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STUDIES ON COMBINING ABILITY FOR GRAIN YIELD AND ITS ATTRIBUTING TRAITS IN MAIZE (*Zea mays* L.)

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ABSTRACT

An investigation was conducted to assess the Combining ability for yield and its attributing traits in maize (*Zea mays* L.) during *rabi*, 2024–25 at S. V. Agricultural College, Tirupati. A Line × Tester mating design was carried out for 30 inbred lines and 2 testers to evaluate the GCA and SCA effects for grain yield and associated traits. For the considered 12 traits, *sca* variance exceeded GCA variance for all traits except for ear length, confirming the predominance of non-additive gene action. Based on *per se* performance and *gca* effects, the lines PL 23084 and PL 23110 were identified as best general combiners for grain yield and its components. Among hybrids, PL 23100 × LM 14, PL 23090 × CML 451, and PL 23059 × LM 14 exhibited significant positive *sca* effects for grain yield and its components, identifying them as the best crosses for exploiting hybrid vigour. The two crosses PL 23100 × LM 14 and PL 23059 × LM 14 were identified based on the *per se* performance and *sca* effects for grain yield. These hybrids need to be further evaluated across locations and over seasons to select best hybrids for commercial exploitation.

KEYWORDS: Combining ability, non-additive gene action, line x tester mating design.

INTRODUCTION

Maize (*Zea mays* L.) originated from South and Central America and belongs to the Poaceae family and subfamily Panicoideae with chromosome number 2n=20. It is considered as the "queen of cereals" owing to its high genetic production potential. It is a globally significant staple crop vital for human and animal food (Wang *et al.,* 2023). In India, Maize is the third most important cereal crop, after rice and wheat, accounting for approximately 10 per cent of the country's total food grain production (Anonymous, 2023-24a). Maize grains contains nearly 70 per cent starch, 10 per cent protein, 4 per cent oil and 2.7 per cent crude fibre (Bisen *et al.,* 2017) also offers substantial nutritional benefits to combat malnutrition through QPM variety and it has having wide range of utilities like starch, pharmaceuticals, cosmetics, textiles and biofuel production (Vidadala *et al.,* 2025). Being an allogamous and C_4 plant, it is physiologically more efficient as well as resilient to changing climatic conditions and able to grow successfully throughout the world (Rajesh *et al.,* 2018). It has been successfully exploited in the production of hybrids which played a vital role in increasing the acreage and productivity of maize. Constant efforts have been made to improve grain yield and its contributing characters through hybridization in maize.

Developing a hybrid with high vigour and productivity requires the careful selection and crossing of parent lines that show a favourable combining ability to harness the potential of heteros is fully (Bhavana *et al.,* 2011). In this perspective, L × T analysis has widely been used for evaluation of inbred lines by crossing them with testers (Vardhini *et al.,* 2024). Combining ability gives insights into the potential of inbred lines that can be used to develop hybrids and also reveals the nature and magnitude of different types of gene action, assisting the breeders in selecting parental lines with superior performance. This analysis encompasses both general combining ability (GCA) and specific combining ability (SCA) (Hayman, 1954; Griffing, 19566). GCA reflects the average performance of an inbred line when crossed with various other lines (Chiuta *et al.,* 2020). It reveals the parental line's overall genetic contribution to the hybrid's performance. This information enables the breeder to evaluate and classify selected parental material for their utility in development of high yielding F_1 hybrids in maize, where hybrids are being cultivated on a commercial scale. The *sca* effects help breeders

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to determine heterotic patterns among populations or inbred lines to identify promising single crosses and assign them into heterotic groups (Lahane *et al.* 2014). The ratio of GCA to SCA variance determines the gene action involved in the inheritance of those traits. If ratio that is less than unity represents the predominance of non-additive gene action, while it is greater than unity represents the predominance of additive gene action (Kumawat *et al.* 2021). The current experiment consisted of sixty hybrids and thirty two parents of maize to determine the combining ability for Grain yield and its attributing traits.

MATERIAL AND METHODS

The 60 F_1 hybrids and their 32 parents (30 lines, 2 testers) and 4 checks were planted in separate 8 blocks with 2 replications in an alpha lattice design, during *rabi*, 2024-25, at wetland farm, S.V. Agricultural College, Tirupati (Table 1). Each genotype was planted in two row plots of 4 meter in length with a spacing of 60 cm between rows and 20 cm within rows. All management practices were followed as and when required to establish a good crop. Observations were recorded on 12 grain yield and its attributing traits *viz.,* Days to 50 per cent Anthesis, Days to 50 per cent Silking, Anthesis-Silking Interval, Plant height (cm), Ear height (cm), Days to maturity, Ear length (cm), Ear girth (cm), Kernel rows ear^{-1}, Number of kernels row^{-1}, 100 kernel weight (g) and Grain yield plant^{-1} (g). Data from all the characters studied were exposed to analysis of variance technique on the basis of model proposed by Panse and Sukhatme (1961). The combining ability analysis was carried out according to the method suggested by Kempthorne (1957).

