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IDENTIFICATION OF PARENTS AND CROSSES FOR BREEDING IMPROVED PEARL MILLET RESTORER

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ABSTRACT

A diallel analysis involving seven restorer lines of pearl millet [*Pennisetum glaucum* (L.) R. Br.] derived from the material of Indian and African origin, conducted using data from 21 F_1 and 7 parents without reciprocal showed that mean squares due to general and specific combining abilities were highly significant.

Interaction of general and specific combining abilities with environment was significant for all the traits, i.e., grain yield, time to 50% flowering, plant height, panicle length and panicle girth. General combining ability for grain yield of the pollinators ICMP 451 and ICMP 83401 was positive and consistent across test environments. Other pollinators had either negative general combining ability or nonsignificant general combining ability for grain yield.

Specific combining abilities for grain yield of ICMP 451 × ICMP 501, ICMP 451 × ICMP 84122 and ICMP 501 × ICMP 83401 were high and significant across environments. In these three crosses one parent had high general combining ability for grain yield. The crosses ICMP 501 × ICMP 84122 and ICMP 84913 × ICMP 84122 had high specific combining ability effects for grain yield. In these two crosses both the parents had low general combining ability effects. These five crosses were significantly higher yielding over mean grain yield. However two crosses ICMP 451 × ICMP 501 and ICMP 501 × 84122 were considered superior to the other three based on their ability to produce higher frequency of good progenies.

Key words : Pearl millet, restorers, gca, progeny testing, genetic variance.

In the first phase of breeding pollinator lines in pearl millet at ICRISAT-Patancheru, inbreeding and screening against downy mildew pathogens were the major approaches. Parental materials were landraces, segregating materials from crosses between lines from India and Africa, and composite populations [1]. Some introductions of unknown breeding history from Kansas State University, USA and

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West and East African breeding stations, particularly Kano, Nigeria and Serere, Uganda formed the exotic parents. Parental lines of Indian origin or previous (i.e., pre-ICRISAT) introductions from Africa formed the bulk of adapted parents. These groups were genetically quite diversed from the male-sterile parental lines which were in use, which originated mainly from Tifton, Georgia, USA. Many pollinators, producing hybrids that yielded about 3.5 ton grain ha^{-1}, were identified [1]. For further increase in grain yield effective approach is necessary since the above methods no longer provide evidence of such a possibility.

Time to 50% flowering within the medium-maturity group has effect on realization of potential grain yield. In this group plant height is also correlated positively with grain yield. Decreasing plant height without considerable grain yield loss may lead to improved plant type. Head volume makes positive contribution to grain yield through increase in grain number. Panicle length and panicle girth are components of head volume and often are correlated with grain yield. Burton [3, 4] observed that on the same male-sterile line, superior pollinators could be derived by crossing between elite pollinators and selecting high-yielding crosses, for pearl millet hybrid forage production. In pedigree breeding, the need for identification of the parental lines carrying favorable dominant loci is very high. It is also indicative that in pearl millet grain hybrid breeding, the role of both additive and dominance gene action is important [5, 6]. Perhaps it is as important as in forage [7]. Estimates of general and specific combining ability can be obtained from a diallel analysis. High yielding and heterotic F_1s with parents having high general and specific combining ability could therefore, be identified using diallel analysis including F_1s and parents.

Components of genetic variances interacted with environment [8] in a group of pearl millet materials that were predominantly Indian. We assessed lines of Indian and African origin and those derived from crosses of Indian and African breeding lines. Therefore, it was necessary to examine interaction of the pollinators and their crosses with environment and select the parents and crosses reliably. This is likely to help identify parents to generate progenies that might exhibit superior performance across diversed locations.

MATERIALS AND METHODS

Seven restorer lines were studied that represented elite and diverse materials of pearl millet. Three restorers IPC 0094, IPC 0107, and IPC 0382 are released for cultivation in semi-arid regions of India (Table 1). The remaining four produce hybrids having similar grain yield as the released hybrids. This region is characterized

with low rainfall and relatively lower soil fertility than where higher yielding cereals like maize and rice are grown.

