Original Research Article

ESTIMATION OF COMBINING ABILITY ACROSS DIFFERENT SEASONS IN PEARL MILLET USING LINE × TESTER ANALYSIS

Abstract

The current study was conducted at IIMR, Hyderabad, to estimate the combining ability as well as inheritance of grain yield and its component traits in 36 hybrids of pearl millet that were developed through a line × tester mating design using 12 male sterile lines and 3 restorers as parental material. These hybrids were tested using a randomized block design with three replications in *kharif* and summer of 2022 and 2023, respectively. For the majority of characters, both GCA and SCA variances were shown to be significant in the results except for maximum photosystem II efficiency (F_v/F_{m}). With the exception of panicle length and panicle width, the ratio of GCA and SCA variance showed predominance of non-additive gene action for all of the examined traits. According to GCA effects, parents like 123R among males, 274A, 269A, 04999A, and 260A among females were effective general combiners for grain yield and certain contributing traits. Based on SCA effects, the crosses 252A × 124R, 843-22A × 124R, 843-22A × 132R, 242A × 123R, 264A × 132R, and 274A × 123R were identified as best for grain yield and other contributing traits over the seasons. Therefore, these parents and hybrids were further recommended for the development of promising hybrids as well as for population improvement.

INTRODUCTION:

Pearl millet (*Pennisetum glaucum*) is an important coarse grain millet that belongs to the family Poaceae. It is a diploid plant possessing chromosomal number of 2n = 14 (Sattler *et al*. (2019). It is a resilient and drought-resistant cereal crop that has been grown for a very long time. Pearl millet's origin can be traced back to Africa. It is also known as bajra, bulrush millet, cat tail millet etc. In Telugu it is known as 'sajjalu'. Pearl millet is one of the important cereal crops with nutritious grains and lower water and energy footprints in addition to the capability of growing in some of the harshest and most marginal environments of the world. Pearl millet is a warm season crop growing under rainfall ranging from 150-700mm. It is planted on around 27 million ha with the majority of crop area recorded in Asia (>10 million ha) and Africa (about 18 million ha) (Yadav and Rai 2013) with a production of 36 million tons.

Being a C4 plant, it has high photosynthetic efficiency and dry matter production capability even under low input conditions. As a result of its climatically adaptable nature, pearl millet can thrive not only in the most extreme environments, such as soils with low moisture, high pH, high salinity, low fertility, and high Al3+ saturation, but also in areas that frequently experience drought, have low annual average rainfall (250 mm), experience high temperatures and conditions that prevent other cereals to even survive and produce grain.

Being highly cross-pollinated in nature facilitated by protogynous flowering and owing to the availability of CMS systems, heterosis breeding is the most viable option in pearl millet. The actual breakthrough occurred in India when grain hybrids were created using Tift 23A, the first and most popular cytoplasmic male sterile line (Burton, 1965). Selection based on phenotypic performance alone does not predict the performance of hybrids for grain yield as the trait is governed by non-additive gene action. Hence, emphasis should be laid towards the genotypic performance. The choice of proper type of parent is a vital stage for a plant breeder which demands thorough and deep genetical analysis of existing germplasm as well as newly produced promising lines. It is necessary to elucidate their combining abilities in order to utilize the parental lines (Kanfany *et al*. 2018). This genetic information can be obtained by different mating designs including line x tester mating design. To exploit heterosis to the maximum extent in desirable direction, it is desirable to identify good combining parents as well as superior specific combinations. General combining ability (GCA) estimates the average performance of a line in crosses, as a result, it indicates the line's breeding value. Combining ability studies, therefore, aid in rejection of subpar genotypes. The goal of the current study was to assess combining ability effects and variances in crosses together with the analysis of various genetic variation components and suggesting an appropriate breeding strategy for increasing yield in diverse environments.