RESULTS AND DISCUSSION

Results

Analysis of variance for combining ability in a Line × Tester mating design for yield and yield components revealed that breeding material registered highly significant differences among themselves for all the characters.

Analysis of variance for combining ability

The parents differed significantly for all the characters except for anthesis silking interval indicating the existence of sufficient variability in the material studied and also revealed that the mean sum of squares for parents vs crosses exhibited significant differences ($p \leq 0.01$) for all the traits except for kernel rows cob^{-1}, revealing manifestation of differences among parents and their F_1 crosses in all the characters. The crosses effects were partitioned into line effect, tester effect and line × tester effect. Mean sum of squares line effects exhibited significant differences ($p \leq 0.01$) for all the traits except for anthesis silking interval, ear length, ear girth and number of kernels per row, suggesting a larger contribution of lines towards general combining ability variance components for most of the traits. Mean sum of squares of testers are also significant ($p \leq 0.01$) for the traits ear height and 100 kernel weight, representing the presence of variability for these traits among testers. Crosses recorded significant differences($p \leq 0.01$) for all the yield contributing characters. The interaction effects were significant for all the traits except for ear girth; significant interaction effects ($p \leq 0.01$) revealed the significant contribution of crosses for specific combining ability variance components (Table 2).

Per se performance

A perusal of the *per se* performance of parents for grain yield and yield components indicated that the lines, PL 23065, PL 23071, PL 23095, PL 23110 and PL 23066 registered superior performance for grain yield and most of the yield contributing characters. Among these, the lines PL 23065, PL 23095 and PL 23066 also exhibited superior performance for early maturity traits *viz.,* days to 50 per cent anthesis, days to 50 per cent silking, anthesis silking interval and days to maturity. Hence, it is suggested that these lines could be utilized as parents in the development of hybrids possessing high yield coupled with earliness. Further, the hybrids PL 23110 × CML 451, PL 23043 × CML 451, PL 23043 × LM 14, PL 23077 × CML 451 and PL 23047 × CML 451 has shown superior *per se* performance for grain yield and most of the attributing traits when compared to the high yielding best check hybrid P3396 (151.8g). These outstanding hybrids could be exploited for commercial cultivation after verification of their performance in different locations and environments.

The General combining ability (GCA) effects

Six parents PL 23043, PL 23047, PL 23105, PL 23107, PL 23110 and PL 23084 shown positive significant *gca* effects for grain yield. Among these parents, the line PL 23084 recorded positive significant *gca* effects in desirable direction for ten traits *viz.,* days to 50 per

Table 1. List of list of thirty (30) lines and two (2) testers used in present experiment

	Lines (30)
1	PL 23040
2	PL 23041
3	PL 23043
4	PL 23045
5	PL 23047
6	PL 23048
7	PL 23050
8	PL 23050A
9	PL 23053
10	PL 23056
11	PL 23059
12	PL 23065
13	PL 23066
14	PL 23067
15	PL 23071
16	PL 23077
17	PL 23078
18	PL 23079
19	PL 23082
20	PL 23084
21	PL 23085
22	PL 23090
23	PL 23095
24	PL 23100
25	PL 23102
26	PL 23105
27	PL 23107
28	PL 23108
29	PL 23109
30	PL 23110
	Testers (2)
1.	CML 451
2.	LM 14

cent anthesis, days to 50 per cent silking, plant height, ear height, days to maturity, ear length, ear girth, kernels row^{-1}, hundred kernel weight and grain yield plant^{-1}, whereas the line PL 23110 was identified as the best general combiner as it exhibited significant *gca* effects in desirable direction for Days to 50 per cent anthesis, Days to 50 per cent silking, Plant height, Ear height, Days to maturity, number of kernels row^{-1} and grain yield plant^{-1} and the line PL 23107 exhibited positive significant *gca* effects for anthesis silking interval, plant height, ear height, ear girth, kernel rows ear^{-1} and grain yield plant^{-1}. Crosses involving these parents might produce heterotic hybrids with high *per se* performance for the respective traits. As *gca* effects are attributed to additive gene effects, the lines PL 23084 and PL 23110 might be considered as potential parents for maize improvement programmes aimed at earliness, yield and its contributing traits (Table 3).

Selection of parents based on either *per se* performance or *gca* effects would be misleading as *per se* performance of parents was not always associated with high gca effects. Hence, both *gca* effects and *per se* performance are to be given due importance while selecting parents for use in breeding programmes. Consideration of both *per se* performance and *gca* effects would result in the selection of the best parents possessing desirable genes (Singh and Harisingh, 1985). In the present investigation, among the 32 parents studied, based on *per se* performance and *gca* effects among parents, PL 23110 and PL 23105 were identified as the best parents for grain yield and most of its contributing characters. Hence, these parents could be utilized in the development of the high yielding and early maturing hybrids in maize and also utilized in developing superior recombinants in further selection programmes for the improvement of yield parameters in maize (Table 5).

