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Heterosis in crosses between landraces and elite exotic populations of pearl millet [*Pennisetum glaucum* (L.) R. Br.] in arid zone environments

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Abstract

Stress-adapted landraces of pearl millet [*Pennisetum glaucum* (L.) R. Br.] are prevalently grown in the drought prone regions of northwestern India. This study evaluated 12 crosses between selected landraces and elite composites along with 7 parental populations for two years in arid zone environments. There was significant genetic variation among test entries which was due to variation due to parental populations, crosses and 'parent *vs.* cross'. Landraces and elite exotic composites represented two contrasting, but complementary, groups of genetic material. Landraces produced the greatest amount of biomass and stover yield with lowest harvest index while elite composites had the lowest biomass and stover yield with highest harvest index. Crosses produced almost as high biomass as landraces but their better partitioning resulted into highest grain yield in them. Manifestation of heterosis in crosses varied for different characters. Grain yield was the most heterotic trait with mean heterosis of 17% and other traits *viz.*, days to flowering, plant height, panicle length and harvest index were far less heterotic with mean heterosis ranging between 2-4%. Data indicated that significant heterosis for total biomass is very critical in order to obtain simultaneously improvement in both grain and stover yields. The expression of grain yield heterosis in the best crosses was realized through differential expression of heterosis in various yield-contributing traits.

Key words: Pearl millet, heterosis, adaptation, landrace, arid zone, drought, genetic diversification

Introduction

Pearl millet [*Pennisetum glaucum* (L.) R. Br.], an important cereal grown under rainfed conditions, is the staple food for people living in desert areas. Its stover forms the most important source of dry ration for ruminant livestock. Limited and erratic rains in arid regions of western Rajasthan lead to frequent droughts of unpredictable intensity and duration [1, 2]. The low water holding capacity and poor nutrient status of native soils and high temperature conditions further aggravate the situation of drought. Farmers of arid zone prefer to grow adapted landraces to minimize the risk of crop failure [3] resulting into low adoption of improved pearl millet cultivars [4, 5].

Though landraces are thought to have a fair amount of adaptation to abiotic stresses but are inherently low in their grain productivity [6]. In contrast, the elite materials might have high potential grain productivity but might not necessarily possess adaptation to extreme stress environments [7]. Obviously a need exists to diversify the base of landraces through use of appropriate genetic material to amalgamate the adaptation of landraces with high productivity of elite genetic materials. This study was conducted to assess the performance of crosses between these two groups of materials so as to identify the most heterotic cross combinations to use them in on-station breeding programme targeting the arid zone farming system.

Materials and methods

The material was developed by crossing four pearl millet landraces originating from eastern and central Rajasthan with three elite composites *viz.*, BSEC, MC and EC developed from early maturing lines of Indian and African origin. The crosses between landraces and elite populations were attempted by manual pollination. A minimum of 150 plants of parental populations were involved in each cross.

A total of 19 entries consisting of 12 crosses and 7 parental populations were evaluated at the Central Arid Zone Research Institute, Jodhpur during *kharif* 2001 and 2003 under rainfed conditions. Material could not be evaluated in 2002 because of failure of monsoon rains. The total rains received during this year were 32.6 mm and the crop season was completely lost. Entries were evaluated using randomized block design with 3 replications. The plot size was 2 rows of 4m length and the rows were grown at a distance of 60 cm from each other with plant-to-plant spacing of 15 cm within rows.

Data on days to flowering, number of panicles, grain yield, dry stover yield, biomass and 1000-seed weight were recorded on plot basis. At maturity, plant height and main panicle length were recorded on five randomly taken competitive plants and their mean values were taken as average height and panicle length. Harvest index was calculated as ratio of grain yield to biomass yield and was expressed in percentage. Growth rate was determined as biomass yield/days to flower + 10) [8] as a measure of productivity independent of duration. Panicle m^{-2}, grain yield per panicle and number of grains per panicle were derived from the recorded traits. The analysis of variance was performed across years and heterosis (%) over mid-parent values was calculated.

Results and discussion

The crop growing conditions during both crop seasons were favourable during crop establishment and vegetative stages due to good amount of rainfall (Table 1) during pre-flowering period. This resulted into excellent vegetative growth and a high level of biomass production (8 to 9 tones/ha). Both crop seasons (2001 and 2003) fairly represented the slight terminal moisture stress commonly experienced by pearl millet in arid regions as lesser rains occurred during post-flowering period. Consequently the grain filling was slightly affected resulting into harvest index of only 23-25%.

Mean squares due to genotypes were highly significant for all the characters under study (Table 2) suggesting significant genetic differences among the test entries. The genetic variation due to parents, crosses and 'parent *vs.* cross' contributed significantly to genotypic variation for all traits except panicles m^{-2} (Table 2). Year × genotype interactions were also highly significant for all traits except panicle m^{-2} indicating that it was the most stable trait. The interaction of years with both parent and cross generally contributed to genotype × year interaction but parent *vs.* cross × year interaction was nonsignificant for all traits except harvest index (Table 2).

