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Differential Response of Landrace-based Populations and High Yielding Varieties of Pearl Millet in Contrasting Environments*

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Abstract: Five populations of pearl millet (*Pennisetum glaucum*), having varying degrees of landrace germplasm from Rajasthan in their parentage, were evaluated across a range of environments differing greatly in their productivity levels. The populations showed different response patterns to environments with different productivity potentials. Comparison of landrace-based populations with high yielding control cultivars showed that the productivity of landrace populations for both grain and stover yields was clearly superior in low-yielding environments. In contrast, their productivity was often inferior to that of released high yielding varieties in more productive environments. Two populations, Early Rajasthan Population (ERajPop) and Early High Tillering Population (EHiTiP), flowered earlier than the early control, ICTP 8203. The landrace-derived populations had significantly higher tillering potential than the elite controls and also had more stable flowering time and tillering than high yielding controls in stress environments. Based on these results, the potential use of these landrace-based populations in future pearl millet breeding programmes is discussed. In addition, the breeding history of all populations has been briefly documented to give an overview of selection procedures followed in developing them.

Key words: Landraces, pearl millet, *Pennisetum glaucum*, stress environments, germplasm, adaptation.

In India, pearl millet [*Pennisetum glaucum* (L.) R. Br.] is grown under a wide range of conditions, from areas with assured rainfall and high fertility to highly stress-prone and unpredictable environments. In arid areas of Rajasthan, drought, high temperature at emergence and during grain filling, low soil fertility, and soil crusting at emergence are the most common abiotic stresses. Though various breeding efforts in pearl millet have produced agronomically elite cultivars, both hybrids and open-pollinated varieties (Yadav, 1996) with high yield potential, their adoption has been low in arid areas (Kelley *et al.*, 1996; Jansen, 1989), contributing to continued low pearl millet productivity in this zone. On the other hand, adoption and impact of these agronomically elite cultivars had been far greater in the areas endowed with favorable environments (Bidinger and Parthasarthy Rao, 1990; Yadav, 1996).

For any cultivar to be successful in stress environments it needs to possess adaptation mechanism for the prevalent stresses. Crop landraces originating from stress-prone regions are reported to possess high degree of adaptation to stress conditions (Weltzien and Witcombe, 1989; Weltzien

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Table 1. Comparative performance of Barmer population (BarPop) and 4 checks in two LYEs and four HYEs in 1994

Population	Grain yield (kg ha^{-1})		Time to flower (days)		Panicle number ('000 ha^{-1})	
	LYE	HYE	LYE	HYE	LYE	HYE
BarPop	770	1701	59	49	132	182
Raj 171	551	2332	60	50	67	140
ICTP 8203	454	2159	55	45	61	115
ICMV 155	589	2583	59	47	75	143
Nokha local	435	1697	58	46	176	207
S.E.(±)	84	192	0.9	0.8	13	16

and Fischbeck, 1990; Ceccarelli, 1994), though they characteristically have low yield potential. As a part of broadening the genetic base of pearl millet breeding material for western Rajasthan, several genetically diverse populations have been constituted from landraces originating from the stress environments of Rajasthan. Some landraces have also been intercrossed with other high yielding material in an attempt to combine the adaptation of landraces to stress environments and yield potential of high yielding material. The objective of this study was to compare the performance of landrace-based populations and improved pearl millet cultivars in arid and semi-arid environments that differ widely in their productivity levels.

Materials and Methods

Development of populations

Of the five breeding populations evaluated, three - Barmer Population (BarPop), Early Rajasthan Population (ERajPop), and Western Rajasthan Population (WRajPop) - are based purely on landraces originating from various parts of Rajasthan, and the remaining two - Early High Tillering Population (EHiTiP) and CZP-IC 416 - have genetic contributions from both Rajasthan landraces and high yielding materials of Indian and African origin.

