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Combining Ability Analysis of Maize (*Zea mays* L.) for Grain Yield and Yield Related Traits Using Line X Tester Method

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study aimed to evaluate the combining ability for yield and yield components in newly developed white maize lines. A total of 22 maize inbred lines, derived from various genetic sources at the Agricultural Research Station during the 2023 growing season, were used to create 40

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hybrids. These hybrids, along with two commercial check hybrids (Karimnagar Makka and Kaveri Ekka), were evaluated at Agricultural Research Station.

The analysis revealed highly significant differences for all traits studied. Among the inbred lines, KML-122, KML-7, and KML-6 were identified as good general combiners for grain yield and yield-contributing traits, such as days to 50% anthesis, days to 50% silking, days to maturity, and plant height. Based on specific combining ability (SCA) effects, the hybrids KML124×LM13, KML-131×LM-14, and KML-136×LM-13 were identified as specific combiners for yield and yield-attributing traits.

The successful identification and utilization of these high-GCA inbred lines can significantly contribute to the development of superior maize hybrids, enhancing overall productivity and sustainability in maize cultivation. Data on twelve morphological traits were recorded, with non-additive effects found to be important for all characters.

Keywords: Combining ability; GCA; SCA; Line × Tester model; maize.

1. INTRODUCTION

Maize (*Zea mays* L.) is a versatile crop that can be grown in a variety of climates and soils. It is the second most widely grown crop in the world, after rice. This crop is used for food, feed and industrial products. Maize (*Zea mays* L.) is the world's third leading cereal crop after wheat and rice. It accounts to 8 and 25% of the world's total area and production, respectively under cereal crops. In India, maize occupies an area of 98.90 lakh hectares with an average production of 316.5 lakh tonnes with productivity of 3200 kg ha^{-1}, while in Telangana it is grown in an area of 5.11 lakh hectares with production of 30.08 lakh tonnes and productivity of 5875 kg ha^{-1} during, 2020-21 [1]. Major maize growing districts in Telangana are Kamareddy (13400 ha), Jagtial (11709 ha), Nizamabad (8671 ha), Mahboobabad (9034 ha), Rangareddy (8884 ha), Nagarkurnool (5179 ha), Siddipet (4390 ha) and Vikarabad (3271 ha) (PJTSAU, 2020-21).

Moreover, the degree of genetic components for a specific trait is primarily influenced by the environmental conditions under which the breeding populations are tested. Consequently, it is essential to choose lines with high general combining ability (GCA) that are genetically diverse to produce superior hybrids (Amoon and Abdul Hamed, 2020). The effect of combining ability, both general and specific combining ability *(GCA*) and (*SCA)* are important indicators of potential value for assessing inbred lines in hybrid combination to develop hybrid varieties in maize. This information is helpful to plant breeders for formulating hybrid breeding programmes [2-5]. Habiba et al*.* [6] concluded that the majority of the lines under study demonstrated extremely general combiners, and the superior crossings resulted from a good × good combiner for the majority of characteristics that make up yield components. According to Kamal et al*.* (2023). Efforts are, therefore, required to be made to develop hybrids with high yield potential in order to increase production of maize. Furthermore, Izhar and Chakrabathy (2014) explained that the heterosis and combining ability are prerequisite for formulating hybrid breeding programmes and for developing a good M 215 economically viable hybrid maize varieties.

2. MATERIALS AND METHODS

2.1 Selection of Experimental Material

The experimental material comprised of 20 inbred lines used as female parents, two broad base testers (LM-13 and LM-14) used as male parents and five checks (Karimnagar makka, kaveri ekka, P-3202, PAC-741 and PAC-751).

2.2 Generation of Hybrids and Evaluation

Twenty maize inbred lines, used as female parents and two broad base testers (LM-13 and LM-14), used as male parents were crossed in Line × Tester (20 × 2) fashion to obtain 40 hybrids during *Rabi,* 2022-23 and hybrids along with lines, testers and checks evaluated during *Kharif, 2023* at Agricultural Research station, Karimnagar, situated at altitude of 259.15 m above mean sea level on 18◦44'31" N latitude and 79◦09'52" E longitude and it is categorized under Northern Telangana Zone.. The weather conditions during the growing season were favourable for crop growth, providing a conducive environment.

