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Prospects of enhancing pearl millet (*Pennisetum glaucum*) productivity under drought environments of North-Western India through hybrids

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Abstract

Pearl millet is valued for both grain and stover in crop-livestock production system in the drought-prone arid and semi-arid regions of north-western India. In this work the performance of contemporary hybrids and composites of pearl millet were compared for grain and stover yields in drier zone of these regions. A total of 142 hybrids and 84 composites were evaluated in a combination of 94 environments from 1998 to 2009 in the stales of Rajasthan, Gujarat and Haryana. Mean yield in test locations ranged from 611 kg/ha to 2351 kg/ha for grain and from 18.7 q/ha to 69.8 q/ha for stover. Hybrids yielded significantly higher grain than composites with an overall superiority of 25%. Earliness and ability to produce more panicles by hybrids appeared to contribute toward their higher grain yield. Hybrids had stover yield at par with composites. The data indicated that contemporary hybrids are inherently higher yielder than composites even under adverse conditions of arid and drier semi-arid regions. The population buffering mechanism of composites appeared not to give any advantage with espect to yield. Implications of these results are discussed in breeding pearl millet for drier zone of north-western India.

Key words: *Pennisetum glaucum,* pearl millet, arid, drought, hybrids, composites

Introduction

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is the most important cereal crop in the drought-prone parts of Rajasthan, Haryana and Gujarat in north-western (NW) India and is valued for both grain and stover. In comparison to other regions, productivity of pearl millet is very low in the drier parts of NW India [1] primarily due to harsh agro-climatic conditions with scanty and unevenly distributed rainfall (often <400 mm of seasonal rainfall), high soil and air temperatures and, low soil fertility. These climatic factors have significant influence on new cultivar adoption, which remains very low in arid as comparison to non-arid regions [2].

The pearl millet improvement programme in India have been targeting NW regions by developing suitable cultivars for this region. The available choice of cultivar types in pearl millet include hybrids and composites. The key issue often debated is comparative advantage of hybrids or composites under severe drought conditions. It is generally argued that genetically heterogeneous composites might be useful to exploit population buffering mechanism [3-5] in order to provide higher and stable performance under unpredictable drought environments of arid and drier semi-arid areas. However, empirical evidence from well planned experiment conducted in the target region on relative productivity of two groups of cultivars of pearl millet is lacking. The present paper addressed this issue through assessment of comparative performance of contemporary experimental hybrids and composites for grain and stover yields.

Materials and methods

The genetic material consisted of hybrids and composite varieties evaluated in a trials during 1998-2009 at various All India Coordinated Pearl Millet Improvement Project (AICPMIP) centres located in the drier zones of

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Rajasthan, Haryana and Gujarat states. All hybrids and composites within a year were tested in a common trial named as Advance Hybrid and Population Trial (AHPT). Hybrids were based on more than 30 male-sterile lines and diverse pollinators. On the other hand, composites were developed from a range of genetic material of both African and Indian origin.

The multi-location testing resulted in 94 year x location combinations (referred to as environments). During the nine years of evaluation, a total of 226 cultivars were tested which included 142 hybrids and 84 composites. Entries were evaluated using a randomized block design with three replications. Each test entry was grown in 3-4 rows of 5 m length which were spaced at a distance of 60 cm. The uniform distance of 15 cm was maintained after thinning out seedlings within two weeks of sowing. Trials received 20 kg/ha and 8 kg P_2O_5 at sowing and additional 20 kg/ha was topdressed 3-4 weeks after sowing. All the evaluations were undertaken under rainfed conditions

Flowering time was recorded as number of days from sowing till emergence of stigma on the main panicle of 50% plants of a plot. The grain and dry stover yields were measured on plot basis and converted into kg/ha and q/ha, respectively. Data of individual location and across locations within year were subjected to analysis of variance. The mean performance of hybrids and composites was tested following between-group comparisons through single degree-of-freedom contrast analysis as suggested by Gomez and Gomez [6]. Since the composition of trial varied, the trial was analysed each year separately. The comparisons of means between hybrids and composites were also made within the individual year of evaluations.

Results and discussion

Experimental variation and productivity of evaluation environments

The experimental coefficient of variation for both grain and stover yields during 12 evaluation seasons was mostly between 10% and 20%, and exceeded 25% for grain yield only in one case (2002). In three lowest yielding years, CV varied from 14% to 22% which indicated that experimental variation was well under control and didn't override genotypic variation. Thus the cultivars effects were evidently discernible in this study.