MATERIALS AND METHODS:

For the current study, the experimental materials included twelve lines (04999A, 843-22A, 221A, 242A, 246A, 252A, 260A, 262A, 264A, 269A, 274A and 291A) and three testers (123R, 124R,132R) and single standard check (KSB). During *Kharif* 2022, 12 lines were crossed with 3 testers using Line × Tester design and simultaneously 36 hybrids which were generated during summer 2022 by crossing same set of parental lines were evaluated along with 15 parents and check with 3 replications at Indian Institute of Millets Research, Rajendranagar, Hyderabad. In summer, 2023 another evaluation of 36 hybrids which were generated during Kharif 2022 was carried out along with 15 parents and a check with 3 replications at Indian Institute of Millets Research, Rajendranagar, Hyderabad. Each entry was sown in two rows of 3m length at a spacing of 45 cm between the rows and 15 cm between the plants. To produce a high-quality crop, all suggested cultural practices were followed. Observations were recorded on 17 morphological traits viz. DFF= days to 50% flowering, DM= days to maturity, PH= plant height (cm), ETP= effective tillers per plant, FLL= flag leaf length (cm), FLW= flag leaf width (cm), LL= leaf length (cm), LW= leaf width (cm), Act PS II= actual photosystem II efficiency (ΦPSII), Max PS II= maximum photosystem II efficiency (F_v/F_m), PL= panicle length (cm), PW= panicle width (cm), FB= fresh biomass (kg per plot), DB= dry biomass (kg per plot), GY= grain yield (kg per plot), HI= harvest index (%) and TW= 1000 seed weight (g). The method recommended by Kempthorne (1957) was used to examine the combining ability of the mean data.

RESULTS AND DISCUSSION

1. Combining ability analysis

According to the pooled analysis of variance for combining ability (Table 1). The mean sum of squares owing to environments was significant for all variables except leaf length, which indicated the presence of significant variances among the material utilized for the study. With the exception of maximum photosystem II efficiency, mean sum of squares due to crosses were found to be significant for all traits. Mean sum of squares due to line × tester was found significant for all the traits except for panicle length, panicle width and maximum photosystem II efficiency. Mean sum of squares due to crosses x environment were found significant for all the traits except panicle width and maximum photosystem II efficiency. For days to 50% flowering, panicle length, and panicle width, mean sum of squares due to lines were found to be significant, but the tester mean sum of squares were found to be significant for panicle width. Analysis of Table 2 showed that, for all characters across the seasons except for panicle length and panicle width, the magnitude of variance due to GCA was lower than the magnitude of SCA, indicating the predominance of non-additive gene action. According to Table 2, lines contributed the most to total variance (%) over the seasons, with the biggest contribution was for panicle length (68.04%) and for panicle width (65.59%). The line x tester interaction showed the largest contribution to total variance for the number of effective tillers per plant (79.30%), followed by test weight (69%) over the seasons. The maximum contribution of tester to the total variance was for panicle width (10.89%). Similar results were reported by Kumawat *et al*. (2019), Chaudhary *et al*. (2012), Jethva *et al.* (2011), Mungra *et al*. (2015), Gaoh *et al*. (2023), Pallavi *et al*. (2023).

2. GCA and SCA effects

Based on data collected over two seasons, the GCA and SCA effects in this section have been calculated. The top-performing parents (lines and testers) and cross combinations based on GCA and SCA effects showed that no parent was a good general combiner for all the characters across the seasons, indicating that breeding for these characters would be successful when material is tested across a variety of environments. The female line 274A demonstrated strong GCA effects for twelve characters, including days to 50% flowering, days to maturity, plant height, effective tillers per plant, flag leaf width, leaf length, leaf width, fresh biomass, dry biomass, grain yield, harvest index, and 1000 seed weight, proving to be a good general combiner. When it came to days to maturity, plant height, panicle width, fresh and dry biomass, grain yield, and 1000 seed weight, the line 269A was a good general combiner. The line 260A was good general combiner for flag leaf width, panicle length, panicle width, dry biomass, grain yield and harvest index. Line 04999A was good general combiner for days to 50 % flowering, days to maturity and fresh biomass. Line 262A for plant height and 1000 seed weight while 291A for panicle length. The tester 123R, was a good general combiner for the characteristics days to maturity, effective tillers per plant, fresh biomass, dry biomass, grain yield, and 1000 seed weight while 132R for Panicle length. Similar results were also reported for general combining ability effects in various genotypes of pearl millet by Krishnan *et al.,* (2017), Gavali *et al*. (2018), Lenka *et al*. (2021).