2.3 Experiment Design

These lines were evaluated in Line x Tester mating design during rabi 2023, at experimental farm of maize genetics unit, ARS, Karimnagar. The experimental material consists 40 test cross hybrids, five checks, Kaveri Ekka, Pioneer 3302, karimnagar makka, P -3202, PAC 741, PAC-751 as checks, which were evaluated in randomized block design with bocks and two replications and using 20 parental inbred lines evaluated separately in randomized block design with two replications during kharif 2023 outperform either of the parents in terms of yield and other desirable traits. Harnessing heterosis through the development of heterotic groups has been proven to be an effective strategy for maximizing crop productivity. Heterotic grouping, the classification of inbred lines into distinct groups based on their ability to combine favourably in hybrids, has been a successful approach in maize breeding programmes. Heterotic grouping plays a crucial role in the development of high-yielding maize hybrids. Traditionally, heterotic grouping has been determined through field performance trials and assessment of morphological traits. Morphological characteristics such as plant height, ear length, kernel weight and other quantitative traits are visually observable and provide valuable insights into the performance of maize inbred lines. However, these traditional methods are time-consuming and may not fully capture the underlying genetic diversity and relatedness among inbred lines.

3. RESULTS AND DISCUSSION

The data recorded on 40 hybrids, 22 parents along with 0 check were used for combining ability analysis using Line × Tester mating design (L × T).

3.1 Analysis of Variance for Line × Tester

The analysis of variance for the combining ability of all the traits in the current study.

Table 1. Field plot technique

Design of experiment	Randomized block design
Season	*Kharif* (2023)
Replication	2
Spacing	60 cm X 20 cm
Plot size	4.8 sq.m
No. of rows/entry	2
Location	ARS, Karimnagar

Table 2. Analysis of variance for randomized block design for yield and Yield Component Characters in Maize Genotypes

Character		Mean sum of squares	
Source of variation	**Replications**	**Genotypes**	**Error**
d.f	**1**	**66**	**66**
Days to 50% anthesis	7.17	1.80**	0.42
Days to 50% silking	12.54	1.80**	0.57
Days to maturity	1.07	3.04**	0.77
Plant height(cm)	0.77	4396.40**	9.39
Ear height(cm)	74.62	950.53**	9.47
Ear length(cm)	6.71	11.50**	1.42
Ear girth(mm)	2.19	28.64**	2.77
No.of kernel rows per ear	0.11	5.42**	0.72
No.of kernels per row	3.61	92.44**	10.26
Test weight(g)	10.77	30.05**	4.76
Grain yield (g/plant)	142644.70	13193028.80**	559330.70
Shelling %	1.07	9.01**	2.61

Table 3. Mean performances for yield

Trait	Grand mean	Range		S.E	CV
50% anthesis	53.8	50	55	0.46	1.23
50% silking	55	53	57	0.53	1.37
Days to maturity	87.12	83	88	0.62	1.01
Plant height	168.61	104	242	2.16	1.67
Ear height	160.05	47	112	2.17	3.46
Ear length	15.08	8.10	18.50	0.84	7.98
Ear diameter	38.30	28.76	43.66	1.17	4.42
Number of kernel per row	35.94	17.50	41.50	2.26	10.29
Number of kernel rows per ear	12.85	10	16	0.60	6.54
Test wt	31.31	24.50	37	1.54	6.96
Shelling	77.18	74.15	81.70	1.14	2.05
Grain yield	6619.4	2216.00	10632.00	528.83	10.91

Table 4. Estimates of general combining ability (GCA) effects for inbred lines for yield and yield attributing traits in maize

