodder. It grows over 3 m tall, produces very thick stems and dark green leaves. Further, some special forms which produce spikes more than 40 cm long were found around Narnaul, Pilani in Rajasthan, and in some isolated areas.

Management of Genetic Resources

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) originated and domesticated in the Sudano-Sahelian Zone of West and Central Africa. It later migrated to semi-arid areas of both South Asia and southern and eastern Africa at least a millennium ago. Although West Africa is the center of maximum genetic diversity, there has been considerable evolution of the crop in its secondary centers of diversity, due both to the effects of climatic differences and to conscious and creative human selection. As a result this crop is endowed with enormous genetic variability for yield components, adaptation, and quality traits, which evolved as a result of natural selection for adaptation to diverse agroecological environments along with human selection for local preferences. Diversity of cropping systems also contributed to the variation and differentiation among landraces.

Germplasm constitutes the total gene pool of a species consisting of landraces, advanced breeding lines, popular cultivars, wild and weedy relatives. It forms raw material for any crop improvement program. Realizing the importance of germplasm and to guard against the loss of valuable diversity, intensive collection of different crop species were undertaken by the global community. As a result over 7.4 million *ex-situ* germplasm accessions are conserved in ~1750 gene banks globally of which ~ 11% are in the gene banks of various CGIAR institutions. These genetic materials comprise of landraces, traditional varieties, wild and weedy forms, related wild species, genetic stocks, inbred lines and even our modern cultivars.

The genetic resources management has two important aspects – germplasm conservation and its utilization in crop improvement. Germplasm can be conserved *in situ* by establishing 'reserves' or *ex situ* by assembling collections through exchange or exploration. Maintenance is done by monitoring and protecting the reserves or storing the seed and periodically rejuvenating it, *ex situ,* in controlled conditions along with maintaining passport data, etc. The evaluation involves assaying germplasm for agronomic traits that interact with the environment. Further the germplasm is enhanced by introgressing high value traits from exotic germplasm into adapted varieties (Bretting and Widrlechner, 1995) through pre-breeding

In-Situ Conservation

In situ conservation ensures that the genetic diversity available in the genetic resources rich areas is conserved, while allowing the evolutionary process to continue. In this system, farmers get ample time to observe and make adjustments and to absorb innovations into their farming systems. On-farm conservation is also important in enabling indigenous varieties to adapt to the changing climate. Farmers' use of crop genetic diversity represents a system of *in situ* conservation. The importance of *in situ* conservation lies in the recognition that only a fraction of the total potentially useful genetic diversity to be utilized by the plant breeder is stored in gene banks. In addition, farmer's practices of seed production, selection, storage and exchange in combination with natural selection pressure allow crop evolution to continue. This provides the local crop materials with a genetic adaptation that forms the basis of farmers' sustainable livelihood. Crop genetic diversity that is managed by farmers in marginal areas, i.e. areas characterized by a complex combination of stresses, may form source of important genes and gene combinations for future crop improvement. Activities that directly support farmers from the perspective of *in situ* conservation are: community seed banks, local germplasm collections, and reintroduction of local varieties.

Community seed banks

Community seed banks (CSB) refer to collections of seed that are maintained and administered by the communities themselves, i) to ensure the availability of planting material (relatively large samples of seed), or ii) to ensure the availability of genetic material in situations in which varieties are lost (relatively small samples of seed). Both objectives aim at increasing local seed security, thereby contributing to the possibilities of continued utilization of locally important genetic diversity.

Local germplasm collections and living gene banks

The main objective behind the maintenance of local germplasm collection is to improve farmers' access to genetic diversity. Established gene banks may be too far away or may even not exist in a country. And, even if they are willing to comply with a request from an NGO or farmers' group, gene banks can only provide small seed lots. A large number of NGOs maintain *(ex situ)* germplasm collections. The Swaminathan Foundation in India, have collections that are actively used for participatory experimentation and evaluation in farmers' fields. The NGOs CONSERVE in Mindanao, and SEARICE in Bohol, maintain local collections of crop genetic diversity. In addition to storing the seeds in their own facilities, farmer-collaborators have been told to plant and maintain a number of varieties. The number of varieties that a farmer plants, varies but, collectively, the farmers maintain a collection *in situ*, forming a living gene bank.

