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PROSPECTS OF UTILISING GENETIC DIVERSITY IN PEARL MILLET

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INTRODUCTION

Pearl millet [*Pennisetum typhoides* (Burm.) Stapf and Hubb. Syn. *P. americanum* (L.) Leeke] is a cross pollinating diploid with a wealth of variability accumulated through natural selection. Its polyphyletic origin (genetic load), introgression between weedy and wild relatives and the cultivated types, and the ecological diversity have enhanced this natural variation. Human selection further augmented the diversity of pearl millet. Large numbers of genetic stocks of pearl millet have been assembled at ICRISAT through various agencies (Appa Rao, 1980). Only a part of the germplasm has been extensively evaluated and much less has been utilised.

GENETIC RESOURCES

Little more than 18,000 accessions of pearl millet representing 42 countries have been assembled at ICRISAT (Table 1). India has

Table 1. Pearl millet germplasm accessions at ICRISAT (December, 1986)

Continent	Source	Country(s) (No.)	Accessions (No.)
Africa	Known/	29	6598
	Unknown	—	11
America	Known	3	106
Asia	India	1	11140*
	Others	6	146
Australia	Known	1	4
Europe	Known	2	28
Total		42	18033

*Includes 7600 lines contributed by AICPMIP

provided 11,140 genetic stocks. They include 1,469 collections of Rockefeller Foundation—IARI, which is part of 1,532 world collections from 17 countries catalogued by Murty *et al.* (1967). Nearly 7,600 lines, genetic and breeding stocks, were contributed by Indian Pearl Millet Programme during first half of 1970's.

These Indian collections were further augmented since 1977. Realising that the partial replacement of locals by improved cultivars promoted introgression; ICRISAT and ICAR in association with the Agricultural Universities launched new collecting missions. The efforts yielded 2,794 collections from various states of India (Table 2).

Table 2. Pearl millet germplasm accessions from India, 1977-86 (ICRISAT-ICAR-Agricultural Universities)

State(s)	Date of Collection	Samples collected (No.)
Andhra Pradesh	January, 1977	70
	October, 1980	133
Andhra Pradesh, Orissa	October, 1984	113
Bihar, Orissa, Madhya Pradesh	November, 1986	32
Gujarat	September—October, 1978	455
Karnataka	November, 1980	22
	October—November, 1981	5
	March, 1980	1
Madhya Pradesh	September—October, 1978	17
	December, 1978—January, 1979	24
Maharashtra	September—October, 1978	408
	October—November, 1981	122
Orissa	January, 1977	28
Punjab	October, 1983	204
Rajasthan	January, 1977	366
	September—October, 1978	14
	October, 1986	111
Tamil Nadu	April, 1978	200
	June, 1980	7
Uttar Pradesh	October, 1979	462
Total		2794

CHARACTERISATION AND EVALUATION

Utilisation demands characterisation and evaluation of germplasm. Multilocational evaluation not only uncovers hidden variability but also reveals environmentally induced variation. This is particularly true of outbreeding species like pearl millet.

Murty *et al.* (1967) evaluated 2,345 genetic stocks of pearl millet in 13 environments over 8 locations, but characterised only 1,532 accessions in their catalogue after eliminating the duplicates and entries that failed to germinate. They studied 23 characters which revealed wide range of variation for metric and qualitative characters (Table 3). They also identified promising accessions and countries with high frequency of promising cultures for vegetative characters (early growth vigour, tiller number, days to 50 per cent flowering, plant height etc.), ear characters (length and girth of ear, number of seeds/sq. cm. etc.),

Table 3. Variation for 19 characters in 1532 collections of pearl millet

Characters	Indian	Exotic
1. *Vegetative Characters*		
50% flowering (days)	52–77	53–85
Plant height (cm)	60–77	49–111
Tillers (No.)	5–7	2–13
Plant colour	Green	Green
Node colour	Green-Tan	Green-Purple
Leaf colour	Green-Tan	Green-Tan
2. *Ear Characters*		
Ear length (cm)	16–22	19–40
Ear girth (cm)	50–70	50–80
Grain density (No./sq. cm)	15–35	14–24
Bristle length (mm)	5–15	5–25
1000 grain weight (g)	3–8	5–15
Bristle colour	Red-Purple	Green-Purple
Glume colour	Yellow-Brown	Yellow-Dark Brown
Glume covering	Half covered	3/4 covered
Seed colour	Deep brown-Slate	Brown-Slate
Seed size	Medium	Small-Medium
Seed shape	Oblong-Oval	Oblong-Round
Endosperm colour	White	White
Endosperm texture	Sugary-Partly Glutinous	Waxy-Highly Glutinous
Accessions (No.)	1105	427
Country(s)	1	16