		Characters											
S. No	**Genotypes**	**Days to 50% anthesis**	**Days to 50% silking**	**Days to maturiy**	**Plant height (cm)**	**Ear ht (cm)**	**Ear length (cm)**	**Ear diameter (mm)**	**Number of kernels Per ear**	**No.of kernels per row**	**Test wt (g)**	**Shelling (%)**	**Yield (kg/ha)**
	Lines												
1	KML-121	-0.338	-0.425	-0.363	34.488 **	-17.300**	-3.945 **	-3.413**	0.300	6.563 *	-5.613**	-1.866	2300.925**
2	KML-122	-0.588	-0.675	-0.613	-11.988 **	-4.300*	-0.670	-1.191	0.300	0.688	-0.363	-0.991	-544.175
3	KML-123	0.163	0.325	-0.113	14.013 **	5.200*	0.355	-2.271*	-0.200	3.188	0.888	-0.416	-82.925
4	KML-124	-0.088	-0.425	-0.363	13.738 **	-0.800	1.755 **	2.649 *	1.300 **	1.688	0.888	-0.066	456.825
5	KML-125	-0.088	-0.175	-0.363	11.513 **	4.700*	-0.970	0.192	-0.700	-0.563	-0.613	0.409	-393.175
6	KML-126	-0.588	-0.425	-0.363	1.263	1.450	0.855	1.512	-0.700	2.188	0.388	-0.116	557.075
7	KML-127	0.163	0.325	0.638	9.513**	4.200 **	0.030	-0.953	-0.700	-0.063	1.138	-0.216	690.575
8	KML-128	-0.338	-0.175	-0.113	4.763*	4.450 *	0.880	2.787	0.300	-0.563	0.388	-0.316	499.075
9	KML-129	0.163	0.575	0.638	3.763	-2.550	0.805	0.829	1.300**	1.688	1.138	0.584	300.825
10	KML-130	0.913 *	0.825 *	0.388	10.013 **	0.20	0.930	2.897	0.800	0.938	-1.863	-0.491	-45.675
11	KML-131	0.163	-0.175	-0.113	- 10.738 **	-5.050	-1.070	1.808 *	0.700	-0.313	0.388	0.784	-356.425
12	KML-132	-0.338	-0.675	-0.613	-15.488 **	-5.300	0.330	0.794	-0.200	1.438	-1.363	-1.141	2055.82 **
13	KML-133	-0.088	0.325	0.388	5.513 **	3.200	-0.745	-0.353	-0.700	1.313	1.113	0.009	-188.425
14	KML-134	-0.588	-0.675	-0.613	15.013 **	2.700	-0.595	0.354	-0.200	1.813	2.388	-0.466	-411.675
15	KML-135	-0.588	-0.425	-0.363	6.513 **	3.200	0.830	2.837**	1.300	-2.063	1.113	0.784	421.825
16	KML-136	0.163	0.325	0.388	10.763	4.950*	0.605	0.429	0.700	1.938	0.138	0.309	-178.675
17	KML-137	0.663	0.575	0.638	-3.488 *	0.200	-0.095	-1.971	-0.200	-1.813	-1.613	0.859	159.825
18	KML-138	0.913 *	0.825 *	0.888 *	5.513 **	0.200	-0.445	-2.968 **	1.200 *	-2.313	1.638	0.409	-344.675
19	KML-139	0.663	0.575	0.388	-5.988 *	0.800	0.880	1.269	0.300	2.438	2.888 *	1.534	-526.675
20	KML-140	-0.338	-0.425	-0.363	-2.238	1.450	0.280	-1.623	1.300 *	1.888	0.738 *	0.409	231.575
	Tester												
1	LM-13	-0.113	-0.175	-0.138	2.263 *	0.175	0.260	0.725*	0.300 *	0.838	-0.738 *	-0.054	181.550
2	LM-14	0.113	0.175	0.138	2.263 *	-0.175	-0.260	-0.725 *	-0.300 *	-0.838	2.192	0.054	-181.550
	GCA Line	0.72	0.79	0.88	3.02	3.04	1.50	1.50	0.70	2.61	3.79	1.69	843.19
	GCA Tester	0.22	0.25	0.28	0.95	0.96	0.35	0.47	0.22	1.10	4.38	0.53	266.64

**Significance at 5% probability, **significance at 1% probability*

Table 5. Analysis of variance for combining ability for yield and yield attributing traits in maize