Reintroduction of local varieties

For *ex situ* and *in situ* management of PGR to be truly complementary conservation strategies, there must be a link between farmers and *ex situ* collections (national and international gene banks, breeding institutes): to rescue materials that are no longer attractive for farmers and to reintroduce *ex situ* stored materials when necessary. Materials from germplasm collections can be included in community evaluation trials, and farmers may be invited to visit and select from field-grown demonstration plots. Reintroduction can also be part of seed relief programmes in areas where farmers may have lost their varieties due to war and natural disasters. The bottleneck in reintroductions from *ex situ* collections is the small size of seed samples, which are usually maintained *ex situ*. This is a reason for gene banks and other

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institutions that maintain *ex situ* germplasm to establish links with other organizations, such as NGOs, that can assist in the multiplication and distribution of reintroduced materials.

Genetic Resources Management in Rajasthan

Because of low erratic and uneven distribution of rainfall in western Rajasthan, pearl millet crop frequently faces drought leading to poor plant population or fails to emerge from soil, if it rains heavily following sowing, prompting multiple sowings. For this farmers must acquire their seed from other villages within the region. A preferred source under such situations is those farmers with a reputation for quality seed. The seed system analysis of pearl millet in Rajasthan revealed a specific need for preserving the original western Rajasthan landrace type, for the specific benefit of poor farmers, farming mostly poor quality land (Christinck, 2002). The pearl millet mating system in conjunction with farmers' seed management and regional exchange activities has led to regionally similar but highly heterogeneous populations, as reflected in the results of the AFLP analysis. The low inter- and high intra-population diversity of the landraces suggests that populations managed on farm could form the basis of *in-situ* maintenance projects for pearl millet landraces in western Rajasthan. The marker analysis indicated diversifying selection to be weak in western Rajasthan.

In eastern Rajasthan, the uniqueness of landrace types is linked to specific village situations, i.e., it can only be maintained within the village. The molecular marker study supported farmer's claim that they maintain individual landraces types. On the basis of this information, future in situ conservation projects for eastern Rajasthan could focus on the maintenance of specific landrace types and should be centered on villages renowned for their specific landrace type.

For promotion of *in-situ* conservation there is a need to validate information about the usage of wild species for food or other purposes. This can be achieved through participation of communities and promotion of village level gardens of local diversity (Agrawal *et.al*., 2006).

Farmers as managers of crop genetic diversity

Farmers are the principal managers of crop genetic diversity. They develop agricultural crops and varieties from wild plants through crop cultivation. They decide which crops and varieties to plant; select and store seeds for next season; and exchange seeds with other farmers from the same or other communities to obtain new or lost varieties, and to replace degenerated varieties. Farmers' seed production, selection, storage and exchange, in combination with natural crossing between varieties and wild species, mutations and environmental conditions, represents an integrated, dynamic and evolving Plant Genetic Resource (PGR) system. Hence, farmers produce food and seeds, while at the same time they practice a form of crop development and maintain genetic diversity *in situ*. Crop genetic diversity that is managed by farmers in marginal areas, i.e. areas that are usually characterized by a complex combination of stresses, may in particular provide important genes and gene combinations for future crop improvement.

***Ex-situ* Conservation**

A wide range of diversity in genetic resources is threatened to go extinct. The agents of genetic erosion include drought, diffusion of advanced cultivars, crop replacement, diseases and pests, deforestation, and land-use change. Genetic erosion is mainly caused by massive and wholesale eradication of breeding materials over thousands of square miles of arable land (monoculture). High yielding varieties (hybrid/populations) have replaced thousands of traditional, drought- and pest-resistant varieties, which are facing the threat of extinction. This loss of native crop landraces and cultivars prompted the Food and Agriculture Organization (FAO) and the World Bank to create new institutions for the collection and preservation of plant genetic resources - the *ex-situ* gene banks. Over six million germplasm accessions have been collected and/or assembled and conserved worldwide in 1,308 genebanks (FAO 1998). The Indian National Genebank presently holds more than 3,00,000 accessions of germplasm belonging to about 600 species (Upadhyaya et.al., 2009). In addition, there are more than 50 National Active Germplasm Sites (NAGS) as integral part of national plant diversity conservation network. Gene banks were established in an effort to mitigate the risks of monoculture and they have since become the centers of *ex-situ* (off-site) conservation. Although monocultures are promoted for cultivation by farmers, the *ex-*

situ gene banks conserve the germplasm, but this is largely a one-way collection. It excludes the farmer's critical role as conservers of genetic diversity and innovators in the use and development of biodiversity.