The specific combining ability (SCA) effects

A perusal of *sca* effects recorded in the present investigation, out of 60 hybrids none of the cross combinations recorded significant *sca* effects in desirable direction for all the 12 traits studied. Hence, apart from *sca* effect of grain yield, the *sca* effects recorded by a hybrid for other yield components were also considered judiciously to identify a good specific combiner.

Among 60 hyrbids, three hybrids *viz.,* the hybrid PL 23100 × LM 14, PL 23090 × CML 451 and PL 23059

Table 2. Analysis of variance for combining ability in L × T design for grain yield and its attributing traits

Source of variation	DF	Days to 50% anthesis	Days to 50% silking	Anthesis silking interval	Plant height	Ear height	Days to maturity
				Mean sum of squares			
Replications	1	0.6576	0.6576	0.000	0.5434	10.048	0.440
Treatments	91	27.2538**	26.39 **	0.4271*	1782.869**	504.382**	26.390**
Parents	31	23.9833**	23.1688**	0.2721	1453.467**	399.926**	23.168**
Parents vs Crosses	1	1292.9188**	1274.5935**	0.0654	75247.242**	19701.741**	1274.593**
Crosses	59	7.520**	6.927**	0.515**	710.786**	233.88**	6.927**
Line Effect	29	12.162**	10.902**	0.582	1075.868**	346.547**	10.902**
Tester Effect	1	0.133	1.200	0.533	1147.008	730.133*	1.200
Line × Tester Effect	29	3.133**	0.3059**	0.447*	330.945**	104.116**	3.148**
Error	91	0.3169	0.422	0.2637	87.323	45.708	0.286

*, ** Significant at 5% ($p \leq 0.05$), 1% ($p \leq 0.01$) respectively; Df = Degrees of Freedom.

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Table 2. Analysis of variance for combining ability in L × T design for grain yield and its attributing traits

Source of variation	DF	Ear length	Ear girth	Kernel rows ear^{-1}	Number of kernels row^{-1}	100 kernel weight	Grain Yield plant^{-1}
				Mean sum of squares			
Replications	1	0.00049	0.177	0.356	0.808	0.208	159.849
Treatments	91	13.824 **	3.817 **	2.831 **	81.801 **	42.217 **	3871.822 **
Parents	31	13.114 **	3.149 **	2.170 **	65.097 **	39.390 **	2652.770 **
Parents vs Crosses	1	539.750 **	192.210 **	57.871 **	3326.231 **	1253.442 **	193970.331 **
Crosses	59	5.283 **	0.975 **	2.247 **	35.587 **	23.174 **	1290.333 **
Line Effect	29	6.173	1.116	3.094 *	5.118	29.154 *	1824.470 **
Tester Effect	1	0.252	2.028	2.160	0.630	110.592 **	1832.227
Line × Tester Effect	29	4.556 **	0.798	1.403 **	27.261 **	14.179 **	737.510 **
Error	91	1.939	0.553	0.630	8.523	5.515	299.776

*, ** Significant at 5% ($p \leq 0.05$), 1% ($p \leq 0.01$) respectively; Df = Degrees of Freedom.

Table 3. Estimates of general combining (*gca*) effects of lines and testers for grain yield and its attributing traits in maize

