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Combining Ability for Grain Yield and its Related Traits in Pearl Millet [*Pennisetum glaucum* (L.) R. Br.]

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Abstract: Combining ability analysis for grain yield and its contributing characters was carried out among ten female lines from diverse cytoplasmic male sterility sources, five elite restorers and 50 hybrids through line x tester mating design. The magnitude of specific combing ability (SCA) variances was higher than the general combining ability (GCA) variances for all the characters, which indicated predominance of non-additive gene action in the inheritance of these traits and it was further supported by less magnitude of σ2 GCA / σ2 SCA ratios. Among the females RMS 6A, ICMA 92777 and JMSA 20073 while among the males H77/833-2 and RIB 57SO5 were good general combiner for seed yield and most of the component characters. The cross combinations JMSA 20073 × RCB-IC 925 S3 19-3-1, ICMA 04999 × H77/833-2 and RMS 6A × MIR 97092-2-4 depicted significant and desirable SCA effects for most of the traits studied. In the present investigations two crosses ICMA 92777 × H77/833-2 and JMSA 20073 × H77/833-2 were identified for getting transgressive segregants as the GCA status of the parents was higher than the SCA effects. These hybrids can be recommended for wide spread cultivation in arid part of western Rajasthan after evaluation in multi-location trials for increasing pearl millet production and productivity.

Key words: Pearl millet, combining ability, GCA, SCA, grain yield.

Pearl millet [*Pennisetum glaucum* (L.) R. Br.], one of the most important coarse cereal crop of tropical world have very high photosynthetic efficiency and dry matter production capacity with a short life cycle (Satyavathi *et al*., 2021). It is from *Poaceae* family and sub-family *Panicoideae*. Origin is assumed to be West Africa (Vavilov, 1950) and later on moved to south Asia and other parts wherein it is adapated for cultivation. It is highly cross pollinated due to protogynous behaviour. Pearl millet is nutritionally superior and is daily food source for millions of rural families residing in drought prone arid and semi-arid regions of the world. Besides being human source for food, grains are used in poultry feed and biomass as cattle feed (Yadav and Rai, 2013). Inherently it is potential to withstand abiotic stress to produce economic harvest on marginal soils. It is cultivated in more than 30 countries of Asia, Africa, North America, South America and Australian region; crop acreage

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Table 1. General combining ability scores for seed yield and component traits for ten female parents in pearl millet

Genotypes	DF	DM	PH	NT	EH	EG	TW	HI	BY	SY	TP	TN	GCA
RMS 6A	-1	-1	+1	+1	+1	+1	+1	0	+1	+1	7	2	H
RMS 7A	0	0	0	0	0	0	+1	1	-1	0	2	1	H
RMS 18A	0	0	0	0	-1	0	+1	0	0	0	1	1	L
RMS 21A	0	0	-1	0	1	-1	-1	0	0	0	1	3	L
ICMA 843-22	0	0	0	0	0	-1	0	-1	-1	-1	0	4	L
ICMA 92777	0	0	+1	0	+1	0	+1	0	+1	+1	5	0	H
ICMA 93333	0	+1	0	0	0	0	-1	0	0	0	1	1	L
ICMA 97111	0	0	0	0	0	0	1	0	-1	-1	1	2	L
JMSA 20073	0	0	-1	+1	-1	0	0	+1	+1	+1	4	2	H
ICMA 04999	+1	+1	-1	0	1	0	-1	0	-1	-1	3	4	L
Total	0	1	-1	2	2	-1	2	1	-1	0			

'+1', '-1' and '0' Showing positive (+tive), negative (-tive) and non-significance GCA of parents, respectively
DF: Days to 50 % flowering; DM: days to maturity; PH: Plant height (cm); NT: Number of effective tillers plant^{-1}; EH: Earhead length (cm); EG: Earhead girth (cm); TW: Test weight (g); HI: Harvest index (%); BY: Biological yield plant^{-1} (g); SY: Seed yield plant^{-1} (g); TP: Total positive ; TN: Total negative; GCA: GCA of parents

is about 24.2 m ha giving a production of 16.3 mt. In India, pearl millet is grown in around 6.93 m ha area and giving annual production of 8.61 mt with the average productivity of 1243 kg ha^{-1} (Anonymous, 2019).