Table 3 listed the top crosses for various characters based on their significant and strong SCA effects. The cross combinations with significant and high (highest three) SCA effects for at least three or more characters included 252A x 124R for the characters days to 50% flowering, plant height, effective tillers per plant, flag leaf width, leaf length, and width, fresh biomass, dry biomass, grain yield, and 1000 seed weight, and 274A x 123R for effective tillers per plant, dry biomass, harvest index, and 1000 seed weight. For plant height, flag leaf width, fresh biomass, harvest index, and 1000 seed weight, it was 843-22A x 132R. Gavali *et al*. (2018), Kumawat *et al*. (2019), Swaminaidu *et al*. (2018), Suryawanshi *et al*. (2021) and Chaudhry *et al*. (2022) also reported some specific combiners for yield and its contributing characters in pearl millet.

The cross 252A x 124R proved as best specific combiner over the seasons for twelve characters like days to 50% flowering, days to maturity, plant height, effective tillers per plant, flag leaf width, leaf length, leaf width, fresh biomass, dry biomass, grain yield, harvest index and 1000 seed weight followed by 274A × 123R for eight characters like days to maturity, plant height, effective tillers per plant, fresh biomass, dry biomass, grain yield, harvest index and 1000 seed weight.

Ten out of the 36 crossses that were examined exhibited significant SCA effects that were positive for grain yield per plot throughout the course of the seasons. These crosses are listed in Table 4 along with their per se performances and traits that also demonstrated significant SCA effects in addition to grain yield per plot. In terms of grain yield per plot and some of the component characters, 252A × 124R, 242A × 123R, and 843 × 124R were found to be the top three performers. Sharma *et al*. (2019), Warrier *et al*. (2020) also reported similar results on the basis of SCA effects.

CONCLUSION

For all traits over the seasons, with the exception of panicle length and panicle breadth, the ratio of additive to dominance variance was less than unity, indicating a predominance of non-additive gene action in the inheritance of most of the characters. Therefore, heterosis breeding may be used to exploit non-additive gene action to increase pearl millet production, whereas recurrent selection or mass selection may be used for population improvement to utilize additive gene action in the existing material. Results of GCA showed that the parents 274A, 269A, 260A, 04999A among females and 123R among males were good general combiners for grain yield per plot and several other traits and can be utilized further for developing synthetic populations in pearl millet. Six crosses, namely 252A × 124R, 843-22A × 124R, 843-22A × 132R, 242A × 123R, 264A × 132R, and 274A × 123R, were chosen as the best for grain yield and related traits over the seasons and shown good per se performance. These parents can therefore be utilized to create hybrids that can be tested in multiple locations to determine their suitability as commercial hybrids for high yield and its defining characteristics.

ACKNOWLEDGEMENT:

This is part of the author's post-graduate thesis work at Professor Jayashankar Telangana State Agricultural University. The author is highly grateful for the research facilities provided by the Indian Institute of Oilseeds Research, Hyderabad, and Professor Jayashankar Telangana State Agricultural University.

Conflict of Interest: None.

REFERENCES

Burton, G.W. 1965. Pearl millet Tift 23A released. *Crops Soils*. 17(5): 19.

Chaudhary, V.P., Dhedhi, K.K., Joshi, H.J. and Mehta, D.R. 2012. Combining ability studies in line× tester crosses of pearl millet [*Pennisetum glaucum* (L.) R. Br.]. *Research on Crops*. 13(3): 1094-1097.

Chaudhry, J.P., Prajapati, N.N., Patel, M.S., Chaudhary, A.B. and Kugasiya, K.G. 2022. Estimation of heterosis and combining ability for grain yield and its components in pearlmillet (*Pennisetum glaucum* (L.) R. Br.). *The Pharma Innovation Journal*. 11(4): 1908-1917.

Gaoh, B.S.B., Gangashetty, P.I., Mohammed, R., Ango, I.K., Dzidzienyo, D.K., Tongoona, P. and Govindaraj, M. 2023. Combining ability studies of grain Fe and Zn contents of pearl millet (*Pennisetum glaucum* L.) in West Africa. *Frontiers in Plant Science*. 13: 1027279.

