Annals of Arid Zone 34(2) : 105-110, 1995

Improvement of Landrace Cultivars of Pearl Millet for Arid and Semi-Arid Environments

F. R. Bidinger, V. Mahalakshmi, B. S. Talukdar and R. K. Sharma*
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru P O, Andhra Pradesh 502 324, India
** SKN College of Agriculture, Rajasthan Agricultural University, Jobner 303 329, India*

Abstract : Successful cultivars for arid and semi-arid environments must combine adaptation to drought stress for dry years with a reasonable yield potential for better years. Improving the yield potential of adapted landrace cultivars may be the easiest way to achieve this combination for breeding programs with limited resources. This study, conducted with four adapted pearl millet landrace cultivars, compared the yield improvement from one cycle of S_1 progeny plus mass reselection with that from topcrossing the landraces on an early male-sterile line, with a good combining ability for grain yield. A single cycle of reselection increased mean yield of the landraces by 11% over seven test environments, ranging in yield from 470 to 3010 kg ha^{-1}. Topcrossing raised yields by an average of 32% over the same test environments. Topcrossing increased responsiveness to improved environmental resources, as the advantage of the topcross hybrids over their parent landraces increased as environmental mean yield increased. Reselection, in contrast, increased mean yield but did not improve the response of the reselected cultivars to a changing environmental yield level.

Key words : Cultivars, landrace reselection, pearl millet, *Pennisetum glaucum* (L.) R. Br., response to environment, topcross hybrids.

Cultivars for variable moisture environments in arid and drier semi-arid zones require adaptation to the common drought stress patterns found in these environments, plus a reasonable yield potential to allow them to respond to favorable growing conditions in good rainfall years. Modern, high-yielding cultivars bred exclusively for favorable conditions yield well in favorable conditions, but frequently lack adaptation to the extreme stress conditions of arid environments (Weltzien and Fischbeck, 1990). Landrace varieties, which have evolved under these conditions and perform reliably in them, characteristically lack the yield potential to compete with modern varieties in better years/locations (Bidinger and Parthasarthy Rao, 1990).

A plant breeder developing cultivars for such variable moisture environments is faced with the challenge of combining adaptation and yield potential. Transferring "adaptation" to high yielding cultivars is complicated by a lack of understanding of the genetic and physiological bases of adaptation, making selection for adaptation slow and difficult. Improving the yield potential of already adapted materials may be a more promising approach, provided that there is genetic variation for yield potential within such materials, and provided that the breeder has access to favorable subsets of the target environment for selection. For a cross-pollinated crop such as pearl millet [*Pennisetum glaucum* (L.) R. Br.] both simple mass selection (Rattunde *et al.*, 1989) and selection methods, based on progeny evaluation (Singh *et al.*, 1988), have been shown to be effective for improving yield potential.

Recent experience with topcross hybrids, based on adapted landrace pollinators, has suggested that these may be a rapid and efficient way of combining both adaptation and yield potential in pearl millet, particularly for breeding programs with limited resources (Mahalakshmi *et al.*, 1992). This paper reports a study comparing the results of one cycle of reselection for improved yield and adaptation in four adapted pearl millet landrace populations, with the results of top-crossing these landraces on an early flowering male-sterile line with good combining ability for yield.

Materials and Methods

The study was based on four landrace populations/cultivars adapted to the arid zone of north-western India. Two of these were bred from local landraces from Jobner (Raj I) and Sikar (Raj II) areas of central Rajasthan, at the Rajasthan Agricultural University campus at Jobner. The other two (IP 9369 and IP 9407) are landraces from northern Ghana which were selected from an ICRISAT-NBPGR (National Bureau of Plant Genetic Resources) collaborative germplasm evaluation nursery under severe drought stress at the Central Arid Zone Research Institute in Jodhpur in the arid zone of Rajasthan in 1981. Raj I and II are characterized by intermediate tillering, intermediate to long panicles and small grains. The two African introductions are low tillering, with broad panicles and large grains.

All four of the original landrace populations/cultivars were improved by one cycle of S_1 progeny selection at Jobner, followed by one generation of mass selection under simulated terminal drought conditions at ICRISAT Center (reselected cultivars). The four landraces were sown at ICRISAT Center under both midseason and terminal drought stress in the dry season of 1983. A large number of plants were self-pollinated, and S_1 progenies of those with good seed set (approximately 10% of the total plants sown) were evaluated visually in a replicated progeny trial at Jobner in the rainy season of 1983. Selected progenies from each population (19 each from the two Ghana landraces, 35 from Raj I and 42 from Raj II, equivalent to 15-30% selection intensity) were random-mated by hand-pollination at ICRISAT during the 1984 dry season. The four random mated bulks were then mass-selected, retaining approximately 20% of the large, uniform panicles with good seed set, under terminal drought stress in the 1984 dry season at ICRISAT Center.