Table 1. Description of parental lines used for assessment in diallel

Line	Identity	Pedigree	Identification remarks
ICMP 423	IPC 0094	EC-S_3-211-1-2	Tall, medium flowering, high tillering and conical-shape panicles
ICMP 451	IPC 0107	LCSN 2-1-2-1-1	Tall, medium flowering bristled, candle-shape panicles
ICMP 501	IPC 0382	(B 282 × 3/4 EB-1001-11)-9-2-1 (Dwarf)	Dwarf, late flowering, bold, semi-compact panicles, purple glumes
ICMP 84913	IPC 1329	(NEp 7-5603 × SS 48-40)-4-6	Medium height, medium flowering and small panicles
ICMP 84122	IPC 0338	(LCSN 439-3-3-2 × gulisitha)-B-1-1- 1	Tall, medium flowering, hairy nodal ring and candle-shape panicles
ICMP 83506	IPC 1443	(B 282 × SIOB)-3-1-3-2	Tall, medium flowering, cylindrical panicles and pigmentation in internode and leaf base.
ICMP 83401	IPC 0417	[(G73-FS-41 × J 1188 × cassady)] 5-6-1-2	Tall, early flowering an spindle-shape with loose base

The parents were sown at staggered interval at ICRISAT- Patancheru, in dry season nursery 1988 and crossed in a half diallel fashion. Sufficient F_1 seeds were produced for four trials. Seven parental lines and 21 F_1's were evaluated in a randomized complete block design with three replications across four environments over two years. In 1988, one trial was grown in Alfisoil at ICRISAT-Patancheru at 17.5° N, and the other at the ICRISAT-TNAU (Tamil Nadu Agricultural University) Cooperative Nursery, Bhavanisagar at 11.0°N, in India. In 1989, one trial was grown in Alfisoil and the other in Vertisoil at ICRISAT- Patancheru. Fertilizer dose was 40 kg ha^{-1} N and the same amount of P_2O_5 as basal dose one week prior to planting and 40 kg ha^{-1} N as topdressing 30 days after seedling emergence using di-ammonium phosphate and urea. Weed control was done through interculture and hand weeding. Gross plot size was 4 rows and 4 m length with 0.75 m distance between rows. Plant to plant distance within row was 0.1 m. Two central rows were harvested after trimming 0.5 m of both ends for grain yield data. Other observations, plant

height, time to 50% flowering, panicle length, panicle girth were recorded as :

1) *Plant height* : Measured as the mean length from ground level to the tip of panicle of five randomly selected plants.

2) *Time to 50% flowering* : Measured as number of days from the date of sowing to emergence of panicle from flag leaf.

3. *Panicle length* : Measured as the mean length, in 10 randomly selected panicles, from the base to the tip of the panicles.

4. *Panicle girth* : The circumference of the middle portion of 10 randomly selected panicles.

Five crosses, including four with high F_1 yield and SCA effects and one with both parents having high GCA effects but relatively low yield were selected for deriving F_6 inbreds. Five F_6 progenies from each of these crosses were randomly selected for crossing on to inbred seed parent 81A and broad-based tester BSDIT (Bold Seeded Dwarf Inbred tester). These 50 hybrids were evaluated at ICRISAT-Patancheru in a randomized complete block design with three replications during rainy season 1995 and dry season 1996. Agronomic practices were similar to 1988 trial. The observations were also recorded in the similar fashion as in the diallel cross evaluation.

Previous work at ICRISAT-Patancheru involving many inbred lines indicated no evidence of significant reciprocal difference for the traits studied. Other studies also indicated similar trend [8]. Therefore no attempt had been made to study reciprocal difference with the present set of materials. Validity of assumptions, such as (1) independent effect of nonallelic genes, (2) no multiple allelism, and (3) independent gene distribution required for variance component estimates, are not critical in the present study since only combining abilities have been taken into consideration for selection. Therefore no attempt was made to test these assumptions. Genetic parameters were estimated according to Model-1 method -2 of Griffings [9] and [10], elaborated by [11, 12] using GENSTAT program.