BarPop was developed by intermating five superior landraces (BNO 46, BNO 52, BNO 58, BNO 59 and BNO 66) from Barmer district of Rajasthan. ERajPop was bred from four early maturing Rajasthan landraces - IP 3188, IP 3228, IP 3464 and IP 3246 - collected from Devikot, Jodhpur, Anadra and Nagaur, respectively. WRajPop was developed from 13 landrace accessions from north-western India. EHiTiP was bred from 600 full-sibs, 30 from each of 20 population crosses that were previously derived either from landraces or high yielding materials of Indian and African origin. CZP-IC 416 was developed from two interpopulation crosses, viz., EC C6 x LRE 128 and PakLR 74 x EC 89.

Evaluation of populations

These populations were evaluated as part of testing diverse breeding materials across a wide range of environments during 1992-96, and at four to six locations per year in the states of Haryana, Rajasthan and Andhra Pradesh. Three released open-pollinated varieties - Raj 171 (RCB-IC 9),

Table 2. Comparative performance of Early Rajasthan Population (ERajPop) and 4 checks in seven LYEs and ten HYEs in 1992-94

Population	Grain yield (kg ha^{-1})		Time to flower (days)		Panicle number ('000 ha^{-1})	
	LYE	HYE	LYE	HYE	LYE	HYE
BarPop	803	1966	49	44	131	238
Raj 171*	551	2332	60	50	67	140
ICTP 8203	484	1903	50	45	81	123
ICMV 155	644	2530	54	48	98	156
Nokha local	586	1740	54	45	160	260
S.E.(±)	71	148	0.8	0.6	9	16

* Based on two LYEs and four HYEs.

ICTP 8203 (MP 124), and ICMV 155 (MP 155) - were included as controls. Nokha Local, a landrace variety obtained from village Nokha in Bikaner district, was included as a local control.

The trials were conducted under rainfed conditions at Jodhpur, Fatehpur-Shekhawati, Jaipur, Hisar and Patancheru in lattice or randomized complete block designs, with three to four replications of four-row plots of 4 m length, spaced at 50 to 65 cm. Plant-to-plant spacing was 30 cm at drought-prone locations in Rajasthan (Jodhpur, Fatehpur-Shekhawati and Jaipur) and 15 cm at Hisar and Patancheru. Weeds were controlled by intercultivation and one or two hand weedings.

Data were recorded for days to flower when stigmas emerged on the main panicle of 50% of the plants in a plot. At harvest, number of plants harvested and number of panicles were counted from entire plot. Panicles were sun-dried before threshing and grain weight recorded. Grain yield and dry stover yield were estimated on plot basis. Data were analyzed using the statistical software package PLABSTAT (Utz, 1991).

As different combinations of timing, severity and duration of naturally occurring environmental stresses - mainly drought, high temperature and poor soil fertility - and also their interaction resulted in varying yield levels in different environments, it was not possible in this study to group the environments by the type of stress. Rather we grouped them by productivity level which is the reflection of intensity of stresses in these environments. Environments (location x year combinations) were classified as low- (LYE) or high-yielding-environments (HYE). Locations with a trial mean below 1000 kg ha^{-1} were considered as LYEs while those with mean yield above 1000 kg ha^{-1} as HYEs.

Results and Discussion

There were wide differences in the performance of both landrace populations and high yielding varieties under LYEs and HYEs. The grain yields in HYEs was 2-4 times greater than in LYEs. Similarly, stover yields were also consistently 2-3 times higher in HYEs. Tillering was drastically reduced and also there was a delay of 3-13 days in flowering time in

Table 3. Comparative performance of western Rajasthan population (WRajPop), CZP-IC 416 and early high tillering population (EHiTiP) and 4 checks in LYEs and HYEs in 1994-96

Population	Grain yield (kg ha^{-1})		Time to flower (days)		Stover yield (kg ha^{-1})		Panicle number ('000 ha^{-1})	
	LYE (5)[1]	HYE (11)	LYE (5)	HYE (11)	LYE (2)	HYE (10)	LYE (3)	HYE (1)
WRajPop	818	2047	51	48	2379	5207	104	210
CZP-IC 416	942	2064	53	49	2934	5309	96	186
EHiTiP	746	1942	50	45	2604	4494	109	216
Raj 171	689	2464	57	51	2612	5892	73	149
ICTP 8203	529	2060	51	46	1399	3859	55	118
ICMV 155	722	2524	55	50	2411	5798	65	150
Nokha local	532	1453	53	46	1534	4364	98	185
S.E.(±)	96	177	0.9	0.9	267	504	21	32

[1]Figures in parentheses indicate the number of environment.