The four original landrace cultivars were also used as topcross pollinators on ICMA 2 (843A), an early, bold seeded male-sterile line which has been widely used in the breeding of single cross hybrids (eg. RHB 30, HHB 67) in north-western India. The topcross hybrids produced had varying degrees of male fertility, but under the test conditions, there was sufficient pollen available and seed set was good in all cases.

The original four landraces, their reselected versions, their topcross hybrids, and two adapted variety checks (RCB 2 and WC-C75) were grown in seven test environments (Table 1) which ranged from severely stressed (Fatehpur, 1989) to favorable (Patancheru, 1990). The tests were sown in four row x 4 m long plots in 4 to 6 replications, depending on location. All trials were fertilized (20 - 80 kg N ha^{-1} and 9 - 20 kg P ha^{-1}, depending on location) and well managed, so that yields were primarily a response to the moisture and temperature conditions of the test environment. A combined analysis of variance was performed, with genotype effects partitioned into effects of

Table 1. *Location, season, time to flowering and grain yield for the seven test environments*

Location	Season[1]	Environment	Flowering (days)	Yield (kg ha^{-1})
Fatehpur	RS 1989	Severe stress	56	470
ICRISAT	DS 1990	Terminal stress	55	1450
Hisar	RS 1990	Terminal stress	52	1570
ICRISAT	RS 1989	Average season	43	2040
ICRISAT	DS 1990	Irrigated crop	54	2240
Anantapur	RS 1990	August planting	39	2660
ICRISAT	RS 1990	Favorable season	44	3050

[1]RS = rainy season; DS = dry season.

cultivar type (original landrace, reselected landrace, and topcross hybrid), cultivar source (Rajasthan or Ghana) and individual population within each source, plus their interactions.

Results

Differences in cultivar types

There were significant differences among the cultivar types (landraces, reselected landraces and topcross hybrids) for all variables measured, and between the two improved types for all variables except grain weight per panicle (Table 2). Both the reselected landraces and the topcross hybrids outyielded the original landraces, by 11% in the case of the reselected landraces and by 32% in the case of the topcross hybrids (Table 3).

Reselection increased grain yield per panicle from 11.5 to 13.2 g, but reduced panicle numbers from 17.0 to 16.0 per square meter, without affecting time to flowering. Topcrossing the landraces on 843A reduced time to flowering by 6 days, increased productive tiller numbers from 17.0 to 19.5 m^{-2}, and increased grain yield per panicle from 11.5 to 12.7 g (Table 3).

The two sources of the landraces also differed for all variables measured, as did the interaction of cultivar type and source (Table 2). The Rajasthan-derived cultivars (landraces, reselected landraces and topcross hybrids) had higher numbers of productive tillers, but a lesser grain weight per panicle than the Ghana- derived cultivars (Table 3). The Ghana-derived cultivars were somewhat higher yielding (9%) in these trials, which was a result of a greater response to reselection and topcrossing in the Ghana landraces than with the Rajasthan landraces. The original Rajasthan landrace cultivars actually outyielded the Ghana landraces (1800 vs 1730 kg ha^{-1}), probably because they had already been improved, whereas, the Ghana landraces were the original landrace accessions collected from farmers' fields. The individual entries within each source also differed for all variables, but except for flowering, the mean squares for entry within source were less than the mean squares for source (Table 2).

Responsiveness to environment

The tests were conducted in a range of droughted and non droughted environments, in which mean grain yields varied from 470 to 3050 kg ha^{-1} (Table 1). Yields in the three lowest yielding environments were affected by drought

Table 2. Analysis of variance for flowering, yield components and grain yield. Genotype effect (11 df) is partitioned into: cultivar type (2 df), landrace source (1 df), entry within source (2 df) and their interactions (6 df). The cultivar type effect (2 df) is partitioned into single degree of freedom contrasts between (1) the two improved and the original versions of the landraces, and (2) the two improved versions

Source of variation	df	Mean squares for variables			
		Flowering	Panicle No.	Yield per panicle	Grain yield*
Test environment	6	3030.00	2960.00	603.00	457.00
Reps within env.	34	7.29	37.30	6.98	4.12
Genotype	11	447.00	317.00	219.00	43.20
Cultivar type	2	2120.00	646.00	122.00	163.00
Original vs impr.**	1	950.00	89.90	246.00	163.00
Resel. vs. hybrid	1	3270.00	1140.00	< 1.00	164.00
Landrace source	1	15.90	1620.00	1160.00	40.00
Entry within source	2	66.50	192.00	330.00	17.20
Type x source	2	203.00	46.80	68.80	31.70
Type x entry (source)	4	29.00	25.40	53.40	2.86
Genotype x environment	66	29.30	23.50	22.90	6.31
Error	358	3.44	9.91	4.85	1.37
CV (%)		3.70	17.90	17.70	18.30

* mean square x 10^{-3}.
** impr. = reselected landrace plus top-cross hybrids.