Parents	Days to 50% anthesis	Days to 50% silking	Anthesis silking interval	Plant height	Ear height	Days to maturity	Ear length	Ear girth	Kernel rows ear^{-1}	Number of kernels row^{-1}	100 kernel weight	Grain yield plant^{-1}
LINES												
PL 23040	-1.950**	-1.583**	0.367*	15.775**	-2.617	-1.583**	0.251	-0.350	-1.253**	-2.869	2.595*	-14.589
PL 23041	-0.950**	-1.083**	-0.133	22.775**	16.633**	-1.083**	-0.324	0.225	-0.152	-1.969	2.470*	2.461
PL 23043	-0.950**	-0.833**	0.117	15.025**	9.633*	-0.833**	2.051**	0.500	-0.953**	4.381**	4.945**	36.211**
PL 23045	-1.450**	-1.833**	-0.383*	-19.225**	-10.117**	-1.833**	-0.924	-1.150**	-0.652	2.031	-4.630**	-12.489
PL 23047	0.300	0.417	0.117	3.775	7.883*	0.417	0.876	0.250	-0.053	4.781**	1.620	30.736**
PL 23048	-0.200	-0.583*	-0.383*	-4.975	2.133	-0.583*	0.851	0.000	-0.653	1.231	1.720	6.186
PL 23050	-1.450**	-1.333**	0.117	-7.725	-2.117	-1.333**	-0.524	-0.725*	-0.553	-1.319	-2.030	-14.614
PL 23050A	-2.450**	-2.333**	0.117	-25.975**	-17.117**	-2.333**	-2.624**	-0.175	0.148	-5.569**	-3.030*	-36.664**
PL 23053	0.050	0.167	0.117	-1.225	-1.617	0.167	0.451	-0.075	-0.253	1.081	-1.655	-12.214
PL 23056	4.050**	3.667**	-0.383*	-28.475**	-14.117**	3.667**	-0.799	-0.725*	0.747*	-5.269**	-1.780	-35.964**
PL 23059	2.050**	2.667**	0.617**	-19.725**	-8.867*	2.667**	0.026	-0.200	0.247	-2.594	-2.130	-14.814
PL 23065	-0.200	-0.083	0.117	8.275	4.133	-0.083	0.826	0.725*	-0.053	1.731	1.495	15.561
PL 23066	-0.700*	-0.083	0.617**	19.275**	10.883**	-0.083	0.151	0.275	-0.752*	-0.019	1.970	0.786
PL 23067	2.550**	2.167**	-0.383*	13.525*	6.383	2.167**	-0.124	0.100	-0.753*	-3.919**	3.795**	12.861
PL 23071	0.300	0.167	-0.133	17.025**	9.633*	0.167	0.526	-0.225	-1.053**	-0.269	4.195**	8.561
PL 23077	-1.700**	-1.833**	-0.133	-2.225	-7.367*	-1.833**	0.376	0.300	1.247**	4.281**	-3.705**	13.761
PL 23078	0.800**	0.917**	0.117	-6.725	-5.867	0.917**	0.351	0.475	1.848**	0.781	-4.205**	-3.814
PL 23079	3.050**	3.167**	0.117	-7.475	-3.617	3.167**	0.151	-0.650*	0.448	-0.094	-3.355**	7.436
PL 23082	0.050	0.417	0.367*	3.525	3.133	0.417	-1.224	0.200	-0.153	1.431	-1.130	-3.514
PL 23084	-0.950**	-1.083**	-0.133	13.775*	9.633*	-1.083**	2.051**	0.825*	-0.277	3.506*	4.595**	20.586*
PL 23085	-0.700*	-1.083**	-0.383*	4.275	-3.867	-1.083**	1.201	0.225	-0.352	4.481**	0.845	16.186
PL 23090	-1.450**	-1.833**	-0.383*	-46.725**	-22.117**	-1.833**	-3.924**	-0.650*	-0.552	-9.819**	-2.230	-55.114**
PL 23095	-0.700*	-0.333	0.367*	-11.725*	-5.617	-0.333	-0.699	-0.125	-0.253	-1.619	-0.855	-15.614
PL 23100	0.800**	0.667*	-0.133	-7.225	0.383	0.667*	-0.474	-0.650*	-0.053	0.881	-2.130	-5.939
PL 23102	0.050	0.167	0.117	9.525	5.883	0.167	0.851	0.525	1.347**	-0.019	1.670	14.136
PL 23105	4.050**	3.167**	-0.883**	11.275*	5.133	3.167**	0.026	-0.225	1.348**	2.731	-0.955	26.936**
PL 23107	1.800**	1.167**	-0.633**	16.525**	13.133**	1.167**	1.076	1.300**	2.447**	1.081	1.320	23.336*
PL 23108	-0.700*	0.167	0.867**	-3.975	-3.367	0.167	-0.299	0.125	-0.253	0.531	-0.455	-5.714
PL 23109	-2.450**	-2.333**	0.117	0.525	-6.117	-2.333**	-1.399	-0.275	-0.553	-2.819	-0.705	-25.464**
PL 23110	-0.950**	-0.833**	0.117	18.525**	9.883**	-0.833**	1.251	0.150	-0.253	3.231*	1.745	20.786*
SE (g_i)	0.2751	0.2721	0.1826	5.3019	3.6241	0.2759	0.7177	0.3180	0.3543	1.4555	1.2183	9.0434
CD at 5%	0.5506	0.5444	0.3653	10.6091	7.2518	0.5521	1.4362	0.6362	0.7089	2.9124	2.4379	18.0958
CD at 1%	0.7324	0.7241	0.4860	14.1124	9.6465	0.7344	1.9104	0.8463	0.9430	3.8742	3.2429	24.0713
TESTERS												
CML 451	-0.033	-0.1	-0.067	-3.092*	-2.467*	-0.1	0.046	0.129	0.134	-0.073	0.960**	3.907
LM 14	0.033	0.1	0.067	3.092*	2.467*	0.1	-0.046	-0.129	-0.134	0.073	-0.960**	-3.907
SE (g_j)	**0.0710**	**0.0702**	**0.0471**	**1.3690**	**0.9357**	**0.0712**	**0.1853**	**0.0821**	**0.0915**	**0.3758**	**0.3146**	**2.3350**
CD at 5%	**0.1422**	**0.1406**	**0.0943**	**2.7393**	**1.8724**	**0.1426**	**0.3708**	**0.1643**	**0.1830**	**0.7520**	**0.6295**	**4.6723**
CD at 1%	**0.1891**	**0.1870**	**0.1255**	**3.6438**	**2.4907**	**0.1896**	**0.4933**	**0.2185**	**0.2435**	**1.0003**	**0.8373**	**6.2152**