RESULTS AND DISCUSSION

Combined analysis of variance (Table 2) indicates that for all the five traits measured, except for panicle girth both the general and specific combining ability effects were highly significant as in previous studies [4, 5, 13, 14]. Both the types of effects, general and specific combining ability interacted significantly with the environments studied. Mehindratta *et al.* [8] had similar results in a diallel cross of

Table 2. Mean squares for combining ability for the characters studied across four environments

Source	df	grain yield (kg ha^{-1})	Time to 50% flowering (days)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)
GCA	6	665960***	79.972***	1151.556**	139.166***	6.772
SCA	21	3561770***	32.926**	1933.548***	12.379**	1.1120**
GCA × ENV	18	303744**	4.193*	323.148**	1.706**	0.636*
SCA × ENV	63	218142**	2.235**	135.952**	0.930*	0.341*
Error	216	54741	1.111	39.433	0.673	0.138

* = $p < 0.05$; ** p = < 0.01; *** = $p < 0.001$

18 pearl millet inbred lines of unknown parentage in a number of planting date environments.

Table 3. Parental means for the characters studied across four environments

Parents	Grain yield (kg ha^{-1})	Time to 50% flowering (days)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)
ICMP 423	1749	55	211	16	8.4
ICMP 451	1854	52	197	25	9.6
ICMP 501	944	64	115	22	9.9
ICMP 84913	1670	54	192	18	7.8
ICMP 84122	1179	54	204	16	9.1
ICMP 83506	1364	52	180	22	8.8
ICMP 83401	1719	49	191	20	8.4
SE ±	121.4	0.56	3.32	0.41	0.19
Mean	1497	54.3	184.3	19.9	8.9

Mean values of parents and their general combining ability effects across locations are presented in Tables 3 and 4. ICMP 451 has the highest mean and significant and positive general combining ability effects for grain yield. This parent also has significant general combining ability effects for four traits, time to 50%

Table 4. GCA effects of parents across four environments

Parents	Grain yield (kg ha^{-1})	Time to 50% flowering (days)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)
ICMP 423	–33.987	0.489**	5.983**	–2.525**	–0.379**
ICMP 451	225.763**	–0.946**	3.270**	2.132**	0.291**
ICMP 501	–7.394	2.851**	–10.360**	0.234**	0.597**
ICMP 84913	–62.079	–0.149	–0.165	–0.655**	0.640**
ICMP 84122	–26.469	0.276	5.038**	–2.247**	0.044
ICMP 83506	–205.505**	–0.631**	–3.554**	1.317**	0.2977**
ICMP 83401	109.670**	–1.890**	–0.212	–0.257	–0.209**

* = $p < 0.05$; ** = $p < 0.01$

flowering, plant height, panicle length, and panicle girth. The other parent with high grain yield and significant positive general combining ability effect for grain yield is ICMP 83401. This parent has significant negative general combining ability effects for time to 50% flowering, and panicle girth.

Table 5. SCA effects of eight crosses across four environments

Crosses	Grain yield (kg ha^{-1})	Time to 50% flowering (days)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)
ICMP 451 × ICMP 501	832.417**	–2.396**	29.269**	1.137	0.402*
ICMP 501 × ICMP 84122	925.398**	–2.285**	18.917**	0.933	0.300
ICMP 451 × ICMP 84122	684.741**	–1.322**	5.120	0.701	–0.412*
ICMP 84913 × ICMP 84122	810.250**	–0.785	7.139	0.238	0.095
ICMP 501 × ICMP 83401	616.176**	–2.951**	20.917**	1.359	0.236
ICMP 84913 × ICMP 83401	624.028**	–0.618	0.472	0.414	0.231
ICMP 423 × ICMP 451	394.176**	–0.618	–2.157	0.146	0.062
ICMP 451 × ICMP 83401	238.186*	–1.572**	–2.380	–0.206	0.083

* = $p < 0.05$; ** $p = < 0.01$

ICMP 83506 has significant but negative general combining ability effects for grain yield. It has significant general combining ability effects in the desirable direction with respect to other traits, i.e., negative for time to 50% flowering and plant height, and positive for panicle length and panicle girth. However, as this parent has neither high general combining ability for yield nor high specific combining ability in crosses with other parent (Tables 5 and 6), it has been dropped from the breeding program for breeding new pollen parents.

