Pearl millet germplasm at ICRISAT genebank – status and impact

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Introduction

Pearl millet (*Pennisetum glaucum*) is an important food and forage crop in Africa and Asia, and forage in Americas. It is probably the world's hardiest crop and has great potential because of its suitability to the extreme limits of agriculture. It is mainly cultivated in Niger, Nigeria, Burkina Faso, Togo, Ghana, Mali, Senegal, Central African Republic, Cameroon, Sudan, Botswana, Namibia, Zambia, Zimbabwe and South Africa in Africa; and India, Pakistan and Yemen in Asia. The success in crop improvement programs depends largely on the extent of genetic variability available to the researchers. Pearl millet is endowed with enormous genetic variability for various morphological traits, yield components, adaptation and quality traits. In ensuring that the plant breeders will have genetic resources for use in plant breeding programs, collection, conservation, characterization, evaluation, documentation and distribution of plant genetic resources is very important. Large efforts were made to collect and conserve the pearl millet diversity before it is lost forever. In this article, we have summarized the current status of pearl millet germplasm assembled in the genebank at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and discussed its impact.

Germplasm assembly

Assembly of germplasm is the most important among all activities of genetic resources. Initially, ICRISAT had made concerted efforts to introduce the germplasm that was assembled at different national and international institutes, universities, national agricultural research systems (NARS), etc. A total of 65 organizations contributed 10,764 accessions including those contributed by different disciplines at ICRISAT, in different years. The major donors contributing more than 900 accessions include Institute Francais de Recherche Scientifique pour le development en Cooperation (ORSTOM) (2,178), Rockefeller Foundation, New Delhi, India (2,022) and International Bureau for Plant Genetic Resources (IBPGR), Rome, Italy (974). ICRISAT identified the gaps in the collection and also priority areas for systematic collection of germplasm in different countries. So far, ICRISAT had launched 212 germplasm collection missions for all its mandate crops and could collect 10,830 pearl millet samples during 76 collection missions in 28 countries.

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* (Table 1). 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. 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.

Conservation and maintenance

To maximize the longevity and preserve the genetic integrity of accessions, pre-dried seeds are packed in moisture-proof containers and stored in chambers with controlled environment. Short-term store maintained at 18–20°C and 30–40% relative humidity (RH) is used for seed cleaning, processing, packing and conserving for a year or two. Seeds for medium- and long-term conservation are dried in seed drying room operated at 15°C and 15% RH to dry the seed to a desired level of about 7–9% and 4–5% moisture content, respectively. About 400 g each of all accessions (21,594) is conserved in medium-term store maintained at 4°C and 20–30% RH (active collection). Viability of the seeds can be maintained above 85% for 10–15 years. Seeds only from medium-term store are available for immediate utilization and distribution. About 75 g each of 17,670 accessions are conserved in long-term store in vacuum packed aluminum foils, which is maintained at –20°C (base collection). Remaining accessions would be transferred in the near future. Under long-term storage, viability of seeds can be maintained above 85% for about 50 years. Monitoring the seed viability of active collection is carried out at an interval of 5 years and those conserved as base collection at 10-year intervals. Top of paper method is used to test the

Table 1. Geographic distribution of pearl millet germplasm assembled at ICRISAT genebank (as on 1 January 2007).

Country	No. of accessions		
	Cultivated	Wild	Total
Africa			
Algeria	5	–	5
Benin	46	–	46
Botswana	82	–	82
Burkina Faso	862	5	867
Cameroon	911	85	996
Cape Verde Islands	2	–	2
Central African Republic	142	10	152
Chad	98	36	134
Congo	8	–	8
Ethiopia	2	1	3
Gambia	15	–	15
Ghana	283	–	283
Kenya	98	1	99
Lesotho	–	4	4
Malawi	298	12	310
Maldives	1		1
Mali	1048	109	1157
Mauritania	6	31	37
Morocco	4	–	4
Mozambique	31	2	33
Namibia	1118	10	1128
Niger	1130	178	1308
Nigeria	2064	10	2074
Senegal	393	12	405
Sierra Leone	59	1	60
Somalia	4	–	4
South Africa	162	3	165
Sudan	587	27	614
Tanzania	478	25	503
Togo	520	–	520
Tunisia	6	–	6
Uganda	118	1	119
Zaire	11	3	14
Zambia	155	7	162
Zimbabwe	1384	13	1397
Asia			
India	6502	145	6647
India – ICRISAT	1333	–	1333
Korea (South)	1	–	1
Lebanon	108	–	108
Myanmar	10	–	10
Pakistan	168	2	170
Russia & CISs	15	–	15
Sri Lanka	–	2	2
Turkey	2	–	2
Yemen	290	3	293
Europe			
France	11	–	11
Germany	3	–	3
UK	31	1	32
Americas			
Brazil	2	–	2
Mexico	10	1	11
USA	219	10	229
Oceania			
Australia	8	–	8
Total	20844	750	21594