LYEs as compared to HYEs (Tables 1 to 3).

BarPop significantly outyielded controls Raj 171 and ICTP 8203 and also provided 30% more grain yield than the other high yielding control ICMV 155 in the LYEs in one year of testing, but it had significantly lower yield than high yielding controls, similar to that of the local control variety, in HYEs (Table 1). This difference in the performance of BarPop under stress conditions is interesting as it does not seem to be due to drought escape, because this population flowered at the same time or slightly later than the high yielding controls. This suggests that BarPop possesses a useful degree of adaptation to stress conditions but seems to lack yield potential under favorable growing conditions. The degree of reduction in LYEs in number of panicles also varied between BarPop and high yielding controls. The reduction was, on an average, 50% in controls while it was only 27% in BarPop. The lesser reduction in number of panicles in BarPop might have helped it to perform better in stressful environments. Maintenance of more number of tillers under stress conditions is an important stress adaptation mechanism in pearl millet (Mahalakshmi and Bidinger, 1986).

ERajPop significantly outyielded all, but ICMV 155, controls in LYEs in three years of testing (Table 2). All the high yielding control cultivars except ICTP 8203 were, however, distinctly superior to ERajPop in HYEs. ERajPop flowered as early as the earliest flowering control variety, ICTP 8203, in stress environments. This clearly indicates that earliness is available in highly adapted landraces. The earliness of ERajPop might have helped it in escaping late season drought effects of 1993. It is interesting to note that delay in flowering under LYEs is of lesser magnitude in ERajPop as compared to that in high yielding controls. Though the tillering of ERajPop was lower than the local control, it could still maintain 1.3 to 2.0 times greater number of tillers than the improved controls even under LYE conditions.

WRajPop provided significantly greater grain yield than ICTP 8203 and the local control, and also outyielded the other high yielding controls by 13 to 19% under LYEs over three years. It did not outperform any of the high yielding controls under HYEs though it produced significantly higher grain than local control (Table 3). Stover yield of WRajPop was also significantly higher than ICTP 8203 and the local control in both sets of environments. However, stover yielding capability of WRajPop was at par with controls Raj 171 and ICMV 155 under stress conditions. Tillering of WRajPop was significantly superior to all three high yielding controls, but similar to that of the local control.

Grain yield of CZP-IC 416 was significantly greater than controls Raj 171 and ICTP 8203 in LYEs and 30% higher than ICMV 155 over three years (Table 3). It produced more than twice the stover yield of ICTP 8203 and also produced 12-22% greater stover yield than Raj 171 and ICMV 155. CZP-IC 416 flowered significantly earlier in LYEs than Raj 171 and ICMV 155 controls and only two days later than earliest flowering control ICTP 8203. It had the same flowering and tillering behavior as the local control, but provided significantly higher grain and stover yields in both groups of environments.

Population EHiTiP also produced 41% more grain than control ICTP 8203, but its performance was only marginally superior to Raj 171 and ICMV 155 in LYEs over three years. Under non-stress conditions also, it yielded as much grain as control ICTP 8303. It flowered one day earlier than the earliest flowering control ICTP 8203 and provided 16 and 86% more stover than this control under stress and non-stress conditions, respectively. EHiTiP is significantly higher yielding than Nokha Local, for grain under both stress- and non-stress conditions, and for stover under stress conditions. EHiTiP is remarkably better in its tillering ability than all the high yielding controls. Under stress environments it produced 1.5 to 2 times more panicles than these controls. Under high yielding favorable conditions EHiTiP still produced 44 to 83% more panicles than these controls. Its tillering habit is similar to that of the local control.