*, ** Significant at 5% ($p \leq 0.05$), 1% ($p \leq 0.01$) respectively

Table 4. Estimates of specific combining ability (*sca*) effects of crosses for grain yield and its contributing traits in maize

Crosses	Days to 50% anthesis	Days to 50% silking	Anthesis silking interval	Plant height	Ear height	Days to maturity	Ear length	Ear girth	Kernel rows ear^{-1}	Number of kernels row^{-1}	100 kernel weight	Grain yield $plant^{-1}$
PL 23040 × CML 451	-0.033	0.15	0.183	6.158	-2.467	0.15	0.521	-0.07	0.134	0.578	-0.39	3.982
PL 23040 × LM 14	0.033	-0.15	-0.183	-6.158	2.467	-0.15	-0.521	0.07	-0.134	-0.578	0.39	-3.982
PL 23041 × CML 451	-0.467	-0.15	0.317	-0.158	-2.283	-0.15	-0.296	0.195	-1.234*	0.622	5.115**	0.467
PL 23041 × LM 14	0.467	0.15	-0.317	0.158	2.283	0.15	0.296	-0.195	1.234*	-0.622	-5.115**	-0.467
PL 23043 × CML 451	-1.467**	-1.900**	-0.433	-0.908	-0.783	-1.900**	0.179	0.22	-0.434	-0.428	2.09	-2.282
PL 23043 × LM 14	1.467**	1.900**	0.433	0.908	0.783	1.900**	-0.179	-0.22	0.434	0.428	-2.09	2.282
PL 23045 × CML 451	-0.467	-0.4	0.067	3.342	-3.033	-0.4	0.554	0.12	-0.334	2.222	0.215	1.017
PL 23045 × LM 14	0.467	0.4	-0.067	-3.342	3.033	0.4	-0.554	-0.12	0.334	-2.222	-0.215	-1.017
PL 23047 × CML 451	-0.217	-0.65	-0.433	9.842	0.467	-0.65	0.404	0.42	0.466	0.873	-2.135	-2.308
PL 23047 × LM 14	0.217	0.65	0.433	-9.842	-0.467	0.65	-0.404	-0.42	-0.466	-0.873	2.135	2.308
PL 23048 × CML 451	0.783*	0.850*	0.067	11.592	3.717	0.850*	-0.821	0.42	0.066	-3.677	3.015	-5.657
PL 23048 × LM 14	-0.783*	-0.850*	-0.067	-11.592	-3.717	-0.850*	0.821	-0.42	-0.066	3.677	-3.015	5.657
PL 23050 × CML 451	1.533**	1.100**	-0.433	11.342	9.467	1.100**	2.254*	0.095	-0.434	5.973**	0.715	14.642
PL 23050 × LM 14	-1.533**	-1.100**	0.433	-11.342	-9.467	-1.100**	-2.254*	-0.095	0.434	-5.973**	-0.715	-14.642
PL 23050A × CML 451	0.533	1.100**	0.567*	-3.408	0.967	1.100**	0.254	0.145	0.066	0.923	-0.235	6.593
PL 23050A × LM 14	-0.533	-1.100**	-0.567*	3.408	-0.967	-1.100**	-0.254	-0.145	-0.066	-0.923	0.235	-6.593
PL 23053 × CML 451	1.033*	1.100**	0.067	0.342	1.467	1.100**	0.429	-0.055	0.066	1.172	-0.56	5.642
PL 23053 × LM 14	-1.033*	-1.100**	-0.067	-0.342	-1.467	-1.100**	-0.429	0.055	-0.066	-1.172	0.56	-5.642
PL 23056 × CML 451	-0.967*	-0.900*	0.067	-5.408	-2.033	-0.900*	-0.021	-0.705	-0.734	1.122	-3.585*	-13.108
PL 23056 × LM 14	0.967*	0.900*	-0.067	5.408	2.033	0.900*	0.021	0.705	0.734	-1.122	3.585*	13.108
PL 23059 × CML 451	1.033*	1.100**	0.067	-12.658	-9.783	1.100**	-0.646	-0.68	-0.434	-1.403	-1.885	-29.208*
PL 23059 × LM 14	-1.033*	-1.100**	-0.067	12.658	9.783	-1.100**	0.646	0.68	0.434	1.403	1.885	29.208*
PL 23065 × CML 451	-0.717	-1.150**	-0.433	-7.658	-7.783	-1.150**	-0.346	0.445	0.266	-0.777	0.49	-7.233
PL 23065 × LM 14	0.717	1.150**	0.433	7.658	7.783	1.150**	0.346	-0.445	-0.266	0.777	-0.49	7.233
PL 23066 × CML 451	0.283	0.35	0.067	-4.158	-3.033	0.35	0.079	-0.205	-0.234	-0.027	0.715	-3.458
PL 23066 × LM 14	-0.283	-0.35	-0.067	4.158	3.033	-0.35	-0.079	0.205	0.234	0.027	-0.715	3.458
PL 23067 × CML 451	-0.967*	-0.900*	0.067	0.592	-4.033	-0.900*	0.504	0.12	-0.034	1.873	0.59	0.767
PL 23067 × LM 14	0.967*	0.900*	-0.067	-0.592	4.033	0.900*	-0.504	-0.12	0.034	-1.873	-0.59	-0.767
PL 23071 × CML 451	-0.217	-0.4	-0.183	3.092	2.217	-0.4	0.404	0.695	0.266	0.823	1.44	11.468
PL 23071 × LM 14	0.217	0.4	0.183	-3.092	-2.217	0.4	-0.404	-0.695	-0.266	-0.823	-1.44	-11.468
PL 23077 × CML 451	0.283	0.1	-0.183	12.342	4.717	0.1	1.404	0.970*	0.966	1.573	0.99	15.267
PL 23077 × LM 14	-0.283	-0.1	0.183	-12.342	-4.717	-0.1	-1.404	-0.970*	-0.966	-1.573	-0.99	-15.267
PL 23078 × CML 451	-1.217**	-0.65	0.567*	2.342	-0.783	-0.65	0.029	0.195	0.566	0.373	0.54	7.843