Source : Murty *et al.*, 1967

Table 4. Range of characters in pearl millet germplasm in rainy and post-rainy seasons at ICRISAT Centre

Characters	Kharif (Rainy season)				Rabi (Post-rainy season)			
	Minimum	IP No.	Maximum	IP No.	Minimum	IP No.	Maximum	IP No.
Plant height (cm)	35	10401	475	6574	11	10401	310	5115
Flowering (Days)	33	4021	140	6894	34	4021	90	6051
Tillers (No.)	1	5427	210	1200	1	6271	263	1200
Stem thickness (mm)	2.8	4021	15	5365	2.5	4021	13	5150
Leaf/node number	6	3123	25	6011	6	8210	21	7470
Leaf length (cm)	25	10401	120	5533	19	10401	105	6231
Leaf width (mm)	11	10402	78	6251	13	3586	82	1960
Hairiness*	Glabrous	3859	Villous	6223	Glabrous	5854	Villous	8482
Pigmentation*	Green	5150	Purple	5420	Green	5387	Purple	5731
Spike exertion (cm)	—45	5296	39.5	5271	—37	5243	31	7409
Spike length (cm)	5	8190	165	5428	5	8190	120	5335
Spike thickness (cm)	11	8210	64.5	5299	13	4708	77	7443
Spike density*	V. loose	5797	V. compact	6294	V. loose	5794	V. compact	5321
Grain No./spike	489	8190	3337	5428	371	4021	2814	5335
1000 grain weight (g)	2.54	3089	19.32	10437	2.84	3586	17.16	9404
Grain shape*	Obovate	397	Globular	6388	Obovate	3807	Globular	5296
Grain colour*	White	8027	Purple	8032	White	6132	Purple	8182
Endosperm texture*	Corneous	3072	Starchy	5197	Corneous	3595	Starchy	5153
Bristle length (mm)	2	3872	60	8025	2	4935	50	2095
Bristle colour*	Green	2095	Purple	8845	Green	6801	Purple	2695

*See Descriptors for Pearl millet, IBPGR/ICRISAT, 1981.

disease resistance (downy mildew, *Sclerospora graminicola*; ergot, *Claviceps fusiformis*; smut, *Tolyposporium penicillariae*; rust, *Puccinia penniseti* etc.) and drought resistance.

ICRISAT evaluated 16,968 accessions for 18 characters. This unfolded wide morphological diversity for components of growth and production (Table 4). The ICRISAT collections also revealed greater genetic diversity for all the characters as compared to the collections by Murty *et al.* (1967). These differences appear to be due to the number of collections and the countries represented, and consequently the depth of diversity assembled. This underlines the need for free international collection, conservation, documentation and exchange.

Special screening efforts revealed disease, insect and drought resistant accessions (Table 5). The identification of ergot and smut resistant lines added fillip to disease-resistance breeding.

Table 5. Evaluation of pearl millet germplasm

Characters	Accessions (No.)	Promising lines	
		Number	Per cent
Disease Resistance[1]			
Downy mildew	2753	124	4,50
Ergot	2800	24	0.86
Smut	1800	34	1.89
Rust	2562	86	3.36
Insect Resistance[2]			
Mythimna sp.	100	8	8.00
Shootfly	424	45	10.61
Aphids	100	14	14.00
Shoot Bugs	100	8	8.00
Thrips	29	3	10.34
Spider mites	324	31	9.57
Drought Resistance[3]	509	2	0.39
Quality Characters[4]			
Protein	3523	100	2.84
Sugar	8	4	50.00
Other Characters[5]			
Male sterility	16968	5	0.03
Glossy leaf	16968	8	0.05
Dwarf lines	15388	6	0.04
Genetic stocks	15388	692	4.50
Viable chlorophyll mutants	16968	11	0.06

Source : Pearl millet subprogrammes : 1. Pathology, 2. Entomology, 3. Physiology, 4. Biochemistry and 5. Genetic Resources Unit : ICRISAT, Patancheru, 502 324, Andhra Pradesh, India.

Chemical analysis revealed few protein rich lines. Biochemical characterisation and enzyme typing would go a long way in improving the nutritional and processing quality, and the physiological efficiency for increasing productivity.