Gavali, R.K., Kute, N.S., Pawar, V.Y. and Patil, H.T. 2018. Combining ability analysis and gene action studies in pearl millet [*Pennisetum glaucum* (L.) R Br.]. *Electronic Journal of Plant Breeding*. 9(3): 908-915.

Jethva AS, Mehta DR, Raval L, Madriya RB, Mandavia C. 2011. Combining ability over environments for grain yield and its related trait in Pearl millet. *Journal of Crop Improvement*. 38(1): 92-96.

Kanfany, G., Fofana, A., Tongoona, P., Danquah, A., Offei, S., Danquah, E. and Cisse, N. 2018. Estimates of combining ability and heterosis for yield and its related traits in pearl millet inbred lines under downy mildew prevalent areas of Senegal. *International Journal of Agronomy*.

Kempthorne, O. 1957. An introduction to genetic statistics. John Wiley and Sons Inc. New York. 458-471.

Krishnan, M.R., Patel, M.S., Gami, R.A., Bhadauria, H.S. and Patel, Y.N. 2017. Genetic analysis in pearl millet (*Pennisetum glaucum* (L) R. Br.). *International Journal of Current Microbiology and Applied Sciences*. 6(11): 900-907.

Kumawat, K.R., Gupta, P.C. and Sharma, N.K. 2019. Combining ability and gene action studies in pearl millet using line x tester analysis under arid conditions. *International Journal of Current Microbiology and Applied Sciences*. 8(04): 976-984.

Lenka, B., Kulkarni, G.U., Mehta, D.R., Tomar, R.S., Mungra, K.D. and Patel, J.B. 2021. Combining ability studies for grain and dry fodder yield per plant in pearl millet [*Pennisetum glaucum* (L.) R. Br.] Using line x tester analysis over environments. *The Pharma Innovation Journal*. 10(12): 2483-2491.

Mungra, K.S., Dobariya, K.L., Sapovadiya, M.H. and Vavdiya, P.A. 2015. Combining ability and gene action for grain yield and its component traits in pearl millet (*Pennisetum glaucum* (L.) R.Br.). *Electronic Journal of Plant Breeding*. 6(1): 66-73.

Pallavi, M., Reddy, P.S., Ratnavathi, C.V. and Krishna, K.V.R. 2023. Combining ability for rancidity and associated traits in pearl millet (*Pennisetum glaucum*). *Plant Breeding*. 142(3): 345-356.

Sattler, F.T., Pucher, A., Kassari Ango, I., Sy, O., Ahmadou, I., Hash, C.T. and Haussmann, B.I. 2019. Identification of combining ability patterns for pearl millet hybrid breeding in West Africa. *Crop Science*. 59(4): 1590-1603.

Sharma, S., Kumar, R. and Yadav, H.P. 2019. Combining ability of new male sterile lines of diverse sources in pearl millet for yield and forage components. *Journal of Pharmacognosy and Phytochemistry*. 8(1): 533-536.

Suryawanshi, M.B., Deore, G.N., Gavali, R.K., Karvar, S.H., Shinde, G.C., Langi, A.M. and Banik, M. 2021. Combining ability studies in pearl millet [*Pennisetum glaucum* (L.) R. Br.]. *Journal of Pharmacognosy and Phytochemistry*. 10(1): 1882-1885.

Swaminaidu, N., Ghosh, S.K., Chandrashekar, R. and Mallikarjuna, K. 2018. Combining ability and gene action analysis for yield and its components in pearl millet (*Pennisetum glaucum* (L.) R. Br.). *The Journal of Indian Botanical Society*. 97(3and4): 65-71.

Warrier, S.R., Patel, B.C., Kumar, S. and Sherasiya, S.A. 2020. Combining ability and heterosis for grain minerals, grain weight and yield in pearl millet and SSR markers based diversity of lines and testers. *Journal of King Saud University-Science*. 32(2): 1536-1543.

Yadav, O.P. and Rai, K.N. 2013. Genetic improvement of pearl millet in India. *Agricultural Research*. 2: 275-292.