Table 1. Mean flowering time, biomass, harvest index and grain and stover yields of trials conducted during 2001 and 2003 at Jodhpur. Total amount of rainfall received during pre- and post-flowering periods of crops has also been given

Trait	Unit	2001	2003	Mean
Time to flower	Days	47.2	47.1	47.1
Biomass yield	q/ha	90.4	85.4	87.9
Harvest index	%	23.3	24.7	24.0
Grain yield	q/ha	20.8	21.0	20.9
Stover yield	q/ha	56.9	53.6	55.3
Pre-flowering rains	mm	317.0	292.0	304.5
Post-flowering rains	mm	11.0	35.0	23.0
Total rains	mm	328.0	327.0	327.5

Two groups of parental populations significantly differed from each other for all traits as indicated by significant mean squares due to a single df contrast 'landrace *vs.* elite composite' (Table 2). The landraces produced the greatest amount of biomass, tillers and stover yield (Table 3), however, their mean harvest index was lower than elite populations resulting into poor grain yield. Elite composites though had more harvest index but their poor biomass accumulation capacity led to lower stover yield. This probably reflects the reason for continuing preference by farmer for local landraces over elite cultivars in the mixed crop-livestock farming system in northwestern India [9] where stover is as important as grain to sustain their livestock. Landraces and elite exotic composites appeared to represent two contrasting, but complementary, groups of genetic material. Therefore, the adapted landraces need to be diversified through introgression of suitable genes to generate new combinations of traits.

The differences between parental populations and their crosses were also significant and consistent across years for all characters except harvest index (Table 2).

Table 2. Mean squares from pooled analysis of variance for eight traits in pearl millet

Source	df	Days to flower	Panicles m^{-2}	Grain yield	Stover yield	Biomass	Harvest index	1000-seed weight	Growth rate
Year (Y)	1	0.31	43.8**	161	30500**	70593**	49.6**	2.53**	1647**
Genotype	18	35.9**	4.6**	4090**	41447**	61951**	63.5**	1.54**	1450**
Parent (P)	6	45.6**	9.6**	4396**	72052**	102089**	112.9**	1.63**	2366**
Landrace (L)	3	23.0**	12.0**	7659**	17246**	63819**	26.7**	1.39**	2454**
Elite composite (E)	2	35.4**	6.9*	1061*	5014	838	33.3**	0.41	90
L vs. E	1	134.1**	7.7**	1274**	370545**	419403**	530.5**	4.78**	6651**
Cross (C)	11	32.3**	2.3	1787**	24889**	30905**	38.8**	1.52**	531*
P vs. C	1	17.5*	0.5	27590**	39968**	162630**	39.0**	1.18**	6069**
Genotype × Y	18	7.2**	3.2	1934**	13371**	22533**	14.8**	0.30**	745**
P × Y	6	10.2*	6.2**	1281**	18428**	35294**	13.3**	0.45*	1195**
L × Y	3	14.3**	2.2	278	8529	5823	11.8**	0.11	196
E × Y	2	6.2	11.6**	2475**	5287	22480*	13.9*	1.12**	991*
L vs. E × Y	1	5.8	7.5*	1902**	74406**	149334**	16.5*	0.12	4603**
C × Y	11	6.0*	1.8	2434**	11262**	16889**	15.7**	0.23	561**
P vs. C × Y	1	2.3	0.6	362	6228	8065	14.6*	0.21	74
Error	72	2.55	1.96	425.1	3810.2	6299.1	3.17	0.142	213.6

*,**Significant at $P < 0.05$ and 0.01 respectively

Table 3. Mean performance of landraces, elite composites and crosses for time to flowering, grain yield, stover yield, total biomass, growth rate and harvest index (data are mean of 2001 and 2003

Group	Time to flower (days)	Panicles m^{-2}	Grain yield (gm^{-2})	Stover yield (gm^{-2})	Biomass (gm^{-2})	Growth rate (gm^{-2} d^{-1})	Harvest index (%)
Landraces	49.2	10.4	184	609	917	149.4	20.1
Elite composites	45.6	9.6	195	420	715	124.0	27.3
Crosses	46.8	9.9	221	567	908	153.6	24.4
SE (d)	0.48	0.49	6.75	20.24	27.90	5.10	0.47

Crosses produced higher grain yield though their performance was intermediate between their parental means for stover yield and harvest index (Table 3). Crosses produced almost as high biomass as landraces but significantly higher biomass partitioning (harvest index) of crosses than landraces resulted into their highest grain yield. Since there were meaningful differences between mean flowering time of landraces and other two groups of material (Table 3), the growth rate performance is more appropriate measure than total biomass. By this criterion, crosses exhibited the greatest growth rate and elite composites the least.