Source of variation	d.f.	Mean sum of squares for											
		Days to 50% anthesis	Days to 50% silking	Days to maturity	Plant height (cm)	Ear height (cm	Ear length (cm	Ear girth (mm)	Number of kernel rows per ear	Number of kernels per row	Test weight (g)	Shelling (%)	Grain yield (kg/ha)
Replications	1	7.75	13.55	1.16	11.64	82.266	4.266	1.323	0.03	7.25	9.87	0.149	245373.03
Treatments	61	108.45**	1.87**	3.08**	4508.59**	1001.922**	11.36**	29.11**	4.75**	84.41**	26.46**	9.28**	13395438.27
Parents	21	51.72**	2.89**	2.16**	88.55**	87.35**	7.516**	19.24**	1.12	18.93*	7.70	5.57*	576345.88**
Parents (Line)	19	24.47**	1.44*	1.65*	92.63**	93.52**	7.664**	18.15**	1.11	17.37	6.91	5.42*	525461.71
Parents (Testers)	1	0.25	0.0	0.25	12.25	20.250	0.062	7.92	0.00	12.25	2.250	1.44	193600.00
Parents (L *vs* T)	1	27.00**	33.27**	13.82**	87.30*	37.23	12.144*	51.25**	2.62	55.30*	28.00*	12.64*	1925891.13
Parent vs Crosses	1	18.84**	12.93**	100.89**	257230.40**	56570.11**	364.09**	818.16**	173.56**	3991.54**	901.45**	361.95**	726600998.52**
Crosses	39	37.88*	1.03*	1.07	408.57**	69.55**	4.39**	14.19**	2.37**	19.49*	14.12**	2.245	2010704.42**
Line Effect	19	18.13	1.08	0.95	617.35*	109.96*	5.780	15.71	2.25	20.39	13.82	2.48	2596436.55
Tester Effect	1	1.01	2.45	1.51	409.51	2.450	5.408	42.06	7.20	56.11	43.51	0.231	2636832.20
Line x **Tester**	19	18.73*	0.92	1.17	199.74**	32.68**	2.96*	11.20**	2.25	16.66	12.88**	2.107	1392018.20*
Error	61	27.75	0.60	0.83	9.35	9.430	1.423	2.91	0.75**	10.84	5.05	2.62	598164.93
Total	123	143.95	1.33	1.95	2240.70	502.23	6.378	15.89	2.73	47.30	15.71	5.90	6941911.94

Table 6. Estimates of specific combining ability (SCA) effects for hybrids for yield and yield attributing traits in maize