Constant efforts are being made to improve yield and yield contributing characters through hybridization in pearl millet. Proper selection of parents is very crucial in any planned hybridization program including pearl millet (Sabharwal and Nijhawan, 2003). Selection of the parents for hybridization is an important aspect in the crop improvement program and the performance of varieties in a trial may give an idea of their relative superiority. Hence, the present investigation was undertaken to study the magnitude of components of genetic variance through combing ability analysis, general combining ability of parents and specific combing ability of hybrids.

Materials and methods

The experimental material for the present investigation consisted of ten female parents from diverse cytoplasmic male sterility sources *viz.*, RMS 6A , RMS 7A, RMS 18A, RMS 21A, ICMA 843-22 , ICMA 92777, ICMA 93333, ICMA 97111, JMSA 20073 and ICMA 04999 and five elite restorers *viz.*, H77/833-2, RIB 57SO5, MIR 97092-2-4-1, RCB-IC 925 S3 19-3-1 and BIB I 6 developed in AICRP breeding program on pearl millet, ARS Bikaner. All the parental material was planted during summer season 2014 at ICRISAT, Hyderabad and hybridized under L X T fashion. The developed fifty fresh F_1 hybrids and three standard checks (HHB 67 (I), RHB177 and GHB 538) were evaluated in randomized block design with 3 replications at ARS, Bikaner during kharif 2014. Each plot consisted of two rows each of 4 meter length. The spacing between row to row was 50 cm and between plant to plant was 15 cm. Normal and uniform cultural operations were followed during the crop season to raise a good crop. The observations were recorded on five randomly selected competitive plants from each replication for 10 traits viz., days to 50% flowering, days to maturity, plant height (cm), number of effective tillers per plant, ear head length (cm), ear head diameter (cm), test weight (g), biological yield per plant (g), harvest index (%) and seed yield per plant (g). The effects of testers and male-sterile lines and their interactions were determined following the line x tester analysis of (Kempthorne, 1957). General and specific combining abilities for the studied traits were estimated according to Singh and Chaudhary (1979).

Results and discussion

Analysis of variance indicated significant variation among parents and hybrids for the studied traits indicating the diversity in the material tested. The magnitude of SCA variances was higher than the GCA variances for all the characters, which indicated predominance of non-additive gene action in the inheritance of these traits and it was further supported by less magnitude of σ2 GCA / σ2 SCA ratios.

Table 2. General combining ability scores for seed yield and component traits for five elite restorer in pearl millet

Genotypes	DF	DM	PH	NT	EH	EG	TW	HI	BY	SY	TP	TN	GCA
H77/833-2	-1	-1	0	+1	0	+1	+1	+1	+1	+1	6	2	H
RIB 57SO5	-1	-1	+1	0	+1	-1	0	0	+1	+1	4	3	H
MIR 97092-2-4-1	+1	+1	0	-1	0	-1	-1	0	-1	-1	2	5	L
RCB-IC 925 S3 19-3-1	+1	+1	-1	0	0	0	0	0	-1	-1	2	3	L
BIB I 6	+1	+1	-1	-1	0	0	-1	-1	-1	-1	2	6	L
Total no of tester for high GCA	1	1	-1	-1	1	-1	-1	0	-1	-1			

'+1', '-1' and '0' Showing positive, negative and non-significance GCA of parents, respectively
DF: Days to 50 % flowering; DM: days to maturity; PH: Plant height (cm); NT: Number of effective tillers plant^{-1}; EH: Earhead length (cm); EG: Earhead girth (cm); TW: Test weight (g); HI: Harvest index (%); BY: Biological yield plant^{-1} (g); SY: Seed yield plant^{-1} (g); TP: Total positive ; TN: Total negative; GCA: GCA of parents