Table 3. Mean time to flowering, panicle number and grain yield per panicle and per hectare for the types of cultivars, sources of the original landraces and the check cultivars

	Mean (d)	Panicle No. (m^{-2})	Grain yield ($g\ panicle^{-1}$)	Grain yield ($kg\ ha^{-1}$)
Original cultivars	51	17.0	11.5	1760
Resel. cultivars	51	16.0	13.2	1950
Topcross hybrids	45	19.5	12.7	2330
Rajasthan origin*	49	19.5	10.9	1930
Ghana origin*	49	15.6	14.0	2100
Checks**	53	19.3	10.1	1730

* Mean of original landraces, reselected landraces and topcross hybrids based on Rajasthan or Ghana parents.
** Recommended varieties RCB 2 and WC-C75.

presented). Test environment differences were highly significant (as tested against the replication within environment mean square) for all measured variables (Table 2). The experiment thus offered the opportunity to compare the effects of reselection and topcrossing over a broad range of yield levels.

Response to improved environmental conditions was tested by joint regression analysis (Eberhardt and Russell, 1966) of original landrace, reselected landrace and topcross hybrid group mean yields on test environment mean yield (Fig. 1). The slopes of the regressions of cultivar type yield on environmental mean yield were not statistically different for the original landrace cultivars (b = 0.890 +-0.0354) and the reselected landraces (b = 0.956 +-0.0294), despite the higher mean yield of the latter (Table 3). The slope of the regression for the topcross hybrids (b = 1.178 +-0.0421) was significantly greater than that of both of the other two cultivar types, however. Thus the reselection procedure improved average yield across all environments by an approximately similar amount, while the improvement achieved by topcrossing increased as the environmental yield potential increased (Fig. 1).

Discussion

Reselection vs. topcrossing

The 11% improvement in grain yield achieved through reselection was quite substantial, considering the limited effort invested in selection. The results indicate that a single cycle of combined S_1/mass selection is very effective in improving yield in adapted but not necessarily high-yielding landrace cultivars. The effectiveness of additional cycles of reselection needs further testing. Rattunde and Witcombe (1993) showed that recurrent selection in breeding populations resulted in 1 to 5% improvement in yield per cycle in pearl millet, so it is unlikely that the high rate of improvement from the first cycle of reselection could be sustained.

A substantially larger increase in grain yield (32%) was achieved by topcrossing the landrace cultivars on 843A. Mahalakshmi *et al.* (1992) also reported substantial but somewhat smaller (22%) increases in grain yield by topcrossing a diverse set of landraces and improved open-pollinated varieties on the same male- sterile used in this study. In both topcrossing experiments there was a simultaneous improvement in both productive tiller number and grain yield per panicle with topcrossing, whereas, reselection in this experiment resulted in an improvement only in grain yield per panicle (Table 3).

The experiment did not include standard (single cross) hybrid checks to compare to the landrace-based topcross hybrids. The best open-pollinated check in the trial, WC-C75, usually achieves 85-90% of the yield of single cross hybrids (AICPMIP, 1988). As the mean yield of the topcross hybrids (2330 kg ha^{-1}) exceeded the mean yield of WC-C75 (2010 kg ha^{-1}) by 16%, it is probable that the topcross hybrids are competitive with single cross hybrids in these arid to semi-arid environments.

Responsiveness to better environments

The experiment contained a higher proportion of high yielding test environments than was originally planned, as several trial sowings in the arid zone (Fatehpur and Jodhpur) had to be abandoned because of poor plant stands. The data set thus allows a comparison of reselection and topcrossing for response to improved environmental conditions, but the lack of enough highly stressed environments does not permit firm conclusions about performance in arid conditions.

The greater mean yield improvement achieved by topcrossing the landraces on 843A, as opposed to improving them by a cycle of S_1/mass selection, was almost certainly due to the expression of heterosis in the topcross hybrids in the higher yielding environments. Reselection, by removing poorer individuals from the landraces populations, increased the frequency of favorable genes for the grain yield per panicle component, and hence improved the yield of the reselected landraces across all environments. Topcrossing the landrace on a modern, male-sterile line, had two effects: it improved the productive tiller number by an approximately similar amount across all environments, and increased the grain yield per panicle component in the favorable environments. The effects on grain yield per panicle appeared to be an expression of heterosis resulting from the crossing of genetically dissimilar parents. The expression of this was limited by environmental conditions in the low yielding environments, resulting in little yield advantage to the topcross hybrids in these environments (Fig. 1). As environmental conditions improved, the heterosis for grain yield per panicle was expressed and the hybrids outyielded the open-pollinated