viability of pearl millet seeds. Regeneration of accessions is required when the seed viability and or the seed quantity in active collection is below the critical level (<1/4 of total quantity and/or <85% viability) (Kameshwara Rao and Bramel 2000). Pearl millet germplasm regeneration is carried out during the postrainy season at ICRISAT farm, Patancheru, India. A sample size of about 160 plants are grown in 4 rows, each 4 m long with a spacing of 75 cm between rows and 10 cm between plants. Irrigation is provided at regular intervals. Fertilizers are applied at the rate of 100 kg ha^{-1} N and 40 kg ha^{-1} P_2O_5. Being a cross-pollinating crop, the genetic integrity of accessions is maintained by cluster bagging method of pollination control for landraces, selfing for genetic stocks and sibbing for male sterile lines. In cluster bagging method, panicles from 2 to 4 adjacent plants in a row are covered in one parchment paper bag. This method is cost-effective and allows some cross-pollination between plants of the same accession to overcome the problem of inbreeding depression caused if individual plants are selfed. Wild relatives of pearl millet are regenerated in field genebank and the species that do not produce seed (eg, *P. purpureum*, *P. macrourum, P. lanatum, P. squamulatum*) are maintained as live plants.

Characterization and evaluation

Germplasm collection is of little value unless it is characterized, evaluated and documented properly to enhance its utilization in crop improvement. A multi-disciplinary approach is followed at ICRISAT genebank and the data generated in various disciplines are fed to the pearl millet germplasm characterization database. By the end of 2006, all cultivated accessions were characterized and evaluated for 23 morpho-agronomic characters following the descriptors for pearl millet (IBPGR and ICRISAT 1993). Time to 50% flowering, plant height, panicle length and thickness were recorded during both rainy and postrainy seasons, whereas number of nodal, productive and total tillers, panicle exsertion, synchrony of panicle maturity, panicle shape, spikelet density, bristle length, grain yield potential, fodder yield potential and overall plant aspect were recorded only during the rainy season. Observations on grain characters such as 1000-seed weight, seed shape, seed color and endosperm texture were recorded after harvesting during the postrainy season. To realize the true potential of the accessions and to facilitate the selection of genotypes by researchers, sets of selected pearl millet germplasm were evaluated for important agronomic characters at different locations in India and several other countries in Africa at or near the place of origin during the suitable season.

Diversity in the collection

Large phenotypic diversity in collection has been observed for almost all the characters. There are accessions in the collection, which can flower as early as in 33 days and as late as in 159 days in rainy season. Similarly, plant height ranged from 30 cm to 490 cm with a mean of 246.2 ± 0.46 (Table 2). Total tillers varied from 1 to 35 and 1000-seed weight varied from 1.5 to 21.3 g. Distribution of qualitative traits indicates occurrence of nine panicle shapes (cylindrical, conical, spindle, club, candle, dumb-bell, lanceolate, oblanceolate and globose), five seed shapes (obovate, oblanceolate, elliptical, hexagonal, globular) and ten seed colors (ivory, cream, yellow, gray, dark gray, gray brown, brown, purple, purplish black and mixture of white and gray) in the entire collection. Accessions with candle-shaped panicles (11132), short bristled panicles (20004), globular seed shape (5420), gray seed color (10473) and seeds with partly corneous endosperm texture (13296) are predominant in the collection. In the entire collection, only 141 accessions for green fodder yield potential and six accessions for seed yield potential scored 9 (maximum). The phenotypic diversity index (H′) ranged from 0.427 (total tillers in rainy season) to 0.632 (plant height in postrainy season) for quantitative traits. Among qualitative traits, diversity was maximum for endosperm texture (H′ = 0.772) and minimum for bristle length (H′ = 0.443). Diversity for qualitative traits was higher (H′ = 0.610 ± 0.031) than that for quantitative traits (H′ = 0.573 ± 0.021). Averaged over all traits, the diversity index was 0.588 ± 0.018.