Pearl millet germplasm management at genebanks

The responsibilities to collect, maintain, conserve, document and distribute pearl millet genetic resources were entrusted with ICRISAT. Presently ICRISAT has the largest collection of pearl millet germplasm. By the end of 2006, the genebank at ICRISAT had 21,594 accessions from 50 countries, including 750 accessions belonging to 24 species of genus *Pennisetum*. Pearl millet collection includes samples from institutions (10,201 accessions), farmers' fields (6,537 accessions), commercial markets (1,681 accessions), farmer's stores, (1,357 accessions), threshing floors (479 accessions) apart from wild species (750 accessions). Biological status of accessions indicates presence of landraces (18,447), breeding materials (2,268), advanced cultivars (129) and wild relatives (750) in the collection. These include 2141 collections from the Rockefeller Foundation and ALAD. These collections are subjected to, phenotypic characterization and evaluation, **c**onservation, regeneration, and documentation. For safety purpose as per FAO agreement germplasm collections are conserved in countries outside India at –18 ^{o}C. For benefit of the scientists germplasm data is uploaded on the online genebank management system.

Pearl millet germplasm distribution

Since 1974, ICRISAT have distributed 59,558 samples to scientists in India and 30,015 samples in 79 other countries, while 38,507 samples have been distributed to researchers working in different disciplines at ICRISAT. A very early flowering accession from Gujarat, India was IP 4021was distributed 106 times followed by Sogue landrace from Mali (IP 6271) and Jakhrana landrace (IP 3122) from India), both 87 times (Upadhyaya *et al*., 2009).

Constraints in germplasm utilization

Some of the constraints realized in optimum utilization of germplasm are lack of detailed evaluation of available germplasm accessions held in genebank. Also, there has been intense genetic erosion of primitive types and landraces. Many wild and related species are difficult to maintain due to differences in their adaptability and seed biology/dormancy. Most wild species are not easily crossable with cultivated species. However, use of new biotechnology tools has resulted in development of few inter-generic and inter-specific varieties in some of the crops. Moreover, the genes carrying resistance/tolerance to stresses in wild relatives are linked with undesirable genes that slow down the progress in breeding. Although in most of the crops, a large number of accessions have been assembled their management for effective use has become difficult. Core germplasm collections and mini core germplasm collections have been developed in pearl millet. Therefore, there is a need for strengthening the application of techniques like development of gene pools, core collections, trait specific core sets, etc. (NBPGR 2007).

Enhancing germplasm utilization

The assessment and characterization of diversity in germplasm collections is important to plant breeders for crop improvement. One of the reasons that plant breeders are using less basic germplasm in research, is the lack of information on traits of economic importance, which often show high genotype x environment interactions and requires replicated multilocational evaluation. This is a very costly and resource-demanding task owing to the large size of the germplasm collections. To overcome this 'core collections' of pearl millet has been developed. This pearl millet core collection has about 10% (1600 accessions) of the entire collection of pearl millet at ICRISAT (Bhattacharjee, 2000), representing maximum diversity. When the size of the entire collection is very large, even a core collection size becomes unwieldy for evaluation by breeders. To overcome this, a mini-core collection has been developed which includes 10% of the accessions of the core collection (and hence only 1% of the entire collection) (Upadhyaya and Ortiz, 2001). This mini-core collection still represents the diversity of the entire core collection. In pearl millet, mini core collection comprising of 238 accessions was constituted by using data on 10 qualitative and 8 quantitative traits of 2094 core collection accessions (Upadhyaya et.al., 2011).