Evaluation over 12 years resulted in a wide range of grain and stover yields in trials (Table 1). Grain yield ranged from 611 kg/ha to 2351 kg/ha and stover yield from 18.7q/ha to 69.8 q/ha in 1999 and 2006, respectively. This huge range of environmental means for both grain and stover yields obtained during experimental period underlines extreme variability of environment conditions experienced by pearl millet in drier regions. These yield levels represent a whole range of pearl millet productivity normally achieved in NW India [7] and thus provided excellent opportunities to assess

Table 1. Summary performance of test locations, number of cultivars, grain yield and stover yield in pearl millet evaluation trials during 1998-2009 in A_1 zone of northwestern India

Year	No. of test locations	No. of test cultivars			Grain yield		Stover yield	
		Hybrids	Composites	Total	Mean±SE (kg/ha)	CV (%)	Mean±SE (q/ha)	CV (%)
1998	5	18	4	22	1515±59	15.0	27.1±1.3	18.7
1999	2	15	9	24	611±36	14.4	18.7±1.2	15.9
2000	5	15	8	23	1022±63	21.5	19.6±1.2	21.8
2001	11	5	8	13	1672±51	17.4	33.5±0.9	14.6
2002	3	9	7	16	2053±200	29.2	40.7±2.7	19.6
2003	9	10	6	16	1978±49	12.8	42.2±0.9	11.4
2004	6	14	6	20	1666±65	16.7	44.9±1.8	16.9
2005	10	17	4	21	1690±55	17.8	42.0±1.2	15.8
2006	11	7	9	16	2351±69	16.8	69.8±1.8	15.1
2007	11	7	11	18	2138±50	13.6	58.2±1.2	11.4
2008	12	14	6	20	1801±39	12.9	39.9±0.8	12.2
2009	9	11	6	17	1422±46	16.9	36.2±1.1	15.6

the performance of hybrids and composite under a wide range of conditions. Such an extensive range of both grain and stover yields also suggested that the comparative yield performance of two groups of cultivars judged in this study would be valid across low- and high-yielding conditions.

Hybrids vs composites performance

There were significant differences in grain yield of two groups of cultivars. In all but one year (1999), hybrids yielded significantly higher grain than composites with an advantage of hybrids ranging from 19% in 2007 to 35% in 2003 (Table 2) . The overall advantage of hybrids over composites across all years was 25%. There was a wide range in grain productivity of both hybrids and composites. Each year, the highest yielding hybrid was always superior to highest yielding composite. The potential advantage in grain yield of best hybrid was up to 62% in 1998 and 20-40% higher yield in best hybrids was very common. The mean advantage of highest yielding hybrids was 33%.

Hybrids, in general, flowered earlier than composites though earliness was not always necessarily significant (Table 3). Similarly, hybrids produced significantly higher panicles/plant than composites. Grain yield was always negatively correlated with day to flowering ($r = -0.11$ to -0.51) and positively correlated with panicle number ($r = 0.31$ to 0.63) during present evaluations. Thus combined contribution of both earliness and ability to produce more panicles might have helped hybrids in yielding higher than composites as these traits have been reported to be most important phenotypic traits in determining the grain yield performance under water-limiting conditions. Early flowering helps in escaping the late season moisture stress [8-11] which is very common in NW India. Ability of genotypes to produce higher panicle number under drought conditions provides them development plasticity as damage to main panicle by drought can be effectively compensated by tiller panicles [12-14].

There might also be certain physiological basis of higher grain yield of hybrids than composites. Present results could only be explained that hybrids had either increased access to water or had higher transpiration efficiency. Establishing such relationship was beyond the aim of present research but there are reported genotypic differences of transpiration and transpiration efficiency determining crop productivity under drought environments [15-19]. Blum [20] also suggested that enhanced crop production under drought stress can be achieved primarily by maximizing soil water capture while diverting the largest part of the available soil moisture toward stomatal transpiration.

Unlike grain yield, hybrids didn't offer any advantage for stover yield over composites. The mean stover yield of hybrids and composites was similar in 10 out of 12 seasons (Table 4) and in remaining two

Table 2. Grain yield performance of pearl millet hybrids and composites in A1 zone of northwestern India during 1998-2009

Year	Grain yield of hybrids (kg/ha)			Grain yield of composites (kg/ha)		
	Mean*	Minimum	Maximum	Mean*	Minimum	Maximum
1998	1573b	1164	2066	1254a	1218	1279
1999	630a	243	1196	580a	249	845
2000	1116b	901	1449	845a	615	1032
2001	1905b	1748	2191	1526a	1245	1835
2002	2278b	1937	2716	1765a	1937	2249
2003	2192b	1755	2714	1621a	1526	1690
2004	1798b	1577	1994	1360a	1085	1632
2005	1748b	1171	2171	1445a	1191	1637
2006	2661b	2287	3176	2111a	1687	2470
2007	2371b	1898	2656	1990a	1626	2475
2008	1901b	1792	2070	1570a	1428	1673
2009	1544b	1310	1768	1199a	1072	1290