Stability of accessions and gene pools

Each accession of pearl millet is a small random sample enriched with rare phenotypic variants. The sample size and cross pollination, therefore, change the composition of the accessions of pearl millet. The variability has been, therefore, assessed over years and seasons to identify stable and variable accessions of pearl millet. Comparison of germplasm collections from Rajasthan (Vyas and Srikant, 1984 ; Appa Rao *et al.*, 1986), Maharashtra (Appa Rao *et al*, in press), Uttar Pradesh (Appa Rao *et al.*, 1983), Tamil Nadu (Appa Rao *et al.*, in press), Malavi (Appa Rao *et al.*, 1985) and Ghana (App Rao *et al.*, 1985) during *kharif* (rainy season) and *rabi* (post rainy season) at Patancheru, revealed wide range of variability for several traits (Table 6). Most of the Uttar Pradesh accessions flowered a week earlier and grew taller in *kharif* than in *rabi*. Most other characters listed in Table 6 remained stable indicating that the accessions can be classified into logical groups. The Uttar Pradesh collections were, therefore, divided into 7 groups based on shape, length and thickness of spike. Similarly, the Rajasthan collections were grouped into 7 types—Jakharana, Sulkhania, Gullisita, Karauli and Barmer types had basal tillers, longer earheads, non-shattering spikelets and small glumes that partly covered the grain, while Chadi and Desert types had several nodal tillers, sequentially maturing earheads, shattering spikelets and glumes which almost covered the grain.

UTILISATION AND POTENTIAL

The pearl millet variability, as discussed in previous section, provides unlimited potentialities for its utilisation. Some aspects of genetic diversity directly related to productivity or its components, and useful sources of genes are discussed.

Flowering and maturity

Flowering time and maturity assume special significance in crops like pearl millet grown under dry conditions during monsoon season. Flowering time is also influenced by photoperiod sensitivity enabling selection of grain and forage types. The 50 per cent flowering time ranged from 33 to 140 days in the world collection offering wide scope for tailoring the genotypes to the environmental conditions. Appa Rao (1979) identified early flowering genotypes in collections from Gujarat.

Early flowering appears to be controlled by two genes-e_1 and e_2 (Hanna and Burton, 1985). e_1 e_1 genotypes flower in 49 days and e_2 e_2 genotypes in 38 days as compared to the control (76 days). Early flowering could, therefore, be easily transferred into productive and adapted genotypes. ICRISAT constituted a medium maturity composite by random mating 197 geographically diverse Indian and African lines, all flowering in 45-55 days (Rai *et al.*, 1985). They also mentioned that Serere Composite 1 introduced from Uganda flowers in 47 days.

of peral millet accessions

U.P. 1983(d)		Tamil Nadu In Press(e)		Malawi 1986(f)		Ghana 1985(g) (227)
Kharif (456)	*Rabi* (456)	*Kharif*	*Rabi*	*Kharif* (243)	*Rabi* (243)	
67	73	87	74	64	62	47
48–80	50–79	53–135	53–95	56–116	50–78	37–140
250	140	274	129	249	154	225
162–291	84–198	160–392	68–174	146–380	79–225	120–315
2	2	3	—	2	—	2
1–5	1–4	1–11	—	1–5	—	1–3
9	9	7	—	—	—	7
5–13	5–12	5–9	—	—	—	5–12
11	10	12	—	—	—	—
7–17	7–15	9–15	—	—	—	—
60	58	57	—	—	—	46
45–82	41–77	47–74	—	—	—	30–60
35	33	28	—	—	—	31
25–45	23–42	23–37	—	—	—	20–45
23	22	21	14	25	25	22
14–34	12–38	13–34	8–20	16–33	15–39	6–53
23	22	18	—	22	22	27
17–33	15–29	13–32	—	16–35	15–45	15–39
6	6	3	—	2	—	—
5–38	4–36	2–17	—	1–9	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
7	7	—	5	6	—	14
6–8	6–8	—	3–7	2–9	—	8–18

Rao *et al.*, (In press); (d) Appa Rao *et al.*, 1983; (e) Appa Rao *et al.*, (In press);

Plant height

Variation for plant height offers the greatest potential for the evolution of varieties for different agricultural systems—dry, irrigated, mechanised etc. Five dwarf genotypes have been identified by Burton and Fortson (1966). Fourteen dwarf stocks of pearl millet were isolated after screening 15,388 accessions (Appa Rao *et al.*, 1986). The dwarfing gene in 10 of the 14 dwarfs was allelic to d_2 and 4 indicated two gene