The data on GCA effects indicated that the GCA effects varied significantly for different characters (Table 1). The high GCA effects in desirable direction for yield and its components indicated that such lines would combine well with other lines to produce superior progeny. In the present investigation, among the female parents RMS 6A, JMSA 20073 and ICMA 92777 was the best general combiner for seed yield per plant. The female parents RMS 6A also had significantly desirable GCA effects for plant height, number of effective tiller per plant, ear head length, ear head diameter, test weight and biological yield per plant and desirable negative significant GCA effect for days to 50% flowering and days to maturity. Line JMSA 20073 also exhibited desirable and significant GCA effect for number of effective tillers per plant, harvest index and biological yield per plant. Line ICMA 92777 exhibited desirable and significant GCA for plant height, ear head length, test weight and biological yield per plant also. Amongst the testers, positive and highly significant GCA effects for grain yield per plant were exhibited by H77/833-2 and RIB 57SO5. Tester H77/833-2 also had significant GCA effects for number of effective tiller per plant, ear head diameter, test weight, harvest index and biological yield per plant. RIB 57SO5 also exhibited positive and significant GCA effect for plant height, ear head length and biological yield. Significant positive GCA effects for yield and its components were observed by Dutt *et al.* (2003), Lakshmana *et al.* (2003) and Mungra *et al.* (2015).

RMS 6A was considered as good general combiner for this trait RMS 6A also had significantly desirable GCA effects for days to maturity, plant height, number of effective tiller per plant, ear head length, test weight, biological yield per plant and seed yield per plant. Two testers *viz.,* H77/833-2 and RIB 57SO5 were good general combiner for days to 50% flowering. H77/833-2 had also positive significant GCA effects for days to maturity, number of effective tiller per plant, ear head diameter, test weight, harvest index, biological yield per plant and seed yield per plant (Table 2). While, RIB 57SO5 had positive significant GCA effects for days to maturity, plant height, ear head length, biological yield and seed yield per plant. These results were comparable with findings of Rathore *et al.* (2004), Karad and Harer (2005) and Mungra *et al.* (2015) who reported the additive gene action for days to 50% flowering. RMS 6A showed desirable negative and significant GCA effects for days to maturity. RMS 6A also had significantly desirable GCA effects for days to 50% flowering, plant height, number of effective tiller per plant, ear head length, test weight, biological yield per plant and seed yield per plant. Amongst male parents, H77/833-2 and RIB 57SO5 were good general combiners for days to maturity. H77/833-2 had positive significant GCA effects for days to 50% flowering, number of effective tiller per plant, ear head diameter, test weight, harvest index, biological yield per plant and seed yield per plant. While RIB 57SO5 had significant GCA effects for days to 50% flowering, plant height, ear head length, biological yield and seed yield per plant. These results are comparable with findings of Lakshmana *et al.,* (2003). Amongst the females, RMS 6A and ICMA 92777 were found to the best general combiner for the plant height. Among the testers, RIB 57SO5 was considered to the best general combiner for the plant height along with days to 50% flowering, ear head length, biological yield and seed yield per plant.These results are comparable with the

Table 3. Specific combining ability effects of fifty crosses and GCA effect of fifteen diverse parents in pearl millet

