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Performance of landraces and hybrids of pearl millet [*Pennisetum glaucum* (L.) R. Br.] under good management in the arid zone

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Abstract

The limited adoption of modern pearl millet (*Pennisetum glaucum*) hybrids in the arid zone of western Rajasthan has been attributed to the lack of hybrids with sufficient adaptation to this zone, a conclusion based largely on the on-farm performance of hybrids under traditional management systems. The objective of this research was to determine if this conclusion is also true under improved management conditions. This study compared six recommended hybrids and six traditional landraces in 16 environments created through a combination of locations and years over five crop seasons. Across all environments the average grain yield ranged from 439 kg ha^{-1} to 3200 kg ha^{-1}. The mean grain yield of the landraces was similar to that of the hybrids but the landraces provided significantly higher biomass and stover yield. Only above a mean trial grain yield of 2000 kg ha^{-1} the hybrids outyielded the landraces for grain productivity. These results confirm that even under well managed, but rainfed, arid zone environments, current hybrids offer farmers little advantage over their traditional landraces.

Key words: *Pennisetum glaucum,* pearl millet, landraces, hybrids, grain yield, and response to environment

Introduction

The widespread adoption of publicly and privately bred single cross hybrids of pearl millet [*Pennisetum glaucum* (L.) R. Br.] and the increase in national average productivity of pearl millet from 323 to 731 kg ha^{-1} between the period of 1950-54 to 2000-02 [1] has been one of major successes of Indian agricultural research. This has been a remarkable achievement in a crop grown in the most drought prone areas of the country. The one exception to this success has been the arid zone of western Rajasthan, where adoption of hybrids is minimal and grain yields have changed very little during the period of rapid change elsewhere in the country. The reason usually cited is that currently available hybrids are not adapted to environmental conditions of the arid zone [1, 2]. This is not too surprising as most current hybrids have neither been directly selected for performance in arid zone, nor are their parental lines necessarily adapted to the environmental conditions of this zone.

However, there is very little published data from well-conducted, multi-environment comparisons of currently available hybrids and local landraces to support this conclusion. On-farm surveys, which tend to support the conclusion that hybrids are not competitive with local landraces [3, 4], are based on observations under farmers' traditional management systems. It is very possible that arid zone farmers' level of crop management and inputs is too poor for the greater yield potential of hybrids to be expressed under typical farm conditions. As a consequence, farmers do not perceive any advantages with hybrids when grown on their own farms, despite their superior yield potential demonstrated in research station trials. The objective of this paper is to test this hypothesis, using data from a larger comparison of cultivar types, which were evaluated over sixteen well-managed, but strictly rainfed, research station environments in the arid zone of western Rajasthan between 1999 and 2004.

Materials and methods

The experiments compared two groups of cultivars. The first group included four farmer-maintained landraces [5] and two landrace-based, but breeder-selected populations [6]. The second group included both older (BJ 104, ICMH 451) and current (HHB 94, Pusa 23,

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Pusa 322 and ICMH 356) hybrids recommended for the A (>400 mm rainfall) and AI (<400 mm rainfall) zone environments of north India. These two groups were part of a larger comparison of five different cultivar choices potentially available to arid zone farmers (F. R. Bidinger, unpublished data).

All the entries were grown in bordered 4 row plots (2.4 m x 4.0 m) in replicated trials in an alpha lattice design, between 1999 and 2004 at the Central Arid Zone Research Institute (CAZRI), Jodhpur and the Regional Research Stations, Rajasthan Agricultural University at Nagaur and Mandor (Table 1). All trials were grown under improved management practices for the zone (40 to 60 kg ha^{-1} N and 15 to 20 kg ha^{-1} P, plant populations of approximately 100,000 plants ha^{-1}, complete weed control, timely harvest etc.) but under entirely rainfed conditions.

No trials were abandoned due to low grain yields. Days to flowering were recorded as number of days from sowing to the emergence of stigmas in the main panicle of 50% plants in a plot. Panicle and stover yields were recorded on a net harvest area of 3.6 m^2 (2 rows x 3 m), panicles threshed and the data used to calculate grain yield, biomass and harvest index. Each trial was analyzed separately by the REML method, with replication and block as random effects and cultivar type and genotype within cultivar type as fixed effects. Cultivar type means across trials were determined in an across-trial REML META analysis (Genstat version 9) that adjusted results for the unequal residual variances among trials. Mean grain yields of each group were regressed against location mean biomass, used as a measure of the environmental resources available for crop growth, to assess response to varying environmental resources.