Table 6 Comparative performance of pearl millet germplasm

Character	Statistical para-meters	Rajasthan 1984(a) (122)*	Rajasthan 1986(b) *Kharif* (380)	Rajasthan 1986(b) *Rabi* (380)	Maharashtra [In Press(c)] *Kharif*	Maharashtra [In Press(c)] *Rabi*
50% flowering (days)	Mean	56	58	68	65	65
	Range	52–66	45–71	51–79	42–85	51–70
Plant height (cm)	Mean	186	217	197	225	151
	Range	139–241	120–310	153–270	135–310	120–200
Productive tillers (No.)	Mean	3	3	—	2	2
	Range	1–8	1–6	—	1–5	1–5
Stem thick-ness (mm)	Mean	10	7	—	9	8
	Range	8–12	6–9	—	6–14	5–13
Node number	Mean	10	10	—	10	10
	Range	8–13	9–10	—	8–12	8–11
Leaf length (cm)	Mean	65	53	—	57	49
	Range	56–77	48–60	—	48–63	39–56
Leaf width (cm)	Mean	35	30	—	36	32
	Range	27–48	22–34	—	27–43	23–37
Ear length (cm)	Mean	30	24	—	19	15
	Range	20–33	10–40	—	11–17	10–22
Ear girth (mm)	Mean	7	20	—	23	24
	Range	8–10	9–33	—	16–29	17–33
Bristle length (mm)	Mean	—	3	—	3	—
	Range	—	1–10	—	1–20	—
Grain density (cm)	Mean	21	—	—	—	—
	Range	12–34	—	—	—	—
1000 grain weight(g)	Mean	8	—	8	8	8
	Range	6–10	—	6–11	5–11	6–12

*Accessions (No.) evaluated

Source : (a) Vyas, K.L. and Srikant, 1984; (b) Appa Rao *et al.*, 1986; (c) Appa Rao *et al.*, (In press) (f) Appa Rao *et al.*, 1986; (g) Appa Rao *et al.*, 1985.

non-allelic loci. They are from Niger (IP 8056), Mauritania (IP 8214), India (IP 10401) and ICRISAT (IP 10402). The d_2 has been incorporated into ms lines like Tift 23 A_1, Tift 239 A_1, 126 A_1 and 81 A_1. Seven diverse tall composites have also been converted into d_2 background providing a broad dwarf genetic base for breeding dwarf parents and dwarf open pollinated varieties (Andrews *et al.*, 1985).

Seed characters

Seed size and grain weight are the most significant factors that directly contribute to grain yield. Seed size is positively correlated with seedling growth vigour which indirectly influences plant height, tiller number, ear length and grain yield (Chhina and Phul, 1982). The seed size in pearl millet varies from very small (1000 grains weigh 3 g.) to very bold (1000 grains weigh 19 g.) seeds with different grades of sizes. Bold seeded collections predominantly occur in accessions from Ghana, Togo and Uganda.

Pearly white pearl millets

Depigmented pearl millet grain blended with wheat improves surface appearance, internal appearance and eating characteristics (Naikare *et al.*, 1986). Light pigmented pearl millet grains which vary from white to yellow have been identified in germplasm from Chad, Ghana, Togo and Uganda. These pearly pearl millets are also sweeter and contain higher protein (more than 15 per cent) and may have great future in bettering the nutritional quality and improving the appearance of bakery products. They may also find a place in irrigated farming and acceptability by the elite segment of the society.

Sweet pearl millets

The search for alternate uses of pearl millet revealed the occurrence of genotypes with high sugar in their stems (Table 5). Comparative studies at ICRISAT indicated 5 to 20 per cent sugar in 8 accessions: 4 being from Tamil Nadu (Appa Rao *et al.*, 1982). At Coimbatore, the sugar content in 68 genotypes ranged from 3 to 16 per cent based on brix readings (AICMIP, 1985). FD 832 (16.2 per cent) recorded the highest sugar content followed by NEP 18-5023-2 (15 per cent) and Giant Bajra (13.8 per cent). Popularisation of sweet pearl millets coupled with extraction of jaggery like in sweet sorghums may boost the shrinking economy and the social lives of the chronically poor pearl millet growers inhabiting the semi-arid tropics. It is likely that several genotypes with high sugar still remain undiscovered in the germplasm.