Four other parents ICM 423, ICMP 501, ICMP 84913, and ICMP 84122 have nonsignificant general combining ability effects for grain yield (Table 4). The parent ICMP 423, in combination with other parents, such as ICMP 451, produced significant specific combining ability effects. However, mean hybrid performance is not significantly higher than overall mean (Table 6).

Table 6. Mean performance of Seven superior yielding hybrids across four environments

Crosses	Grain yield (kg ha^{-1})	Time to 50% flowering (days)	Plant height (cm)	Panicle length (cm)	Panicle girth (cm)
ICMP 451 × ICMP 501	3888*	50.0	229	27.4	10.8
ICMP 501 × ICMP 84122	3729*	51.3	220	22.8	10.5
ICMP 451 × ICMP 84122	3721*	48.5	220	22.5	9.5
ICMP 84913 × 84122	3559*	50.0	229	27.4	10.8
ICMP 501 × ICMP 83401	3555*	48.5	217	25.3	10.2
ICMP 423 × ICMP 451	3423	49.4	214	21.7	9.5
ICMP 451 × ICMP 83401	3411	46.1	207	23.6	9.7
SE ±	121.4	0.56	3.32	0.41	0.19
Mean	3280	49.3	214	22.6	9.8

* = Significantly superior to mean

ICMP 501 and ICMP 84122 in combination with themselves or in combination with ICMP 451 produced high yield and highly significant SCA (Tables 5 and 6). ICMP 84913 produced high yield and is highly significant specific combiner with ICMP 84122. The parents ICMP 451 and ICMP 83401 are good general combiners and in combination with themselves produce significant specific combination. The hybrid yield of this combination is, however, significantly lower than the three top

yielding combinations; (1) ICMP 451 × ICMP 501, (2) ICMP 501 × ICMP 84122, and (3) ICMP 451 × ICMP 84122.

Frequency of superior hybrids derived from various crosses are shown in Table 7. The cross having both the parents with high GCA appears to be inferior to the crosses having at least one parent with low GCA in producing superior inbreds. Out of four high yielding crosses two crosses ICMP 451 × ICMP 501 and ICMP 501 × ICMP 84122 were superior over the other two in generating superior progenies.

Burton [7] studied genetic variance of pearl millet and indicated the importance of heterosis in forage hybrid breeding. In pearl millet, many studies have been conducted to estimate combining ability effects involving primarily material of Indian origin [6, 13, 14]. In ICRISAT, many restorers have been bred and evaluated for adaptation to diverse environments from 11° N to 29° N latitude in India. The parental lines used to derive these materials contain both Indian and African germplasm in their parentage (Table 1). The parental lines involved in this study differed in genetic make up, and produced single-cross hybrids that yielded more than then widely cultivated single-cross hybrids in India. However such trend is no longer continuing. It is, therefore, essential to obtain higher grain yield potential through breeding new pollinators using appropriate approach.

In maize, in USA, it has been amply exemplified that crossing between elite restorers would generate variability to select for superior progenies. Variance component analysis indicates that in pearl millet, major proportion of genetic variability is nonadditive [15], however, additive genetic variance is also substantial, which is to certain extent different from maize. These conclusions, however, are drawn based on the materials of primarily Indian origin and as pointed out by [16], these estimates on the components of genetic variances to certain extent may be biased because of nonvalidity of assumptions of diallel analysis. Nevertheless, examination of combining ability estimates by different workers confirms the conclusion that both GCA and SCA are important in pearl millet grain hybrid breeding for increasing grain yield.

Burton [2] observed that by crossing elite pollinators and then inbreeding in high yielding F_1 superior pollinators on the same male-sterile parent could be derived for higher forage yield. It was suggested that such results could be obtained if inbred lines are derived from the high yield could be obtained out of three high GCA × low GCA parental combinations. One low GCA × low GCA parental combinations also provided high F_1 yield. The only one high × high GCA combination available in this study did not provide high F_1 yield (Table 6). High × low combinations, however, are more frequent than low × low combinations, in producing high F_1

Table 7. Performance of hybrids of the lines derived out of the crosses involving parents of varying levels of GCA in 1995 rainy season (E1) and 1996 dry season (E2) at ICRISAT