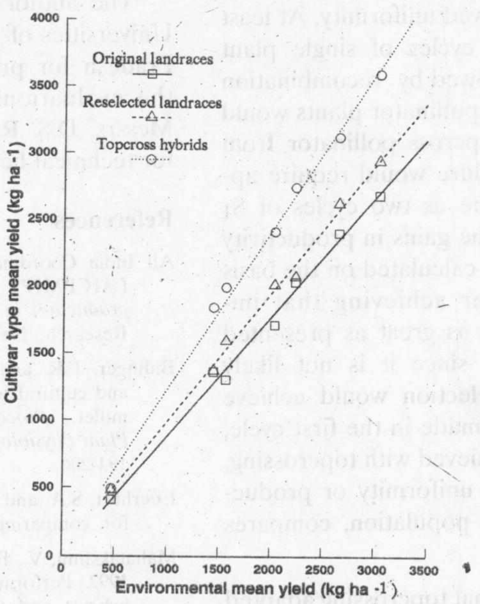

Fig. 1. Grain yield response (fitted linear regression) of the three cultivar types to environments of differing potential yield. The regression slopes of mean cultivar type grain yield on environmental mean grain yield are 0.890±0.0354 (r^2=0.992) for the original landraces, 0.956±0.0294 (r^2=0.995) for the reselected landraces, and 1.178±0.0421 (r^2=0.993) for the topcross hybrids. Data points are the means of the four genotypes within each cultivar type

varieties. The heterosis thus resulted in a greater degree of responsiveness to improving environments, that neither of the open- pollinated types of varieties expressed (Fig. 1).

Implications for breeding programs

This experiment used unimproved landraces as pollinators for the topcross hybrids. If such landraces were to be used as pollinators in an actual breeding program, however, they would have to be specifically reselected for both fertility restoration and for improved uniformity. At least one, and probably two, cycles of single plant test cross evaluation, followed by recombination of selfed seed of selected pollinator plants would be necessary to make topcross pollinator from the landrace. This procedure would require approximately the same time as two cycles of S_1 progeny selection. Thus the gains in productivity in topcross hybrids, when calculated on the basis of the time required for achieving that improvement, are not quite as great as presented in this paper. However, since it is not likely that two cycles of S_1 selection would achieve double the 11% advance made in the first cycle, the 32% improvement achieved with topcrossing, without any selection for uniformity or productivity within the landrace population, compares very favorably.

These results suggest that topcrossing adapted landrace cultivars on appropriate male-sterile lines could be a very effective way of attaining the improvement in yield potential (i.e. the ability to respond to improved conditions) necessary to justify basing breeding for arid environments on adapted landrace cultivars. However, there were too few severely stressed environments in this experiment to draw any conclusions on the likely performance of the topcross hybrids in the most arid environments. Further research is necessary to determine if this increased responsiveness can be achieved without compromising adaptation to moisture stress and high temperature environments. Those studies should include on- farm evaluations in a wide range of production environments typical of the arid zone, to be sure that the landrace topcross hybrids are exposed to the full range of environmental stresses which any new cultivar for the arid zone must face.

Acknowledgements

The authors wish to thank the Agricultural Universities of Rajasthan, Haryana, and Andhra Pradesh for providing the facilities to conduct the evaluations presented in this paper; and Messrs. D.S. Raju, K.P. Rao, and R. K. Yadav for technical help in conducting the experiments.

References

All India Coordinated Pearl Millet Improvement Project (AICPMIP) 1988. *Technology for increasing bajra production in India.* Indian Council of Agricultural Research, New Delhi.

Bidinger, F.R. and Parthasarathy Rao, P. 1990. Genetic and cultural improvements in the production of pearl millet. *Proceedings of the International Congress of Plant Physiology*, New Delhi, February 15-20, 1988, pp. 194-206.

Eberhart, S.A. and Russell, W.A. 1966. Stability parameters for comparing varieties. *Crop Science* **6**: 36-40.

Mahalakshmi, V., Bidinger, F.R., Rao, K.P. and Raju, D.S. 1992. Performance and stability of pearl millet topcross hybrids and their variety pollinators. *Crop Science* **32**: 928-932.

Rattunde, H.F., Singh, Pheru and Witcombe, J.R. 1989. Feasibility of mass selection in pearl millet. *Crop Science* **29**: 1423-1427.

Rattunde, H.F.W. and Witcombe, J.R. 1993. Recurrent selection for increased grain yield and resistance to downy mildew in pearl millet. *Plant Breeding* **110**: 63-72.

Singh, P., Rai, K.N., Witcombe, J.R. and Andrews, D.J. 1988. Population breeding methods in pearl millet improvement (*Pennisetum americanum*). *L'Agronomie Tropicale* **43-3**: 185-193.

Weltzien, E. and Fischbeck, G. 1990. Performance and variability of local barley landraces in near-eastern environments. *Plant Breeding* **39**: 11-18.