The genetic enhancement has been mainly performed through introgression of genes for specific-traits. Use of limited number of parents in most of the varieties, indicate the narrow genetic base thereby increasing the genetic vulnerability to biotic and abiotic stresses. Therefore, it has become imperative to use diverse genetic resources for broadening the genetic base of varieties resulting in more sustainable productivity. There exists a well established mechanism for distribution of the genetic resources, however, the feedback regarding the utilization is insufficient and, therefore, requires strengthening. For disseminating information regarding the potential value of the germplasm conserved, it is required that more catalogues are published and widely circulated among potential users. There is also a need for creating a national database so that the information on passport, characterization and evaluation can be easily accessed by all the concerned stakeholders.

Characterization of diversity

Conventional markers for characterizing plant genetic resource use morphological/ physiological/ biochemical (viz. isozyme activity) parameters. Being variable in manifestation under varying environmental condition and also in different developmental stages of the plant, these parameters do not qualify for precise dependable markers for germplasm characterization. Thus there is a need to develop a system of dependable molecular marker technology that would precisely characterize valuable germplasm of the country. An array of molecular techniques available over the past couple of decades have provided useful technology for precise characterization of genomes through development of DNA fingerprint that is the ultimate in individualization. DNA markers are considered particularly useful because DNA characters may be studied in all tissues of the plant, are unaffected by environmental changes and also remain detectable through changes in developmental stages of the plant; these are also insensitive to epistatic or pleiotropic effects. The methods used in genome analysis are rapid and reproducible and hence provide comprehensive DNA characterization for development of species-specific parameters as well as specific trait associated DNA markers.

Challenges

Loss of genetic diversity due to monocultures

Following Green Revolution modern varieties spread to large areas leading to the erosion of the plant genetic resources. With the growing threat from the public sector which provides certified seeds and the entry of the private sector that has flooded the market with hybrids, a large proportion of the farmers' varieties/ landraces that represent an important gene pool for resource-poor farmers living in marginal and stress-prone areas have gone out of cultivation resulting in the loss of food-seed and nutritional securities.

Landraces of pearl millet which have evolved over many generations under natural selection in environments like severe drought and high temperature conditions, possess better adaptation to stress environment and thus their cultivation may contribute to farm level resilience in the face of production shocks (FAO, 1998; Ceccarelli and Grando 2002). These could form potential sources of novel biotic and abiotic stress resistance genes or combination of genes if deployed appropriately, of phytonutrients accompanied with optimal micronutrient concentrations which can help alleviate age-related and chronic diseases. Conservation specialists have acknowledged the key role of folk crop varieties or landraces in sustainable agriculture, and called for conservation of the genetic diversity of these crops. The cultivation of landraces further provides *in-situ* conservation of crop genetic diversity, preserving an evolutionary process affected by both human and natural selection. *In-situ* conservation is valuable not only to meet current and future food preferences but also as insurance against future disease threats.

Climate change

Climate is one of the major physical factors that govern the choice of crops, cropping systems or farming systems of a region. Using a regional climate model, PRECIS (Providing Regional Climates for Impact Studies), it has been predicted that by the end of 21st Century mean annual surface temperature of the country may increase by 3.0-5.0 ^{o}C with warming more pronounced in the northern part (RupaKumar et al., 2006). The IPCC 2007 and PRECIS model have projected hotter days and warm nights and a reduction in rainfall in Thar region by 21st century. A study by Poonia and Rao (2013) showed that air temperatures by the end of 21st century are likely to increase by +3.3 ^{o}C at Bikaner, +3.4^{o}C at Jaisalmer,

+2.9°C at Jodhpur and +2.5°C at Pali. A study by Rao and Poonia (2011) revealed that water requirement of pearl millet in the arid region is 308-411mm. Taking the projected 4°C rise in temperature due to global warming by the end of the 21st century, water requirement from current level will increase by 12.9% for pearl millet. The increase crop water requirements will result in reduction in crop growing period by 5 days. As a result the crop acreage where rainfall satisfies crop water requirements will be reduced by 23.5% in pearl millet.