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Table 4. Estimates of specific combining ability (*sca*) effects of crosses for grain yield and its contributing traits in maize

Crosses	Days to 50% anthesis	Days to 50% silking	Anthesis silking interval	Plant height	Ear height	Days to maturity	Ear length	Ear girth	Kernel rows ear^{-1}	Number of kernels row^{-1}	100 kernel weight	Grain yield plant^{-1}
PL 23078 × LM 14	1.217**	0.65	-0.567*	-2.342	0.783	0.65	-0.029	-0.195	-0.566	-0.373	-0.54	-7.843
PL 23079 × CML 451	-0.967*	-0.4	0.567*	5.092	4.467	-0.4	-0.321	-0.63	-0.034	-3.103	-1.76	5.493
PL 23079 × LM 14	0.967*	0.4	-0.567*	-5.092	-4.467	0.4	0.321	0.63	0.034	3.103	1.76	-5.493
PL 23082 × CML 451	-0.467	-0.15	0.317	3.092	0.717	-0.15	-0.296	0.32	0.566	-0.677	-0.535	-0.157
PL 23082 × LM 14	0.467	0.15	-0.317	-3.092	-0.717	0.15	0.296	-0.32	-0.566	0.677	0.535	0.157
PL 23084 × CML 451	0.033	-0.15	-0.183	5.842	11.217*	-0.15	0.729	-0.255	0.091	0.347	-3.31	-7.257
PL 23084 × LM 14	-0.033	0.15	0.183	-5.842	-11.217*	0.15	-0.729	0.255	-0.091	-0.347	3.31	7.257
PL 23085 × CML 451	-1.217**	-1.150**	0.067	-2.658	1.217	-1.150**	-0.821	-0.355	-0.034	-0.927	-1.91	-10.058
PL 23085 × LM 14	1.217**	1.150**	-0.067	2.658	-1.217	1.150**	0.821	0.355	0.034	0.927	1.91	10.058
PL 23090 × CML 451	1.533**	1.600**	0.067	23.342**	8.467	1.600**	3.004**	0.42	-0.034	7.373**	1.665	34.542**
PL 23090 × LM 14	-1.533**	-1.600**	-0.067	-23.342**	-8.467	-1.600**	-3.004**	-0.42	0.034	-7.373**	-1.665	-34.542**
PL 23095 × CML 451	0.783*	1.100**	0.317	-11.158	-4.533	1.100**	0.579	-0.055	0.266	0.573	-0.51	3.642
PL 23095 × LM 14	-0.783*	-1.100**	-0.317	11.158	4.533	-1.100**	-0.579	0.055	-0.266	-0.573	0.51	-3.642
PL 23100 × CML 451	0.283	0.1	-0.183	-24.658**	-11.533*	0.1	-1.796	-0.980*	-0.134	-4.428*	-3.135	-38.533**
PL 23100 × LM 14	-0.283	-0.1	0.183	24.658**	11.533*	-0.1	1.796	0.980*	0.134	4.428*	3.135	38.533**
PL 23102 × CML 451	0.033	0.6	0.567*	-7.908	-5.033	0.6	-0.121	0.145	1.666**	-0.728	0.265	13.693
PL 23102 × LM 14	-0.033	-0.6	-0.567*	7.908	5.033	-0.6	0.121	-0.145	-1.666**	0.728	-0.265	-13.693
PL 23105 × CML 451	1.533**	1.100**	-0.433	-4.658	-1.783	1.100**	-2.496*	-0.805	-1.134*	-5.377*	1.34	-4.207
PL 23105 × LM 14	-1.533**	-1.100**	0.433	4.658	1.783	-1.100**	2.496*	0.805	1.134*	5.377*	-1.34	4.207
PL 23107 × CML 451	0.283	0.1	-0.183	-8.908	3.217	0.1	-0.146	-0.28	-0.434	-1.727	-0.185	-2.507
PL 23107 × LM 14	-0.283	-0.1	0.183	8.908	-3.217	-0.1	0.146	0.28	0.434	1.727	0.185	2.507
PL 23108 × CML 451	-0.717	-0.4	0.317	3.092	0.717	-0.4	-0.271	0.145	-0.134	0.722	-0.26	7.942
PL 23108 × LM 14	0.717	0.4	-0.317	-3.092	-0.717	0.4	0.271	-0.145	0.134	-0.722	0.26	-7.942
PL 23109 × CML 451	1.033*	0.6	-0.433	3.592	0.967	0.6	-1.721	-0.155	0.966	-3.227	-1.16	-12.407
PL 23109 × LM 14	-1.033*	-0.6	0.433	-3.592	-0.967	-0.6	1.721	0.155	-0.966	3.227	1.16	12.407
PL 23110 × CML 451	-0.967*	-1.400**	-0.433	1.592	-0.033	-1.400**	-0.171	0.02	-0.334	0.522	1.59	13.343
PL 23110 × LM 14	0.967*	1.400**	0.433	-1.592	0.033	1.400**	0.171	-0.02	0.334	-0.522	-1.59	-13.343
SE (s_{ij})	**0.3891**	**0.3847**	**0.2582**	**7.4981**	**5.1253**	**0.3902**	**1.0150**	**0.4497**	**0.5010**	**2.0584**	**1.7230**	**12.7893**
CD at 5%	**0.7786**	**0.7699**	**0.5167**	**15.0036**	**10.2556**	**0.7808**	**2.0311**	**0.8998**	**1.0025**	**4.1188**	**3.4477**	**25.5913**
CD at 1%	**1.0357**	**1.0241**	**0.6873**	**19.9580**	**13.6422**	**1.0386**	**2.7018**	**1.1969**	**1.3336**	**5.4789**	**4.5862**	**34.0419**