S. No.	Genotypes	DF	DM	PH	ET	EHL	EHD	TW	HI	BY	SY	GCA
1	RMS 6A × H77/833-2	+**	+**	-**	-	-**	-	-	-	-*	-	H x H
2	RMS 7A × H77/833-2	-	-	-	-	-	-	-	-	-**	-	H x H
3	RMS 18A × H77/833-2	-	-	-	-	-	-	-	-	-*	-	L x H
4	RMS 21A × H77/833-2	-	-	-	-	+**	-	+*	-	-*	-	L x H
5	ICMA 843-22 × H77/833-2	-	-	-	-	-	-	-*	+*	-	+**	L x H
6	ICMA 92777 × H77/833-2	-	-	-	-	+**	-	-	-	+**	-	H x H
7	ICMA 93333 × H77/833-2	-	-	-	-	-	-	-	-	-*	-	L x H
8	ICMA 97111 × H77/833-2	-	-	-	-**	-	-**	-	-	-**	-**	L x H
9	JMSA 20073 × H77/833-2	-	-	-	-	-	-	-	-*	+**	-	H x H
10	ICMA 04999 × H77/833-2	-*	-*	+**	+**	+**	+*	-	-	+**	+**	L x H
11	RMS 6A × RIB 57SO5	-	-	+**	-	-	-	-*	-	-	-	H x H
12	RMS 7A × RIB 57SO5	-	-	-	-	-	-	-	-*	-	-*	H x H
13	RMS 18A × RIB 57SO5	-	-	-	-	-*	-	-	-	-	-	L x H
14	RMS 21A × RIB 57SO5	-	-	-*	-	-	-	+**	-	-	-	L x H
15	ICMA 843-22 × RIB 57SO5	-	-	-	+*	+*	-	-	+*	+*	+**	L x H
16	ICMA 92777 × RIB 57SO5	-	-	-	-	-	+**	+**	+*	-*	-	H x H
17	ICMA 93333 × 7SO5	-	-	-	-	-*	-	-**	-	-	-**	L x H
18	ICMA 97111 × RIB 57SO5	-**	-	-	-	-	-	+*	-	-	+**	L x H
19	JMSA 20073 × RIB 57SO5	-	-	-	-*	-	-	-**	-**	-	-**	H x H
20	ICMA 04999 × RIB 57SO5	+*	+*	-**	-	-	-	-	-	-	-	L x H
21	RMS 6A × MIR 97092-2-4-1	-**	-**	-	-	+*	+**	+**	-	+**	+**	H x L
22	RMS 7A × MIR 97092-2-4-1	-	-	-	-	-	-*	-	-	+**	**	H x L
23	RMS 18A × MIR 97092-2-4-1	-	-	-	-	-	-	-	-	-	-*	L x L
24	RMS 21A × MIR 97092-2-4-1	-	-	+**	-	-	-	-	-	+**	-	L x L
25	ICMA 843-22 ×MIR 97092-2-4-1	-	-	-**	-	-	-	-	-	-	-	L x L
26	ICMA 92777 × MIR 97092-2-4-1	-	-	-	-	-	-	-**	-	-	-	H x L
27	ICMA 93333 × 97092-2-4-1	+**	+**	-	-	-	-	-	-	-*	-	L x L
28	ICMA 97111 × MIR 97092-2-4-1	+**	+*	+**	-	-	-	-**	-	+*	-	L x L
29	JMSA 20073 × MIR 97092-2-4-1	-	-	-**	-*	-	-	+**	+**	-**	-	H x L
30	ICMA 04999 × MIR 97092-2-4-1	-	-*	-	-	-	-	-	-	-**	-	L x L
31	RMS 6A × B-IC 925 S3 19-3-1	+*	-	-	-	-	-**	-*	-	-*	-	H x L
32	RMS 7A × RCB-IC 925 S3 19-3-1	-	-	-	-	-	-	+**	-	-	-	H x L
33	RMS 18A × RCB-IC 925 S3 19-3-1	-	-	-	-	-	-	-*	-	+*	-	L x L
34	RMS 21A × RCB-IC 925 S3 19-3-1	-	-	-	-	-*	-	-	-	-	-*	L x L
35	ICMA 843-22 × RCB-IC 925 S3 19-3-1	-	-	+*	-	-	-	-	-**	-**	-**	L x L
36	ICMA 92777 × RCB-IC 925 S3 19-3-1	-	-	-	-	-	-	-	-	-	-	H x L
37	ICMA 93333 × RCB-IC 925 S3 19-3-1	-	-	-	-	-	-	-	-	-	+**	L x L
38	ICMA 97111 × RCB-IC 925 S3 19-3-1	-	-	-	-	-	-	+*	-	-	-	L x L
39	JMSA 20073 × RCB-IC 925 S3 19-3-1	-**	-**	-	+**	+**	+**	-	-	+**	+**	H x L
40	ICMA 04999 × RCB-IC 925 S3 19-3-1	-	+*	-	-	-	-	-**	-	-	-	L x L
41	RMS 6A × BIB I 6	-	-	-	-	-	-*	-	-	-	-	H x L
42	RMS 7A × BIB I 6	-	-	-**	-	-	-	-**	-	-	-	H x L
43	RMS 18A × BIB I 6	-	-	-	-	+*	-	+**	-	-	+**	L x L
44	RMS 21A × BIB I 6	-	-	-	-	-	-	-**	-	-	-	L x L
45	ICMA 843-22 × BIB I 6	-	-	-	-	-	-	-	-	-	-	L x L
46	ICMA 92777 × BIB I 6	-	-	+**	-	-*	-*	-	-	-	-	H x L
47	ICMA 93333 × BIB I 6	-**	-**	-	-	-	-	+**	-	+**	-	L x L
48	ICMA 97111 × BIB I 6	-	-	-*	-	+*	+**	-	-	-	-	L x L
49	JMSA 20073 × BIB I 6	-	-	-	-	-	-	-	-	-*	-	H x L
50	ICMA 04999 × BIB I 6	-	-	-	-	-*	-	-	-	-**	-*	L x L