S. No.	Genotypes	Characters											
		Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear girth (mm)	Number of kernels per ear	No. of kernels per row	Test wt (g)	Shelling (%)	Grain yield (kg ha-1)
	Hybrids												
1	KML121×LM13	-0.63	-0.82	-0.86	1.76	-5.1	0.84	-3.00*	-1.83	-0.300	0.513	1.10	727.70
2	KML121×LM14	0.63	0.82	0.86	1.76**	5.17	-0.84	3.00*	1.83	0.300	-0.513	-1.10	-727.70
3	KML122×LM13	-0.88	-0.57	-0.61	-7.76**	0.32	0.56	-0.72	1.91	-0.300	0.763	1.32	-343.55
4	KML122×LM14	0.88	0.57	0.61	7.76	-0.32	-0.56	0.72	-1.91	0.300	-0.763	-1.32	343.55
5	KML123×LM13	0.36	-0.07	0.38	-5.26	-0.67	0.79	0.84	2.91	0.200	1.013	-0.59	564.70
6	KML123×LM14	-0.36	0.07	-0.38	5.26	0.67	-0.79	-0.84	2.91	-0.200	-1.013	0.59	-564.70
7	KML124×LM13	-0.38	-0.32	-0.36	-15.01**	-3.67	-0.96	-0.88	0.41	-1.300*	-1.488	0.20	-1338.05
8	KML124×LM14	0.38	0.32	0.36	15.01**	3.67	0.96	0.88	-0.41	1.300*	1.488	-0.20	1338.05
9	KML125×LM13	-0.38	-0.57	-0.86	-2.26	1.32	-0.68	-1.70	-1.33	0.700	0.513	0.32	-76.05
10	KML125×LM14	0.38	0.57	0.86	2.26	-1.32	0.68	1.70	1.33	-0.700	-0.513	-0.32	76.05
11	KML126×LM13	1.11 *	1.17	1.13	-0.01	2.57	-1.16	1.42	-5.08**	0.700	-3.488	0.05	-458.30
12	KML126×LM14	-1.11	-1.17	-1.13	0.01	-2.57	1.16	-1.42	5.08	-0.700	3.488	-0.05	458.30
13	KML127×LM13	-0.13	-0.07	0.13	-0.76	-0.67	1.16	0.91	0.66	0.700	0.013	0.35	1048.20
14	KML127×LM14	0.13	0.07	-0.13	0.76	0.67	-1.16	-0.91	-0.66	-0.700	-0.013	-0.35	-1048.20
15	KML128×LM13	0.13	-0.07	-0.11	5.98*	-2.92	0.41	-1.08	0.16	-0.300	0.263	-0.94	88.20
16	KML128×LM14	0.13	0.07	0.11	-5.98*	2.92	-0.41	1.08	-0.16	0.300	-0.263	0.94	-88.20
17	KML129×LM13	-0.13	0.17	0.13	-3.51	-2.42	-0.41	0.72	-0.08	-0.300	1.013	1.35	181.95
18	KML129×LM14	0.13	-0.17	-0.13	3.51	2.42	0.41	-0.72	0.08	0.300	-1.013	-1.35	-181.95
19	KML130×LM13	0.61	0.42	0.88	2.23	0.82	-0.23	-1.33	-2.83	-0.800	-1.238	-1.12	-304.05
20	KML130×LM14	-0.61	-0.42	-0.88	-2.23	-0.82	0.23	1.330	2.83	0.800	1.238	1.12	304.05
21	KML131×LM13	-0.13	-0.07	-0.11	7.48*	1.57	-1.83	-2.55	-2.08	-1.300*	-2.238	-0.29	-928.80
22	KML131×LM14	0.13	0.07	0.11	-7.48*	-1.57	1.83	2.55	2.08	1.300*	2.238	0.29	928.80
23	KML132×LM13	0.36	0.42	0.38	-14.26**	-5.67	-0.08	-0.24	0.16	0.200	-2.988	-0.42	-287.05
24	KML132×LM14	-0.36	-0.42	-0.38	14.26**	5.67	0.08	0.24	-0.16	-0.200	-2.988	0.42	287.05
25	KML133×LM13	-0.38	-0.07	-0.11	-3.76	0.32	-0.56	0.96	-0.58	0.700	1.263	-0.77	93.20
26	KML133×LM14	0.38	0.07	0.11	3.76	-0.32	0.56	-0.96	0.58	-0.700	-1.263	0.77	-93.20

S. No.	Genotypes	Characters											
		Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear heigh t (cm)	Ear length (cm)	Ear girth (mm)	Number of kernels per ear	No. of kernels per row	Test wt (g)	Shelling (%)	Grain yield (kg ha-1)
27	KML134×LM13	0.11	0.42	0.38	11.23**	2.32	1.19	3.29*	0.91	1.200	0.013	-0.14	252.45
28	KML134×LM14	-0.11	-0.42	-038	-11.23**	-2.32	-1.19	-3.29*	-0.19	-1.200	-0.013	0.14	-252.45
29	KML135×LM13	0.11	-0.07	0.13	8.73**	4.82	-0.83	0.08	-1.83	-0.300	-1.488	-0.49	-241.55
30	KML135×LM14	-0.11	0.07	-0.13	-8.73**	-4.82	0.83	-0.08	1.83	0.300	1.488	0.49	241.55
31	KML136×LM13	0.13	0.42	-0.61	4.48	1.07	-0.31	1.44	2.16	0.700	4.513	-0.37	910.45
32	KML136×LM14	0.13	-0.42	0.61	-4.48	-1.07	0.31	-1.44	-2.16	-0.700	-4.513	0.37	-910.45
33	KML137×LM13	-0.13	0.17	-0.36	0.73	4.82	1.24	0.11	1.91	1.200*	1.263	-0.62	308.45
34	KML137×LM14	0.13	-0.17	0.36	-0.73	-4.82	-1.24	-0.11	-1.91	-1.200*	-1.263	0.62	-308.45
35	KML138×LM13	-0.38	-0.57	-0.11	3.23	1.32	-0.11	1.11	0.41	-0.800	1.513	0.77	283.95
36	KML138×LM14	0.38	0.57	0.11	-3.23	-1.32	0.11	-1.11	-0.14	0.800	-1.513	-0.77	-283.95
37	KML139×LM13	0.36	-0.32	-0.11	7.73	-0.67	0.51	-2.04	1.16	-0.300	0.263	-0.09	-565.55
38	KML139×LM14	-0.36	-0.07	0.11	-7.73	0.67	-0.51	2.04	-1.16	0.300	-0.263	0.09	565.55
39	KML140×LM13	0.86	0.07	0.63	2.48	0.57	0.46	2.66	2.91	-0.300	0.013	0.37	83.70
40	KML140×LM14	-0.86	0.17	-0.63	-2.48	-0.57	-0.46	-2.66	-2.91	0.300	-0.013	-0.37	-83.70
	***sca* at 95 %**	**1.02**	**1,12**	**1.25**	**4.28**	**4.31**	**1.59**	**2.13**	**1.00**	**3.69**	**3.09**	**2.40**	**1192.45**