Table: Pooled Analysis of Variance for combining ability (Line x Tester) for grain yield and other attributing traits in pearl millet

Source of variation	df	Mean sum of squares																
		DFF	DM	PH	ETP	FLL	FLW	LL	LW	PL	PW	Act PS II	Max PS II	FB	DB	GY	HI	TW
Replications	2	0.199	1.190	54.976	0.256	70.938**	0.133	8.136	0.084	8.214	2.067**	0.000	0.001	0.056	0.004	0.009*	23.934	0.230
Environments (e)	1	502.170**	53.542**	21291.690**	23.334**	234.194**	5.242**	110.641	2.834**	590.00**	46.667**	0.066**	1.520**	2.400**	0.234**	0.161**	470.059**	19.065
Crosses (c)	35	20.671**	42.325**	990.419**	1.610**	67.731**	1.269**	76.643**	0.409**	23.717**	0.308*	0.030**	0.005	1.257**	0.083**	0.056**	228.246**	10.680
Line (l)	11	35.045*	47.035	1181.756	0.922	74.627	1.312	111.929	0.531	51.349***	0.643***	0.031	0.004	1.293	0.088	0.061	236.145	9.827
Tester (t)	2	13.644	17.810	101.772	0.760	24.436	0.206	3.252	0.019	30.638	0.588*	0.006	0.007	0.268	0.013	0.016	59.963	3.876
l × t	22	14.123**	42.199**	975.537**	2.032**	68.219**	1.343**	65.671**	0.383**	9.272	0.115	0.031**	0.005	1.330**	0.087**	0.058**	239.595**	11.725
c × e	35	21.994**	36.932**	1120.525**	1.834**	70.036**	1.417**	75.598**	0.616**	11.779**	0.275	0.031**	0.005	1.041**	0.079**	0.049**	179.031**	9.684*
Error	200	5.216	1.648	147.937	0.203	10.998	0.160	30.152	0.140	6.674	0.197	0.000	0.007	0.048	0.004	0.003	43.796	0.261

*** and ** indicate significance at 5 percent and 1 percent levels of significance, respectively**

Table.2 Combining ability variances, components of genetic variation and relative contribution of lines, testers and their interactions to total variance (%) for various traits based on the data pooled over two seasons.

Particulars	DFF	DM	PH	ETP	FLL	FLW	LL	LW	PL	PW	Act PS II	Max PS II	FB	DB	GY	HI	TW
σ^2 gca	0.455	0.68	10.359	0.013	0.819	0.012	0.487	0.002	0.746	0.009	0	0	0.016	0.001	0.001	2.85	0.146
σ^2 sca	1.705	6.728	133.32	0.297	9.257	0.188	5.002	0.036	0.309	-0.012	0.005	0	0.212	0.014	0.009	36.63	1.904
σ^2 gca/ σ^2 sca	0.26	0.1	0.07	0.04	0.08	0.06	0.09	0.05	2.41	-0.75	0	0	0.07	0.07	0.11	0.07	0.07
σ^2 A	0.909	1.3595	20.7177	0.0262	1.638	0.0242	0.9747	0.0047	1.4921	0.0189	0.0008	0	0.0322	0.002	0.0016	5.6995	0.2911
σ^2 D	1.7053	6.7275	133.3203	0.2968	9.2572	0.1882	5.002	0.0357	0.3086	-0.0125	0.0052	-0.0001	0.2123	0.0137	0.0091	36.63	1.9039
σ^2 A/σ^2 D	0.533	0.2021	0.1554	0.0884	0.1769	0.1288	0.1949	0.1323	4.8359	-1.5184	0.1584	-0.1511	0.1516	0.1486	0.1709	0.1556	0.1529
lines (l)	53.28	34.92	37.5	17.99	34.62	32.51	45.89	40.85	68.04	65.59	32.85	26.69	32.3	33.4	33.78	32.51	28.91
testers (t)	3.77	2.4	0.58	2.69	2.06	0.92	0.24	0.25	7.38	10.89	1.2	8.82	1.21	0.86	1.62	1.5	2.07
l × t	42.94	62.66	61.91	79.3	63.31	66.56	53.85	58.88	24.57	23.51	65.94	64.48	66.47	65.72	64.59	65.98	69