'+', and '-' Showing positive, negative SCA of parents; * and ** depicting significant and highly significant response respectively. DF: Days to 50% flowering; DM: Days to Maturity; PH: Plant height (cm); ET: No. of effective tillers plant^{-1}; EHL: Ear head length (cm); EHD: Ear head diameter (cm); TW: Test weight (g), HI: Harvest Index (%), BY: Biological yield plant^{-1} (g), SY: Seed yield plant $^{-1}$(g), GCA: GCA Status of parents findings of Lakshmana *et al.* (2003), Mungra *et al.* (2015), Bhardwaj *et al.* (2015) and Sharma *et al.* (2019). For number of productive tillers per plant, female line RMS 6A and JMSA 20073 was found the best general combiner. JMSA 20073 also had significant GCA effects for harvest index, biological yield and seed yield per plant. Amongst the male parents, H77/833-2 was the best general combiner along with days to 50% flowering, ear head diameter, test weight, harvest index, biological yield per plant and seed yield per plant. The similar results are comparable with the findings of Sushir *et al.* (2005) and Yahia *et al*. (2017).

Female parents, RMS 6A, ICMA 04999, RMS 21A and ICMA 92777 and male parents RIB 57SO5 were found the best general combiner. These results are comparable with Jethva *et al.* (2012) who reported additive gene action for panicle length. Female line RMS 6A and tester H77/833-2 were found to be the best general combiner for ear head diameter. These results are comparable with the findings of Chavan and Nerkar (1994) and Yahia *et al*. (2017). While one tester, H77/833-2 was found to be the best general combiner for test weight. These results are comparable with the findings of Mohan *et al.,*(1999) and Karad and Harer (2005). Two Testers, H77/833-2 and RIB 57SO5 were found to be the best general combiner for biological yield per plant. From the above results, it seems that parents displaying good general combining ability for grain yield also showed either average or good general combining ability for one or more yield contributing traits. These findings clearly indicate that the good general combining ability for grain yield seems to be influenced by good general combining ability for one or more yield attributes. Patil (2005) and Yahia *et al*., (2017) also reported such findings in their studies.

Analysis of specific combining ability is important parameter for judging the specific combinations for exploiting it through heterosis breeding program. The good specific cross combinations were selected based on their SCA effects. Earliness is desirable in crop plants hence the cross combinations with negative SCA effects are of great value as they would result into early segregates. In the present investigation, for days to 50% flowering 5 crosses expressed significant SCA effects in desirable (negative) direction. The cross combinations RMS 6A × MIR 97092-2-4-1 showed maximum negatively SCA effects followed by ICMA 93333 × BIB I6, JMSA 20073 × RCB-IC 925 S3 19-3-1, ICMA 97111 × RIB 57SO5 and ICMA 04999 × H77/833-2. It was resulted from high x low and low x low combining parents (Table 3). The results were in conformity with the findings of, Chavan and Nerkar (1994), Sushir *et al.* (2005), Yadav and Sabharwal (2001), Yadav *et al.* (2005) and Sharma *et al.* (2019). Early maturity is desirable in crop plants hence the cross combinations with negative SCA effects are of great value as they would result into early segregates. Four 4 crosses expressed significant SCA effects in desirable (negative) direction for days to maturity; the cross combination of RMS 6A × MIR 97092-2-4-1 was the best specific combiner followed by JMSA 20073 × RCB-IC 925 S3 19-3-1, ICMA 93333 × BIB I 6, ICMA 04999 × H77/833-2 and ICMA 04999 × MIR 97092-2-4-1. These crosses exhibited high magnitude of SCA effects in desirable (negative) direction. These results are comparable with findings of Rathore *et al.* (2004), Sushir *et al.* (2005), Bhanderi *et al.* (2007), Bhardwaj *et al.* (2015) and Sharma *et al.* (2019) who reported that non additive gene action for days to maturity. Cross RMS 7A × H77/833-2 were the best cross possessing highest SCA effects followed by ICMA 97111 × MIR 97092-2-4-1, RMS 21A × MIR 97092-2-4-, ICMA 04999 × H77/833-2, ICMA 92777 × BIB I 6 and ICMA 843-22 × RCB-IC 925 S3 19-3-1 for plant height. These results are comparable with the research findings of Gandhi *et al.* (1999), Rathore *et al.* (2004), Bhardwaj *et al.* (2015) and Sharma *et al.* (2019). The cross JMSA 20073 × RCB-IC 925 S3 19-3-1 (0.68) exhibited maximum positive and significant SCA effects for effective tillers per plant. The results are similar with the findings of Pethani and Kapoor (1990) and Jethva *et al.* (2012). Ear head length is important yield contributing characters in pearl millet, hence combinations with high SCA effects are desirable. Cross combination JMSA 20073 × RCB-IC 925 S3 19-3-1 had maximum SCA effects for ear head length followed by combination RMS 21A × H77/833-2, ICMA 04999 × H77/833-2 (3.23), ICMA 92777 × H77/833-2 and RMS 18A × BIB I 6. Similar results were reported by Chavan and Nerkar (1994) who reported non additive gene action for panicle length. The cross combination RMS 6A × MIR 97092-