*, ** Significant at 5% ($p \leq 0.05$), 1% ($p \leq 0.01$) respectively

Table 5. Top 5 hybrids based on *per se* performance, *sca* and *gca* effects for grain yield and its contributing traits

S. No.	Character	*per se* performance of lines	*gca effects*	*per se* and *gca* effects	*per se* performance of crosses	*sca* effects	*per se* and *sca* effects
1.	Days to 50% anthesis	PL 23066 PL 23090 PL 23041 PL 23050A PL 23065	PL 230109 PL 230640 PL 23077 PL 23045	PL 23050A	PL 23109 × LM14 PL 23050 × LM14 PL 23050A × LM14 PL 23090 × LM14 PL 23043 × CML451	PL 23050 × LM14 PL 23090 × LM14 PL 23105 × LM14 PL 23043 × CML451 PL 23078 × CML451	PL 23050 × LM14 PL 23090 × LM14 PL 23043 × CML451
2.	Days to 50% silking	PL 23090 PL 23066 PL 23050A PL 23065 PL 23095	PL 23050A PL 23109 PL 23045 PL 23077	PL 23050A PL 23090	PL 23050A × LM14 PL 23090 × LM14 PL 23043 × CML451 PL 23109 × LM14 PL 23045 × CML451	PL 23043 × CML451 PL 23090 × LM14 PL 23110 × CML451 PL 23065 × CML451 PL 23085 × CML451	PL 23043 × CML451 PL 23090 × LM14
3.	Anthesis-silking interval	PL 23065 PL 23090 PL 23107 PL 23050A PL 23095	PL 23105 PL 23107 PL 23090 PL 23067 PL 23085	PL 23107 PL 23090	PL 23105 × CML451 PL 23107 × CML451 PL 23050A × LM14 PL 23090 × LM14 PL 23043 × CML451	PL 23050A × LM14 PL 23078 × LM14 PL 23079 × LM14 PL 23102 × LM14	PL 23050A × LM14
4.	Plant height	PL 23066 PL 23110 PL 23071 PL 23067 PL 23043	PL 23041 PL 23066 PL 23110 PL 23071 PL 23107	PL 23066 PL 23110 PL 23071	PL 23107 × LM14 PL 23066 × LM14 PL 23041 × LM14 PL 23040 × LM14 PL 23102 × LM14	PL 23100 × LM14 PL 23090 × CML451	-
5.	Ear height	PL 23066 PL 23110 PL 23071 PL 23067 PL 23078	PL 23041 PL 23107 PL 23066 PL 23110 PL 23043	PL 23066 PL 23110	PL 23041 × LM14 PL 23084 × CML451 PL 23066 × LM14 PL 23100 × LM14 PL 23065 × LM14	PL 23100 × LM14 PL 23084 × CML451	PL 23100 × LM14 PL 23084 × CML451
6.	Days to maturity	PL 23090 PL 23166 PL 23065 PL 23095 PL 23050A	PL 23050A PL 23109 PL 23045 PL 23077 PL 23099	PL 23050A	PL 23050A × LM14 PL 23090 × LM14 PL 23043 × CML451 PL 23110 × CML451 PL 23085 × CML451	PL 23090 × LM14 PL 23043 × CML451 PL 23110 × CML451 PL 23085 × CML451 PL 23065 × CML451	PL 23090 × LM14 PL 23043 × CML451 PL 23110 × CML451 PL 23085 × CML451