The results of this study show that the five populations reported here are well adapted to stress conditions and thus generally outperform the high yielding controls in LYEs. However, it should be recognized that the yield level at farmers' field in the arid areas is between 200 and 400 kg ha^{-1} which is much lower than that observed in the LYEs of the present study. In fact, apart from environmental stresses, management factors like plant stand, sowing time, fertilizer application, interculture operations and their interaction among themselves and with environmental stresses play very important role in determining the productivity at farmers' field. The experiments are far better managed with optimum plant stand in comparison to farmers' fields, resulting in wide gap in the productivity level. However, some of the environments did have yield levels as low as those obtained in farmers' fields due primarily to higher stress intensity.

In one of the poorest yielding environments, some of the experimental varieties derived from ERajPop and EHiTiP produced 1.5 to 2.0 times greater grain yield than the best high yielding open-pollinated variety control, ICMV 155 (Yadav and Weltzien-Rattunde, 1998). This has given the indication that advantage of these populations over high yielding varieties might increase as the productivity level becomes lower than that of LYEs of this study.

Observations that all five new breeding populations performed better than the local control in both groups of environments also suggests that these pearl millet populations are significantly superior in their yielding ability to the local landraces, both in stress- and non-stress environments. Simultaneously, CZP-IC 416, EHiTiP, WRajPop and ERajPop also produced, on an average, 80% of the grain yield of high yielding controls Raj 171 and ICMV 155 in the HYEs (Tables 2 and 3). These results clearly suggest that these new landrace-based populations, apart from having adaptation to stress conditions, also respond well to favorable growing conditions. This is an encouraging result because an ideal cultivar targeted for harsh growing areas should also have the ability to take advantage of favorable growing seasons during better rainfall years, apart from having good adaptation to stresses. Thus, these broad-based populations should prove highly useful in developing open-pollinated cultivars and parents of hybrids meant for stress areas. Earliness of EHiTiP and ERajPop would be especially advantageous for derivation of early maturing varieties for the areas that are more likely to experience moisture stress at the end of growing season. A few varieties derived from these two populations are in advanced stages of testing in trials of the All India Co-ordinated Pearl Millet Improvement Project (ICAR). Pollinators for developing early single-cross and topcross hybrids can also be derived from these populations after improving them for their fertility restoration capabilities if the restorer gene frequencies are not initially high enough in them (Bidinger *et al.*, 1995). EHiTiP and ERajPop have already been subjected to one cycle of recurrent selection for improved fertility restoration capability for the A_1 cytoplasmic male-sterility system by testing of hybrids based on individual S_1 plants and intermating of only those S_2 progenies that produced fertile hybrids.

Two new observations were made in this study. First, the flowering time in landrace-based populations is more stable under stress conditions than that of high yielding controls included in this study. Landraces are able to produce panicles even under extremely severe moisture stress conditions while high yielding varieties often fail to do so unless stress is relieved (E. Weltzien-Rattunde, unpublished data). It might be that accumulation of certain amount of biomass is an essential requirement for the high yielding cultivars to produce the spike, resulting in relatively greater delay as compared to landraces in their flowering under stress conditions. Second observation is that tillering ability of landrace-based populations shows far greater stability under unfavorable growing conditions than that of the improved controls. In fact, landraces possess far greater degree of plasticity in their tiller development as compared to high yielding controls included in this study. Landraces typically possess asynchronous tillering (Raymond, 1968) and have the potential for regrowth even if stress affects the main stem and primary tillers. In addition, landraces produce flushes of panicles from small nodal tillers formed in the upper nodes of primary tillers as well as from secondary tillers (Nanda and Chenoy, 1958). These growth habits of landraces result in the greater stability for tiller production under stress conditions. Relative stability of flowering time and tillering behavior, as observed in this study, may be useful indicators of the inherent tolerance to stresses in these populations. Thus it may be worthwhile to study these traits further as selection criteria for improved adaptation to low yielding environments.

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