Documentation

Computerization of data started in 1980 using the ICRISAT Data Management and Retrieval System (IDMRS) software developed at ICRISAT. Then, System 1032 was used and now maintained using MS Access for faster and more efficient data management. For each crop, passport, characterization, inventory and distribution databases are being maintained. Passport and characterization databases can be accessed through http://SINGER.grinfo.net. Germplasm catalogs were prepared using multilocational evaluation data.

Germplasm distribution and utilization

A small seed sample of each accession is available on request to all bonafide research workers under Seed Material Transfer Agreement (SMTA). Since 1974, ICRISAT has provided 38,507 samples to researchers working in different disciplines at ICRISAT, 59,558 samples to scientists in India and 30,015 samples in 79 other countries. ICRISAT has also repatriated 922 accessions to Cameroon and 7,189 accessions to India to make the local germplasm available to the researchers. Almost all diversity has been supplied. IP 4021 and IP 3122, early maturing accessions were supplied maximum (>75 times). To enhance the utilization of pearl millet germplasm, sets of selected germplasm accessions were evaluated at different locations in India and several other countries in Africa and field days were organized facilitating the selection of pearl millet germplasm. Trait-specific genepools (early

Table 2. Range of variation for important agronomic characters of pearl millet germplasm assembled at ICRISAT genebank in the rainy season (R) and postrainy season (PR).

Character	Minimum	Maximum	Mean	Variance
Time to flower (days) (R)	33.0	159.0	72.8 ± 0.17	569.75
Time to flower (days) (PR)	32.0	138.0	71.4 ± 0.08	123.47
Plant height (cm) (R)	30.0	490.0	246.2 ± 0.46	4427.63
Plant height (cm) (PR)	25.0	425.0	160.1 ± 0.25	1311.57
Total tillers (no.) (R)	1.0	35.0	2.7 ± 0.01	3.13
Productive tillers (no.) (R)	1.0	19.0	2.1 ± 0.01	1.28
Panicle exsertion (cm) (R)	–45.0	29.0	3.7 ± 0.05	43.34
Panicle length (cm) (R)	5.0	135.0	28.2 ± 0.07	112.90
Panicle length (cm) (PR)	4.0	125.0	25.4 ± 0.07	109.62
Panicle width (mm) (R)	8.0	58.0	24.0 ± 0.03	22.75
Panicle width (mm) (PR)	9.0	61.0	22.9 ± 0.04	25.73
1000-seed weight (g) (PR)	1.5	21.3	8.5 ± 0.02	4.98

Table 3. Status of pearl millet germplasm screening for various biotic and abiotic stresses and important traits at ICRISAT, Patancheru, India.

Stress/Trait	No. of accessions screened	No. of promising accessions identified
Cultivated		
Downy mildew resistance	3164	54
Smut resistance	1747	397
Ergot resistance	2752	283
Rust resistance	2229	332
Drought tolerance	115	7
Salinity resistance	48	32
High seed protein content (>15%)	1270	260
Yellow endosperm	12	2
Sweet stalk	892	16
Male sterility	17000	50
Wild		
Downy mildew resistance	534	220

maturing, high tillering, large panicle and large grain) were developed to provide partially converted genotypes to the breeders. The core collection is an economical, practical and effective method for conservation, maintenance and utilization of the germplasm. ICRISAT has developed a core collection consisting of 504 accessions and representing the diversity of entire collection (Bhattacharjee et al. 2007). A set of this germplasm is being evaluated at Niamey, Niger and five locations in India to identify useful lines for crop improvement.

There has been a general lack of interest in using wild species because of the large amount of genetic variability available in pearl millet landraces. However, *P. glaucum* subsp *monodii* for new source of cytoplasmic-nuclear male sterility (CMS), *P. purpureum* for forage, stiff stalk and restorer genes of the A_1 CMS system, *P. mezianum* for drought tolerance, *P. orientale* for drought tolerance and forage, *P. schweinfurthii* for large seeds, *P. pedicellatum* and *P. polystachion* for downy mildew resistance and *P. squamulatum* for apomictic gene (Rai et al. 1997) are very useful in pearl millet improvement.

Impact of conserved germplasm

The greatest achievement is conserving the vanishing pearl millet germplasm and making available for crop improvement. Besides the utilization of germplasm in ongoing research at different research institutes, universities, NARS, etc, several pearl millet germplasm accessions have gone into the release of varieties in different countries. In general, Indian pearl millet landraces have mainly contributed to earliness, high tillering, high harvest index and local adaptation, whereas African materials have been good sources of high head volume, large seed size, and disease resistance.