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Table 5. Top 5 hybrids based on *per se* performance, *sca* and *gca* effects for grain yield and its contributing traits

S. No.	Character	*per se* performance of lines	*gca effects*	*per se* and *gca* effects	*per se* performance of crosses	*sca* effects	*per se* and *sca* effects
7.	Ear length	PL 23065 PL 23071 PL 23095 PL 23105 PL 23066	PL 23043 PL 23084	-	PL 23105 × LM14 PL 23084 × CML451 PL 23085 × LM14 PL 23043 × LM14 PL 23043 × CML451	PL 23105 × LM14 PL 23050 × CML451 PL 23090 × CML451	PL 23105 × LM14
8.	Ear girth	PL 23065 PL 23095 PL 23071 PL 23105 PL 23066	PL 23107 PL 23084 PL 23065	PL 23065	PL 23107 × LM14 PL 23077 × CML451 PL 23107 × CML451 PL 23084 × LM14 PL 23065 × CML451	PL 23100 × LM14 PL 23077 × CML451	PL 23077 × CML451
9.	Kernel rows cob^{-1}	PL 23066 PL 23105 PL 23100 PL 23095 PL 23059	PL 23107 PL 23178 PL 23105 PL 23102 PL 23077	PL 23105	PL 23102 × CML451 PL 23078 × CML451 PL 23107 × LM14 PL 23077 × CML451 PL 23105 × LM14	PL 23102 × CML451 PL 23041 × LM14 PL 23105 × LM14	PL 23102 × CML451 PL 23105 × LM14
10.	Number of kernels row^{-1}	PL 23065 PL 23105 PL 23071 PL 23066 PL 23095	PL 23047 PL 23085 PL 23043 PL 23077 PL 23084	-	PL 23105 × LM14 PL 23077 × CML451 PL 23085 × LM14 PL 23100 × LM14 PL 23047 × CML451	PL 23090 × CML451 PL 23050 × CML451 PL 23105 × LM14 PL 23100 × LM14	PL 23100 × LM14 PL 23105 × LM14
11.	100 Kernel weight	PL 23071 PL 23095 PL 23066 PL 23043 PL 23077	PL 23043 PL 23184 PL 23071 PL 23067 PL 23040	PL 23071	PL 23041 × CML451 PL 23043 × CML451 PL 23184 × LM14 PL 23071 × CML451 PL 23048 × CML451	PL 23041 × CML451 PL 23056 × LM14	PL 23041 × CML451
12.	Grain yield plant^{-1}	PL 23065 PL 23071 PL 23095 PL 23110 PL 23066	PL 23043 PL 23047 PL 23105 PL 23107 PL 23110	PL 23110	PL 23110 × CML451 PL 23043 × CML451 PL 23043 × LM14 PL 23077 × CML451 PL 23047 × CML451	PL 23100 × LM14 PL 23090 × CML451 PL 23059 × LM14	-

× LM 14 were exhibited significant positive *sca* effects for grain yield (Table 4). Among these three hybrids, the hybrid PL 23100 × LM 14 (poor × poor) and also PL 23059 × LM 14 (poor × poor) registered desirable and significant *sca* effects for other yield contributing traits. Hence, these hybrids could be considered after confirming from heterotic studies for further testing in multi-location trails (Table 5).

Similar results on combining ability *i.e.,* significant positive *gca* and *sca* effects in desirable direction were obtained by Ahmad and Ansari (2017) and Sandesh *et al.* (2018), Rajesh *et al.* (2018), Sabitha *et al.* (2021) and Keerthana *et al.* (2023).

Among 60 hybrids, two crosses PL 23100 × LM 14 and PL 23059 × LM 14 were identified based on the *per se* performance and *sca* effects for grain yield. These crosses could be useful in development of high yielding hybrids in maize (Table 5).

Based on *per se* performance, the lines PL 23065 and PL 23095, PL 23066 and the crosses PL 23110 × CML 451 and PL 23043 × CML 451 exhibited higher grain yield coupled with earliness that indicates the usefulness of these crosses for earliness, so, they can be used in the development of the potential hybris with high yield and short duration that are useful in drought areas or low rainfall regions. Based on GCA effects, PL 23110 and PL 23105 were identified as the best parents for grain yield and most of its contributing characters. Hence, these parents could be utilized in the development of the high yielding and early maturing hybrids and also utilized in developing superior recombinants in further selection programmes for the improvement of yield parameters in maize. Based on SCA effects, two crosses PL 23100 × LM 14 and PL 23059 × LM 14 were identified based on the *per se* performance and *sca* effects for grain yield. These crosses could be useful in development of high yielding hybrids in maize. These hybrids need to be further evaluated across locations and over seasons to select best hybrids for commercial exploitation.

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