Male sterility

Male sterility affords easy production of hybrid seeds on large scale. Both, the genes for sterility (Gill *et al.*, 1973; Rao and Koduru, 1978 and Rao and Devi, 1983) and the sterile cytoplasms appear to occur in the genetic resources. Following the discovery of A_1 cytoplasm (Burton, 1965), Athwal (1961) isolated L 66A_2 from an African (Nyasaland) line IP 189 and L 67 A_3 in a natural cross involving another African line (Athwal, 1966). Pokhriyal *et al.* (1976) also developed 5054 A_1 from a Nigerian line, and 5141 A_1 from an Indian landrace. Appadurai *et al.* (1982) developed another male sterile line 732 A from the cross between an Andhra Pradesh line PT 819 and a Coimbatore line PT 732, the male sterile appears to be different from A_1, A_2 and A_3 sources. Male steriles have been developed from Ugandan germplasm (Vohra, 1982). Marchais and Pernes (1985) further identified a CMS system in Wild × Cultivated Pearl Millet crosses which is different from the identified systems. It is, therefore, apparent that the variability for cytoplasmic systems is as great as for genetic systems in pearl millet.

Disease resistance

Downy mildew, ergot, smut and rust are the important diseases of pearl millet. Downy mildew in particular devastated the single cross hybrids in India, calling for eternal vigilance. Ergot and smut occur in favourable seasons and are less wide spread and less threatening. Rust occurs sporadically. Nevertheless, all these diseases deserve effective control to reduce losses in productivity and to eliminate the toxic principles in the food grains and the forage. The incorporation of host-plant resistance offers the best choice for effectively checking the occurrence and spread of these diseases.

Downy mildew: Fortunately, downy mildew resistance occurs widely in the germplasm. Ex-bornu from Nigeria, 3/4 Ex-bornu and 3/4 Hainei Kirei from Niger have contributed to downy mildew resistance in 1,700 pedigree selected pearl millet lines (Andrews *et al.*, 1985).

Ergot: The resistance to ergot is not as widespred as in the case of downy mildew. More than 2,500 genetic stocks and 7,300 advanced breeding lines have been screened for resistance to ergot (Thakur *et al.*, 1985). Low degree of resistance to ergot has been observed in 20 genetic stocks from India (10), Nigeria (7) and Uganda (3). High level of resistance to ergot has been achieved through pedigree breeding (Thakur *et al.*, 1982) or through the development of composites/synthetic ICMS 8034 (Andrews *et al.*, 1985). Thirteen of these 20 lines showed resistance to downy mildew and smut at ICRISAT revealing the multiple disease resistance which can be incorporated into single cultivar.

Smut : The resistance to smut has been noticed in accessions from India, Mali, Nigeria, Senegal, South Africa and Zimbabwe (Murty *et al.*, 1967 and Sangwan and Thakur, 1981). Thakur *et al.* (1986) screened more than 1,500 genetic stocks and 6,200 advanced breeding lines, and identified smut resistant lines in accessions orginating from Cameroon (4), India (11), Lebanon (1), Mali (8), Niger (2), Nigeria (2), Senegal (4) and Uganda (2). Smut resistance has been transferred into agronomically superior inbred lines as well as into synthetic varieties like ICMS 8282 and ICMS 8283 (Andrews *et al.*, 1985).

Rust : Rust reduced dry matter concentration, dry matter yield particularly yield of leaves and grain, total sugars and *in vitro* digestibility (Monson *et al.*, 1986). Search for rust resistance revealed a dominant gene for resistance in 2696–1–4 S2, a selection from the germplasm originating from Chad (Andrews *et al.*, 1985). Hanna *et al.* (1987) identified a dominant gene for rust in 3 accessions of *Pennisetum americanum* subsp. *monodii* from Senegal.

Weedy and wild relatives

Wild millets (Marchais and Pernes, 1985) and interspecific hybrids like *Pennisetum schweinfurthii* Pilger × *P. americanum* (L.) Leeke (Hanna and Dujardin, 1986) can provide new sources of cytoplasmic male sterility. Bramel-Cox *et al.* (1986) indicated that it is possible to select lines with transgressively increased grain yield and growth rate in crosses between cultivated pearl millet × primitive landraces or weedy or wild relatives. Apomictic genes from related species like *Pennisetum squamulatum* Fresen. (2n=28) could also be incorporated in protogynous pearl millet (Dujardin and Hanna, 1986) for preventing floral diseases.

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