A study of weather parameters over a long period revealed that both maximum and minimum temperatures showed increasing trend over time. The increasing temperature will most likely to have adverse impact on crop productivity in this region. Crop development will be faster, thus reducing the total length of crop growing season. Increasing temperature during kharif season may reduce the life cycle of crops, affect pollination of sensitive crops and exacerbate the water stress through higher evapotranspiration.

The rate of change suggests that in many instances current locally available genetic material will not be adapted to the new conditions, resulting in genetic erosion. As a result the value of genetic resources for food and agriculture will increase in the near future. In order to adapt to climate change, plants spices important for food security will need to adjust to abiotic changes such as heat, drought, floods and salinity. As climate change brings new pest and diseases, new resistances will be required by crop varieties. With the passage of time genetic diversity that is currently underutilized may become more attractive to farmers. Thus maintaining and using a wide basket of genetic diversity at a time of climate change will be an essential insurance policy for the food and agriculture sectors.

Efforts would also be required to enhance crop resilience and adaptation to climate change for sustainable production, food and nutrition security. This may be achieved by developing varieties of arid crops that are tolerant to flowering time high temperature, extra early varieties for shortened moisture availability period and varieties with terminal drought tolerance. Developing varieties with in-built developmental plasticity, i.e., that are early-maturing and capable of yielding grain under short dry periods but should have the ability to make best use of high moisture availability during good rainfall years by prolonging their vegetative phase, resulting in higher grain and fodder yield. Concerted efforts are also required to understand the mechanism involved in controlling heat and terminal drought tolerance to identify genetic stocks for the traits correlated with these stresses.

However pearl millet has several features that make it a climate change ready crop like short life cycle of 62-85 days; low seed rate (3-4 kg/ha), high multiplication rate (Grain yield 20 to 40 quintals/ha); high water use efficiency; high photosynthetic potential and dry matter production ability, being a C4 plant; seedling heat tolerance (survives at >62 °C soil surface temperature); reproductive heat tolerance (seed set at >46 °C air temperature), low temperature tolerance (germinates at 8-10 °C and flowers at 10°C); higher salt tolerance (up to 15 dsm-1); adapted to degraded lands; less susceptible to diseases and insect pests as compared to other crops; practically devoid of stored grain pests; useful as food, fodder and feed crop and being healthy and nutritious food is suitable for lifestyle diseases like diabetes and heart ailments.

Future needs and priorities

A well-established mechanism for distribution of the genetic resources is already in place, but satisfactory and sufficient feedback regarding its utilization is lacking and needs attention. It is required that more catalogues regarding the potential value of the germplasm conserved should be published and widely circulated. Although databases have been developed, there is a need for linking of these databases and creating a national database so that the information on passport data, characterization and evaluation can be accessed by all the concerned stakeholders in a user friendly manner.

Animal husbandry is an important part of the farming systems in Rajasthan, involving use of crop residues, natural rangelands and agroforestry. In the higher-rainfall areas, i.e. the central and eastern parts of the state, single-cross hybrids and open-pollinated improved varieties have been widely grown by farmers for the last 10-20 years. Seed markets are well developed, and in some areas local landrace varieties have largely been replaced. In the western part of Rajasthan, where growing conditions are harsher, farmers prefer to use landraces or grow mixtures of traditional and modern varieties of pearl millet.

The attitude toward landraces has been changing in recent years, as improved cultivars have not always proved to be superior, for example in marginal environments or under specific socioeconomic conditions (Weltzien and Fischbeck 1990; Ceccarelli *et al.* 1992). Landraces are sometimes also preferred by farmers for quality aspects (Dhamotharan *et al.* 1997). Thus, a new interest has arisen to use traditional landraces as such, or in breeding programmes.

Participatory germplasm collection facilitates the identification of landraces that farmers perceive as being unique, of a specific quality and worthy of conservation efforts. Thus, only comparatively few samples are being actually collected for medium or long-term conservation. For each sample, information about the farmers' contribution to the development of this specific seed sample will be available. This includes management of the seed crop, seed selection, processing, storage, exchange and measures to control out- crossing. At the same time, information about morphological characteristics, production behaviour and relative adaptation to specific growing conditions found in the collecting region can also be documented. This strategy would save both time and resources, and could keep the numbers of new samples arriving at a genebank down to a justifiable minimum.