	1995 rainy season (E1)				1996 dry season (E2)			
	No. of 81A hybrids superior over		No. of BSDIT hybrids superior over		No. of 81A hybrids superior over		No. of BSDIT hybrids superior over	
Cross hybrid	P1 hybrid	P2 hybrid	P1 hybrid	P2 hybrid	P1 hybrid	P2 hybrid	P1 hybrid	P2 hybrid
ICMP 501 × ICMP 83401	2 (40)	0 (0)	3 (0)	3 (60)	4 (80)	2 (40)	5 (100)	0 (0)
ICMP 451 × ICMP 84122	1 (20)	1 (20)	0 (0)	0 (0)	1 (20)	3 (60)	2 (40)	5 (100)
ICMP 451 × ICMP 501	0 (0)	5 (100)	1 (20)	4 (80)	0 (0)	5 (100)	0 (0)	5 (100)
ICMP 451 × ICMP 83401	0 (0)	0 (0)	0 (0)	3 (60)	0 (0)	3 (60)	0 (0)	1 (20)
ICMP 501 × ICMP 84122	4 (80)	1 (20)	4 (80)	0 (0)	5 (100)	5 (100)	5 (100)	5 (100)

Numbers in parentheses indicate the percent of superiority over parental hybrid.

BSDIT = Bold Seeded Inbred Tester

P1 = Parent 1

P2 = Parent 2

yield. All high yielding F_1's have high SCA effects. Thus it is safer to select high × low GCA combination with high yield to generate superior pollinator through inbreeding since both GCA and SCA are important in producing superior hybrids in pearl millet.

Interaction of combining ability with environments indicates that before finalizing selection of parents and crosses their performance across locations should be examined. It is observed that 2 out of the top 7 combinations, i.e., (1) ICMP 501 × ICMP 84122, and (2) ICMP 84913 × ICMP 84122 producing progenies for superior hybrid yield involved three parents, ICMP 501, ICMP 84913 and ICMP 84122. Observation on environment-wise results indicated that combining abilities of both ICMP 501 and ICMP 84913 change with environment. Therefore, selection of either of these crosses might be risky. In the present investigation, therefore, it may be a profitable proposition to select the crosses ICMP 451 × ICMP 501, ICMP 451 × ICMP 84122, ICMP 501 × ICMP 83401 to breed superior pollinators. Out of these three crosses however one cross ICMP 451 and ICMP 501 produced high frequency of superior progenies (Table 7). The cross ICMP 501 × ICMP 84122 with both parents with low GCA also had high grain yield and produced high frequency of superior progenies indicating that some but not all high yielding crosses are efficient in producing superior progenies. Effect of environment is however highly pronounced in this cross.

The cross, ICMP 451 × ICMP 83401, has both parents with highly significant general combining ability. This cross is expected to generate progenies with higher grain yield. Such progenies however exhibited low heterosis. For deriving superior pollinator this cross should not be selected.

The results of the present investigation on general and specific combining ability effects are similar to the previous investigations with the materials of Indian origin, in general, in that some superior combining parents were available. The combining ability estimates, as in the previous studies indicate that their interaction with environment is significant. None of the previous studies, however, involved such variety of materials and perhaps environments as diversed as the present ones. The present study emphasizes strongly the need for multilocation evaluation to select parents and crosses.

In the fixed effect model of diallel analysis as in the present set of materials, the main objective is to identify the parents and crosses for further breeding work to generate new lines. Test crosses of inbreds derived out of the selected combinations of parental lines clearly pointed out the need for inbreeding of high × low and low × low GCA parents for generating superior inbred lines. Such inbreds can produce superior single-cross on diversed seed parents (Table 7).

It is obvious that to generate a superior set of pollinators, combining ability analysis to identify superior F_1's is a better approach than selecting F_1's on the basis of superiority in *per se* performance only. In addition to testing for combining ability, progeny testing of the superior crosses further increases effectiveness of breeding superior pollinators. In the present study, all the seven parents are elite pollinators. However, all are not good parents for producing superior progenies. Multilocational evaluation of diallel F_1 likely to identify the parents and crosses better particularly as a substantial proportion of hybrid performance (heterosis) depends on the ability of the F_1 interact with variable environments in this region characterized with low rainfall and low soil fertility.

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