*mean performance of hybrids and composites suffixed by different letter is statistically different at $P<0.05$

years hybrids produced 9 to 14% lower stover. Best of the composites were able to produce 6-15% higher stover yield. Composites grew significantly taller than hybrids at least in half of the evaluation seasons and tended to be later in flowering (Table 3). Stover yield had positive correlation with both days to flowering (r = 0.31 to 0.81) and plant height (r = 0.22 to 0.67). Thus more height and a slightly later flowering of composites might have helped them produce greater stover yield. Indeed, plant height has been reported to contribute

Table 3. Days to flowering, panicles/plant and plant height of pearl millet hybrids and composites in A_1 zone of northwestern India during 1998-2009

Year	Days to flowering (no.)		Panicles/plant (no.)		Plant height (cm)	
	Hybrids	Composites	Hybrids	Composites	Hybrids	Composites
1998	50.3a*	50.8a	1.7a*	1.7a	150a	165a
1999	55.4a	55.1a	-	-	120a	129a
2000	50.5a	51.1a	1.9a	1.9a	141a	146a
2001	44.8a	48.3a	2.5a	2.2a	168a	186b
2002	44.8a	47.9b	2.3b	2.0a	149a	156a
2003	43.8a	47.5b	2.0b	1.8a	176a	191b
2004	43.4a	46.2b	2.8b	2.4a	163a	172b
2005	51.1a	51.8a	2.2a	1.8a	152a	156a
2006	45.3a	48.2b	2.6b	2.2a	187a	206b
2007	47.6a	50.3a	2.4a	2.2a	177a	194b
2008	48.0a	49.3a	2.2b	1.9a	168a	174a
2009	46.5a	49.5b	2.2b	2.0a	148a	158b

*mean performance of hybrids and composites suffixed by different letter is statistically different at $P<0.05$

Table 4. Stover yield performance of pearl millet hybrids and composites in A1 zone of northwestern India during 1998-2009

Year	Stover yield of hybrids (q/ha)			Stover yield of composites (q/ha)		
	Mean*	Minimum	Maximum	Mean*	Minimum	Maximum
1998	27.2a	21.0	33.0	26.8a	24.0	31.0
1999	18.1a	7.0	31.0	19.7a	14.0	27.0
2000	20.1a	16.0	27.0	18.5a	12.0	25.0
2001	30.2a	25.0	36.0	35.6a	27.0	43.0
2002	37.9a	32.0	49.0	44.3b	32.0	50.0
2003	41.9a	36.0	48.0	42.7a	38.0	46.0
2004	45.4a	35.0	53.0	43.5a	31.0	56.0
2005	41.6a	36.0	48.0	43.8a	37.0	49.0
2006	69.0a	54.0	87.0	70.4a	55.0	82.0
2007	54.7a	50.0	59.0	60.4b	52.0	70.0
2008	39.1a	35.0	44.0	41.8a	37.0	46.0
2009	35.4a	28.0	40.0	37.7a	32.0	44.0

*mean performance of hybrids and composites suffixed by different letter is statistically different at $P<0.05$

directly to stover productivity and there is also a positive association between lateness and greater stover productivity [21-23].

Implication in breeding for arid zone

An average advantage of 25% in grain productivity of hybrids over current composites certainly makes a strong case for hybrids for arid and semi-arid regions. Moreover, this scale of advantage in grain yield came without any penalty in stover yield of hybrids in comparison with composites. The data presented in this study clearly indicated that contemporary hybrids are inherently higher yielder than composites at least under the range of productivity levels obtained in present evaluations. The population buffering mechanism operative in genetically heterogeneous open-pollinating composite varieties [3] thus not appear to give advantage over hybrid buffering at productivity levels realized in this study. The present study was not designed to quantify the buffering effects of hybrids and populations buffering. Such studies will be quite interesting.

Other consideration, in cultivar adoption in existing seed supply system of pearl millet is the multiple sowings especially in western Rajasthan. Composites have an edge over hybrids as they are self-perpetuating and harvested seed can be used to plant next crop. However, such an option would come with a significant penalty at least for grain yield.

The data presented in this study clearly demonstrated significant superiority of hybrids over composites for grain yield under arid and semi-arid conditions. Thus hybrids are likely to play a much greater role than composites in enhancing pearl millet productivity in arid regions.

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