In the present scenario of climate change it becomes imperative that wide range of genetic resources are provided to the stake holders (breeders, farmers, NGOs and rural communities) on sustainable basis to adapt to climate change. Collection and *ex-situ* conservation of genetic resources, potentially useful in adaptation and threatened by climate change ought to be supported. Farmers need to be encouraged to continue to develop locally adapted genotypes. Monitor genetic resources being managed *in-situ*. Concurrently international cooperation among developing countries should be strengthened to build capacities to conserve and use genetic resources for food and agriculture to respond to climate change. Reintroduction of locally adapted genotypes after climate change related disasters needs to be undertaken.

CONCLUSION

India is one of the bio-diversity rich countries of the world. Following green revolution, cultivation of modern high yielding varieties on large scale has led to near monoculture situations leading to reduction of genetic diversity by erosion of landraces and local cultivars. This loss of native crop landraces and cultivars prompted the Food and Agriculture Organization (FAO) and the World Bank to create new institutions for the collection and preservation of plant genetic resources - the *ex-situ* genebanks. Since 1970s the task to collect, maintain, conserve, document and distribute pearl millet genetic resources has been entrusted with ICRISAT. By the end of 2006, the genebank at ICRISAT had 21,594 accessions from 51 countries, including 750 accessions belonging to 24 species of genus *Pennisetum*. This is the single largest collection of pearl millet germplasm assembled at any one place in the world. Although the collection is impressive, exploration for pearl millet germplasm cannot be considered as complete as several regions might have been left unexplored or underexplored. After the release of first pearl millet hybrid in 1965, area under hybrids increased rapidly. The spread of pearl millet single cross hybrids and their impact on production and productivity has been more in regions endowed with better production environments. However there has been limited adoption of hybrids in arid zone and this is due to their inadequate adaptation to the conditions of the arid zone. Farmers generally cite a greater risk of crop failure in poor years (compared to local landraces) as one of the main reasons for not growing current hybrids. As a result traditional pearl millet landraces are still grown in this part of the country and are important sources of resistance to various biotic and abiotic stresses as well as traits for improving grain and fodder quality (thinner stem, nodal tillers etc.). These landraces also represent a wide genetic diversity for time to flower, plant height, tillering, panicle and grain characteristics. Landraces of western Rajasthan like Chadi landrace, Barmer landrace and Desert types are different from the ones found in central and eastern parts of Rajasthan i.e. Jakhrana, Karauli, Gullista and Sulkhania. The cultivation of landraces provides *in-situ* conservation of crop genetic diversity. Tempted for hybrid cultivars, farmers will not continue to maintain optimal varietal diversity without any institutional and national policy support. There is thus a need to recognize and reward farmers as well as local communities playing pivotal role in conservation of pearl millet diversity. The attitude toward landraces has been changing in recent years, as improved cultivars have not always proved to be superior, for example in marginal environments. Thus, a new interest has arisen to use traditional landraces as such, or in breeding programmes. The use of germplasm in pearl millet breeding programmes has been limited. Development of core collections, mini-core collections and trait specific core collections would encourage use of genetic diversity. Collecting landrace germplasm (for *ex-situ* conservation), using participatory way would help in collecting unique samples of specific quality. This would save both time and resources and could keep the numbers of new samples arriving at a genebank down to a justifiable minimum.

Estimation of genetic diversity and identification of superior genotypes are some of the prime objectives of any crop improvement programme. Highly diverse genotypes or accessions can be utilized as parents in hybridization programmes to produce superior varieties/hybrids. Molecular markers offer considerable advantages over morphological markers for genetic diversity assessment. Various molecular markers are being used for fingerprinting such as restriction fragment length polymorphisms (RFLP), random amplified polymorphic DNA (RAPD), micro satellites and amplified fragment length polymorphism (AFLP). RAPD is quite efficient in bringing out genetic diversity at DNA level and is an effective tool for pearl millet germplasm management.

Characterization of germplasm and its utilization to broaden the genetic base of the breeding programmes is essential, as it would determine the potential and adaptation of the future varieties to counter the unforeseen challenges of climate change.

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