Some examples of germplasm utilization and varieties released are discussed:

- The most dramatic example of direct use of landraces is the development of ICTP 8203, a large-seeded and high-yielding open-pollinated variety bred at ICRISAT, Patancheru, by selection within a large-seeded *iniadi* landrace from northern Togo (Rai et al. 1990). This variety was released as MP 124 in Maharashtra and Andhra Pradesh and as PCB 138 in Punjab states of India in 1988. The same variety was released as Okashana 1 in Namibia during 1990 and as Nyankhombo (ICMV 88908) in Malawi in 1996. Direct selection within the same landrace led to the development of a large-seeded and downy mildew resistant male sterile line ICMA 88004, a seed parent of an early maturing hybrid (ICMH 356) released in India in 1993 (Rai et al. 1995).
- Okashana 2, a variety derived from a Zimbabwe local landrace IP 16504 (SDGP 1514) crossed with ICMV 87901 and ICMV 88908, was released in Namibia during 1998 (Obilana et al. 1997).
- IKMP 3, a variety released in Burkina Faso was developed from selection within the landrace IP 11381 (CVP 417) from Burkina Faso.
- IKMP 5, a variety released in Burkina Faso was developed from selection within the landrace IP 11317 (CVP 170) from Burkina Faso.
- An open-pollinated variety ICMV-IS 88102, developed from selection within the landrace IP 6426 from Mali,

was released in Burkina Faso in 1993 and as Benkadi Nio in Mali during 1994.

- Kangara (SDMV 92040), a variety released in Namibia in 1998, was derived from two landraces IP 17527 and IP 17531 and S2 progenies of SADC white grain composite. The same variety was also released as PMV 3 in Zimbabwe during 1998 (Obilana et al. 1997).
- Donor parents like 863B (IP 22303), P 1449-2 (IP 21168), ICMB 90111 (IP 22319), ICMP 451 (IP 22442) and IP 18293 were identified as sources for the most important gene, ie, resistance against different pathotypes of downy mildew disease in India.

Impact of above releases needs to be quantified in respective countries. Germplasm with sweet stalk, yellow endosperm, high iron and zinc, new dwarfing genes, CMS lines, early maturing lines and sources of resistance to abiotic and biotic stresses are widely used in crop improvement programs in different countries (Table 3). Several new and useful traits such as narrow leaf, glossy leaf, brown midrib leaf and leaf color variants have been used extensively in academic studies.

Acknowledgment. Authors sincerely acknowledge the contribution of all former and present staff, particularly Dr Melak H Mengesha, former Program Leader and Dr S Appa Rao, former Senior Scientist (Pearl millet germplasm) of Genetic Resources Unit, ICRISAT, in collection/assembly, conservation and characterization of pearl millet genetic resources.

References

Bhattacharjee R, Khairwal IS, Bramel Paula J and **Reddy KN.** 2007. Establishment of a pearl millet (*Pennisetum glaucum* (L.) R. Br.) core collection based on geographical distribution and quantitative traits. Euphytica 155:35–45.

IBPGR and **ICRISAT.** 1993. Descriptors for pearl millet (*Pennisetum glaucum* (L.) R. Br.). Rome, Italy: International Bureau for Plant Genetic Resources (IBPGR); and Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

Kameshwara Rao N and **Bramel PJ.** (eds.). 2000. Manual of genebank operations and procedures. Technical Manual no. 6. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 190 pp.

Obilana AB, Monyo ES and **Gupta SC.** 1997. Impact of genetic improvement in sorghum and pearl millet: Developing country experiences. Pages 119–141 *in* Proceedings of the International Conference on Genetic Improvement of Sorghum and Pearl Millet, 22–27 Sep 1996, Lubbock, Texas, USA. Lincoln, Nebraska, USA: Collaborative Research Support Program on Sorghum and Pearl Millet.

Rai KN, Anand Kumar K, Andrews DJ, Rao A, Raj AGB and **Witcombe JR.** 1990. Registration of ICTP 8203 pearl millet. Crop Science 30:959.

Rai KN, Appa Rao S and **Reddy KN.** 1997. Pearl millet. Pages 243–258 *in* Biodiversity in trust, conservation and use of plant genetic resources in CGIAR centers (Dominic Fuccillo, Lindo Sears and Paul Stapleton, eds.). Cambridge CB2 IRP, UK: Cambridge University Press.

Rai KN, Rao AS and **Hash CT.** 1995. Registration of pearl millet parental lines ICMA 88004 and ICMB 88004. Crop Science 35:1242.