2-4-1 showed highest positive SCA effects for ear head diameter followed by ICMA 92777 × RIB 57SO5, ICMA 97111 × BIB I 6, JMSA 20073 × RCB-IC 925 S3 19-3-1 and ICMA 04999 × H77/833-2. These combinations were resulted from high x low, high x high and low x low combining parents. Pethani and Kapoor (1984) and Krishnan *et al.* (2019) observed that low x low combiners also yielded some crosses with high SCA effects. Out of 50 crosses studied, RMS 7A × RCB-IC 925 S3 19-3-1 was the best specific combiner for test weight. These specific combinations involved parents with low, or high GCA effects, indicating role of non allelic interaction. The results are comparable with Jethva *et al.* (2012), Bhardwaj *et al.* (2015) and Sharma *et al.* (2019) who reported non additive gene action for test weight. The cross combination JMSA 20073 × MIR 97092-2-4-1 was the best specific combination for harvest index followed by ICMA 92777 × RIB 57SO5 , ICMA 843-22 × H77/833-2 and ICMA 843-22 × RIB 57SO5 and it was resulted from high x low and high x high combining parents. Among the 11 hybrids showing positive SCA effects for biological yield per plant, the best specific combination was ICMA 04999 × H77/833-2 followed by RMS 6A × MIR 97092-2-4-, JMSA 20073 × RCB-IC 925 S3 19-3-, JMSA 20073 × H77/833-2and ICMA 93333 × BIB I 6. Similar results are comparable with the findings of Patel *et al.* (2008a) who reported the non additive gene action for fodder yield per plant. Navale *et al.* (1991) and Bhardwaj *et al.* (2015) observed that crosses between good x good, poor x average and poor x poor combiners produced high SCA effects. These results are in agreement with the results obtained by Yadav *et al.* (2002) and Sharma *et al.* (2019) who reported that parents either one or both displaying either high or low GCA effects can produce cross with high SCA effects for fodder yield per plant. The combination JMSA 20073 × RCB-IC 925 S3 19-3-1 was the best specific combination for seed yield per plant, it was followed by combination ICMA 843-22 × RIB 57SO5, ICMA 04999 × H77/833-2, RMS 18A × BIB I 6 and RMS 6A × MIR 97092-2-4-1. These crosses were derived from the parents having high x low, low x low and high x high GCA effects for seed yield per plant. The results are comparable with the results of Dhuppe *et al.* (2006) and Sharma *et al.* (2019).

Conclusion

The current study suggested that among the females RMS 6A, ICMA 92777 and JMSA 20073 and amongst males the parent H77/833-2 and RIB 57SO5 were good general combiner for seed yield and most of the component characters. The cross combinations JMSA 20073 × RCB-IC 925 S3 19-3-1, ICMA 04999 × H77/833-2 and RMS 6A × MIR 97092-2-4 depicted significant and desirable SCA effects for most of the traits studied. Two crosses ICMA 92777 × H77/833-2 and JMSA 20073 × H77/833-2 were identified for getting trangressive segregants as the GCA status of the parents is higher than the SCA effects. These hybrids can be recommended for wide spread cultivation in arid part of western Rajasthan after evaluation in multi-locational trial for increasing pearl millet production and productivity.

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