Table 3: Parents and crosses with the best performance based on GCA and SCA effects when pooled across the seasons

TRAITS	PARENTS		CROSSES
	Lines	Testers	
Days to 50% flowering	1.274A 2.264A 3.04999A	-	1. 242A × 124R 2. 252A × 124R 3. 262A × 132R
Days to maturity	1.274A 2.04999A 3.252A 4.269A	123R	1. 246A × 123R 2. 260A × 124R 3. 252A × 123R
Plant height (cm)	1.274A 2.262A 3.269A	-	1. 252A × 124R 2. 843-22A × 132R 3. 04999A × 124R
Effective tillers per plant	1.274A	123R	1. 252A × 124R 2. 242A × 123R 3. 274A × 123R
Flag leaf length (cm)	1.221A 2.264A 3.274A	-	1. 246A × 124R 2. 252A × 132R 3. 843-22A × 123R
Flag leaf width (cm)	1.260A 2.274A	-	1. 843-22A × 132R 2. 252A × 124R 3. 269A × 124R
Leaf length (cm)	1.274A	-	1. 252A × 124R
Leaf width (cm)	1.274A	-	1. 252A × 124R
Panicle length (cm)	1.260A 2.291A	132R	1. 269A × 123R
Panicle width (cm)	1.260A 2.269A	132R	-
Actual PS II efficiency (ΦPSII)	1.221A 2.242A 3.264A 4.246A	-	1. 252A × 132R 2. 246A × 124R 3. 843-22A × 123R
Fresh biomass (kg/plot)	1.04999A 2.269A 3.274A	123R	1. 252A × 124R 2. 264A × 132R 3. 843-22A × 132R

Dry biomass (kg/plot)	1.260A 2.269A 3.274A	123R	1. 252A × 124R 2. 274A × 123R
Grain yield (kg/plot)	1.260A 2.269A 3.274A	123R	1. 252A × 124R 2. 843-22A × 124R 3. 242A × 123R
Harvest index (%)	1.260A 2.269A 3.274A	-	1. 252A × 124R 2. 843-22A × 132R 3. 274A × 123R
1000 seed weight (gm)	1.262A 2.269A 3.274A	123R	1. 252A × 124R 2. 843-22A × 132R 3. 274A × 123R

Table.4 Crosses demonstrating strong significant specific combining ability effects for grain yield and other attributing traits

SNO	Crosses	SCA effect	Per se performance of grain yield (kg/plot)	Traits showing significant SCA effects
1	**04999A × 124R**	0.061*	0.613	Days to maturity, Plant height, fresh biomass, dry biomass, harvest index and 1000 seed weight
2	**843-22A × 132R**	0.100**	0.590	Days to maturity, plant height, flag leaf width, fresh biomass, dry biomass, harvest index and 1000 seed weight.
3	**242A × 123R**	0.079**	0.547	Effective tillers per plant, flag leaf width, fresh biomass, dry biomass, harvest index and 1000 seed weight.
4	**246A × 123R**	0.113**	0.660	Days to maturity, plant height, flag leaf width, fresh biomass, dry biomass, harvest index and 1000 seed weight.
5	**252A × 124R**	0.146**	0.692	Days to 50% flowering, Days to maturity, plant height, effective tillers per plant, flag leaf width, leaf length, leaf width, fresh biomass, dry biomass, harvest index and 1000 seed weight
6	**260A × 124R**	0.106**	0.701	Days to maturity, effective tillers per plant, dry biomass and 1000 seed weight.
7	**262A × 123R**	0.065**	0.650	Flag leaf width, dry biomass and 1000 seed weight.
8	**264A × 132R**	0.097**	0.540	Days to maturity, effective tillers per plant, flag leaf width, fresh biomass, dry biomass, harvest index and 1000 seed weight.
9	**269A × 124R**	0.084**	0.685	Days to maturity, effective tillers per plant, flag leaf width, fresh biomass, dry biomass, harvest index and 1000 seed weight.
10	**274A × 123R**	0.073**	0.726	Days to maturity, effective tillers per plant, dry biomass, harvest index and 1000 seed weight.

*** and ** indicate significance at 5 percent and 1 percent levels of significance, respectively**