Results and discussion

Total biomass across all 16 trials averaged more than 3500 kg ha^{-1}, ranging from a low of 1553 kg ha^{-1} to a high of 8687 kg ha^{-1}; grain yield averaged more than 1000 kg ha^{-1}, ranging from a low of 439 kg ha^{-1} to a high of 3201 kg ha^{-1} (Table 1). This average is two-to three-times higher than the average grain yield in the arid zone [7] confirming that farmers' typical management and/or input levels are well below optimum, and that grain yields could be increased significantly by improved management, even under purely rainfed conditions. Across this range of environments, the mean grain yield of the hybrids (1128 kg ha^{-1}) was similar to that of the landraces (1114 kg ha^{-1}) (Table 2). However, the two groups of cultivar differed significantly ($P < 0.05$) in total biomass productivity, where the landraces were significantly superior to the hybrids, and in harvest index, where the hybrids were superior. The landraces also had two additional advantages over the hybrids from a farmer's viewpoint: they flowered earlier and produced a significantly higher stover yield. Added to these advantages, a farmer has no seed cost in sowing landraces, and, therefore, no risk of losing his investment if a sowing fails. For all of the above reasons, the landraces clearly appear as the better alternative in the arid zone, even under improved management.

There is still a possibility that the hybrids, despite not being different from the landraces in mean yield across environments, were still more responsive to improved growing conditions than the landraces, and thus could be of benefit to modern farmers who invest in purchasing the inputs. This hypothesis was tested by regressing the mean grain yield of both cultivar groups against the mean trial biomass productivity (Fig. 1). Group mean yields were closely related to site mean biomass in both cases (r = 0.95 for the landraces and r = 0.93 for the hybrids, $P < .001$), confirming the very large environmental effects on grain yield. The slopes of the regression of the hybrid mean grain yield on mean biomass ($Y = -29.6 + 0.420X$) was marginally ($P < .10$) greater that that of the landraces ($Y = -13.2 + 0.352X$). However, the difference in slopes was entirely due to the influence of the highest yielding environment, CAZRI in 2001 (Fig. 1). Excluding this environment, the slope of the regression of hybrid yield ($Y = -4.2 + 0.330X$) on trial mean biomass was identical to that of the landraces ($Y = -7.3 + 0.331X$). This was over a range in grain yield of 400 to 1900 kg ha^{-1}, which effectively covers the whole of the expected yield range in the arid zone, for crops grown without supplemental irrigation, for the vast majority of years. Thus, apart from the very rare high rainfall year, the current hybrids also do not appear to be more responsive to improved environmental conditions than are the farmers' own landraces.

These results are surprising. Published, if less extensive, research [8, 9] would have suggested a crossover response between the landraces and modern hybrids as environmental resources improved. One of the objectives was actually to try to assess where this crossover point occurs and thus in what fraction of years hybrids would offer an advantage to farmers. The lack of evidence of any crossover below a grain yield of 2000 kg ha^{-1} indicates that the hybrids are not more responsive than the landraces to more favorable conditions within the normal range of arid zone environments, even where management is optimal. However, the lack of a crossover also suggests that the landraces are not necessarily better adapted to their traditional arid zone environments than are the hybrids,

Table 1. The seasonal rainfall, days to flower, mean biomass and grain yield in 16 rainfed arid zone environments between 1999-2004

Location	Year	Rainfall (mm)	Days to flower (no.)	Biomass (kg ha^{-1})	Grain yield (kg ha^{-1})
Jodhpur	1999	205	47.8	3171	1023
	2000	256	47.4	4341	1322
	2001	328	48.6	8687	3201
	2003	327	42.4	6202	1869
	2004	169	42.2	2126	506
Mandor	2000	287	50.4	1675	534
	2001	312	54.3	4984	1797
Nagaur	1999	227	48.6	1814	534
	1999*		43.1	2454	623
	2000	342	44.6	1931	487
	2000		44.4	1553	454
	2001	258	49.0	3687	1147
	2000‡	46.8	4345	1285	
	2003	519	46.8	4166	1248
	2003‡		48.5	3231	961
	2004	223	48.9	1859	439
Average			47.1	3514	1089