Mean squares due to single df contrast 'parent *vs.* cross' were highly significant for all traits except panicles m^{-2} indicating crosses were exhibiting a significant amount of heterosis for all traits (Table 2). Though overall heterosis for panicles m^{-2} was not significant but specific crosses did exhibit considerable improvement in their tillering capacity over their parents. The mutual cancellation of positive and negative heterosis in specific crosses might have led to overall zero heterosis for panicles m^{-2}. Manifestation of heterosis varied for different characters; grain yield being the most heterotic trait with mean heterosis of 17% and as many as 6 (50%) crosses exhibiting significant heterosis (Table 4). On the other hand, days to flowering, plant height, panicle length and harvest index were less heterotic traits with mean heterosis ranging between 2 to 4% for them. The negative heterosis for days to flowering indicated that crosses were in general earlier in flowering than their parents. It was interesting to note that average heterosis for biomass was 12% and for harvest index only 3%. Thus heterosis for biomass appeared largely responsible for expression of the heterosis for grain yield. For stover yield, the average heterosis was greater than 10%. Certain crosses showed a heterosis up to 35-40% for grain yield, stover yield, biomass and growth rate. Expression of heterosis in pearl millet has been reviewed [10, 11]. Most of the estimates have been obtained with inbred parents which give inflated value of heterosis especially under stress environments. Only a few studies have determined heterosis in open-pollinated materials [12-16] and magnitude of heterosis observed in these studies compares well with values obtained in this study except in that of Presterl and Weltzien [15] who observed much lower heterosis (7%) both for grain yield and stover yield. However, they did observe higher heterosis in stress prone Rajasthan environments than other favourable environments.

Table 4. Mean, maximum and minimum heterosis (%) and number of crosses with significant heterosis for eight traits in the crosses between 4 landraces and 3 elite composites

Trait	Heterosis (%)			Number of crosses with significant heterosis
	Mean	Maximum	Minimum	
Time to flower	–1.15	7.48	–7.33	4
Plant height	4.13	10.52	–4.59	6
Panicle length	2.41	12.02	–7.46	1
Grain yield	17.42	42.40	–0.50	6
Stover yield	10.79	41.11	–19.30	4
Biomass yield	12.09	37.77	–9.97	4
Harvest index	2.92	22.57	–9.95	2
Growth rate	13.15	35.11	–4.66	5

Five crosses that had highest levels of heterosis for both grain yield and stover yield were based on two landraces only: 9920 appeared in three combinations and 9918 in two (Table 5). These landraces thus appeared potential parents for generating heterotic

Table 5. Magnitude of heterosis (%) for grain yield and its yield components, stover yield, biomass and growth rate in the pearl millet crosses between landraces and elite composites. Figures in parenthesis are mean grain yield (g m^{-2}) and stover yield (g m^{-2}) per se of crosses

Cross	Grain yield	Stover yield	Panicles/ m^2	Grain yield/ panicle	Grain number/ panicle	1000 grain weight	Biomass yield	Growth rate
9920 × MC	42.4** (226)	25.3** (615)	22.5**	15.7	20.4*	–2.9	30.8**	33.7**
9920 × BSEC	35.9** (234)	23.5** (571)	23.0**	5.1	0.4	5.9*	28.1**	35.1**
9918 × BSEC	25.5** (245)	10.0 (552)	–4.71	25.0**	7.5	15.8**	10.7*	10.3*
9920 × EC	26.4** (207)	41.1** (682)	3.21	19.7*	29.5**	–7.3	37.8**	29.2**
9918 × EC	23.5** (230)	23.3** (644)	–14.2*	45.9**	40.9**	3.4	20.4**	18.1**

*,**Significant at P < 0.05 and 0.01 respectively

crosses to use them further in breeding programmes although limited number of crosses involving landraces and elite composites were included in the present study. Five most heterotic crosses for stover and grain yields exhibited positive and significant heterosis for total biomass reinforcing that heterosis for total biomass is very critical in order to obtain simultaneously improvement in both grain and stover yields [17]. Further perusal of data indicated that expression of grain yield heterosis in the best crosses was realized through differential expression of heterosis in various yield-contributing traits. Grain yield heterosis in crosses 9920 × MC and 9920 × BSEC was expressed mainly thorough increased tillering (Table 5). On the other hand, crosses 9918 × BSEC, 9920 × EC and 9918 × EC exhibited heterosis in yield mainly through heterosis in grain yield/panicle that was further due to expression of heterosis in grain weight in cross 9918 × BSEC and heterosis in number of grain/panicle in crosses 9920 × EC and 9918 × EC. These data indicate that enhanced heterosis for one trait might be associated with slightly reduced heterosis in other traits. Such compensation in various yield components is commonly observed in cereals [18].

Out of five most heterotic crosses (Table 5), two crosses *viz.*, 9920 × EC and 9918 × EC did express high mean performance and high magnitude of heterosis for both grain and stover yields. Hence these crosses could be the most potential population crosses for developing dual-purpose genetic materials that can be used to widen the germplasm base and to combine the high yield potential of elite material with good adaptation of landraces.

The results of this study suggested that landraces and elite composites have contrasting but complementary combinations of traits and crosses between them have certain advantages over their parental combinations. It should, however, be noted that only limited number of crosses were evaluated in this study and hence the results need to be interpreted with a caution. It might be quite interesting to know whether magnitude of heterosis, as observed in this study, is a general pattern across a greater number of crosses involving landrace and exotic genetic materials.

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