*Late planting (done on 10th August compared to first planting on 26 July);
‡Reduced level of fertility (20kg ha^{-1} N compared to 40kg ha^{-1} N in the other trials)

Table 2. Comparison of the performance of local farmer landrace cultivars and released single-cross hybrids under well managed (but completely rainfed) research station trials. Data are the means of 16 trials between the years of 1999 to 2004

Comparison	Farmer landraces	Released F_1 hybrids	SEd
Days to flowering	45.8	48.5	0.16
Biomass (kg ha^{-1})	3674	3523	45.7
Harvest index (%)	30.3	32.0	0.37
Grain yield (kg ha^{-1})	1114	1128	ns
Stover yield (kg ha^{-1})	2084	1906	22.8

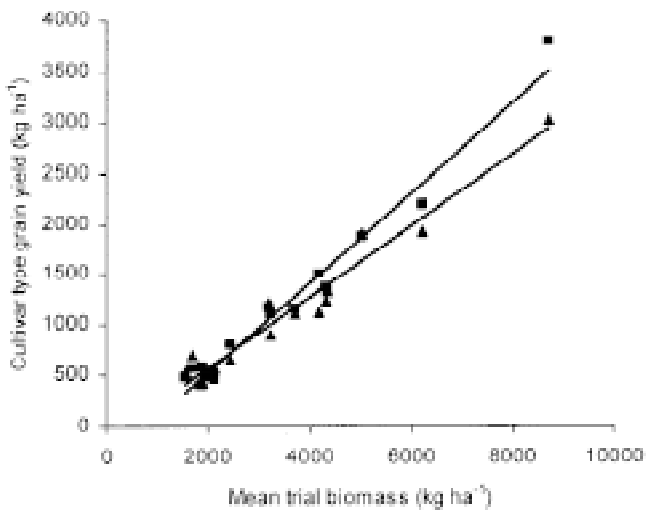

Fig. 1. Grain yield response of six traditional farmer landraces (triangles) and six commercial single cross hybrids (squares) to increasingly favorable environments (quantified by mean biomass) in 16 rainfed arid zone location x year environments from 1999 to 2004

which is also at variance with previous research [8, 9]. The data in Fig. 1 suggested th147at a crossover might occur somewhere between 2000 and 3000 kg ha^{-1}, but this point is far beyond realizable grain yields in the arid zone in the vast majority of years.

The fact that the evaluations were conducted strictly under rainfed conditions, entirely without supplemental irrigation, may be the reason for the failure of the hybrids to demonstrate either a higher overall yield potential or a greater responsiveness to favorable environments. In all except one (CAZRI, 2001) of the 16 environments, moisture was limiting crop growth to some extent, despite trial mean yield levels as high as 1869 kg ha^{-1} (Table 1). The CAZRI 2001 trial was the only one in which the hybrids did have a significantly higher grain yield than the landraces (3814 kg ha^{-1} vs. 3044 kg ha^{-1}), suggesting that non-limiting soil moisture conditions may be a required condition for current hybrids to express their superior yield potential. Two pieces of circumstantial evidence support the link between superior hybrid yields and adequate moisture: (1) the fact that many pearl millet breeding programs targeting the arid zone rely on supplemental irrigation in drier years for both selection and evaluation, implying that there is very little selection actually being done for adaptation to severely drought stressed environments in present breeding programs, and (2) arid zone farmers with supplemental irrigation commonly sow modern hybrids rather than traditional landraces, which is an implicit recognition of hybrid superiority under non water-limiting conditions, but not under rainfed conditions. However, the basic fact of the arid zone is that the great majority of the cropping seasons experience predictable and often severe drought stress at one or more times during the season [10]. The data presented in this paper confirm that under moisture deficit conditions, but otherwise adequate levels of inputs and good management, currently available hybrids offer little yield advantage over farmers' traditional landraces in the arid zone.

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