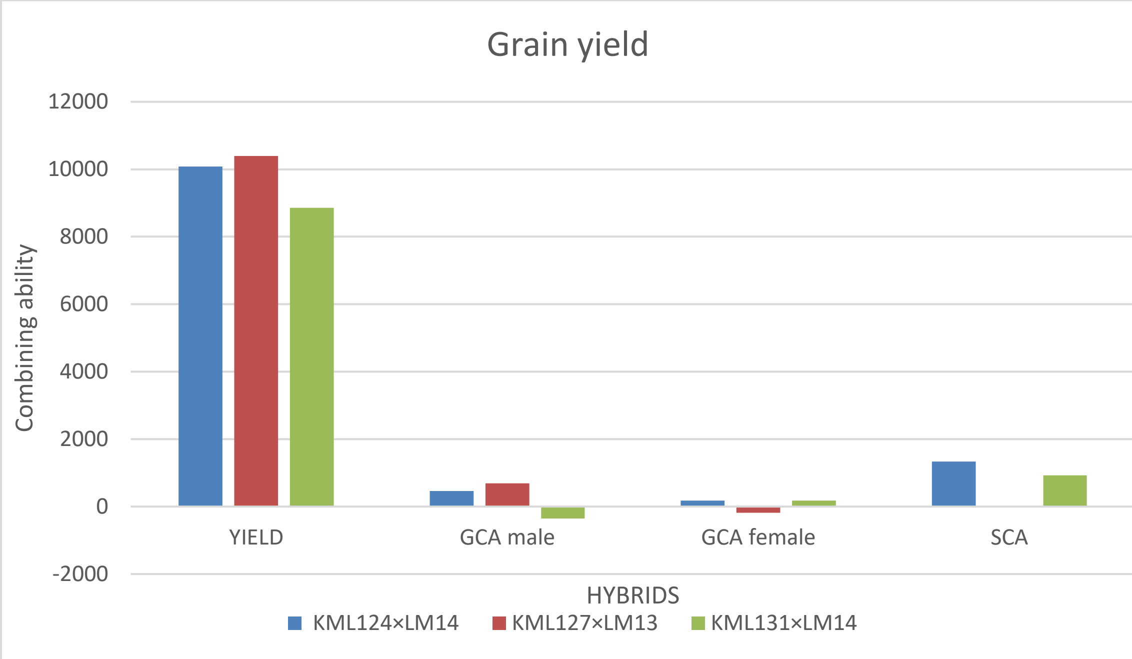

Fig. 1. Top 3 hybrids based on *GCA* and *SCA* effects of grain yield

The results indicate that treatments were significant for all the traits examined. However, the variance due to replications was non-significant. The variance between parents and crosses was significant for all traits. The variance due to lines was significant for all traits. The variance due to testers was significant for moisture trait. When the effects of parents were divided into lines, testers, and line × tester interactions, the interaction effects (lines × testers) were significant for traits such as days to 50% anthesis, days to 50% silking, anthesis silking interval, ear height, the number of kernel rows per ear, the number of kernels per row, 100 kernel weight, and grain yield per plant. This suggests there is sufficient variability in the material studied [7,8].

Significant differences among the parents indicate a high level of diversity among the parents in the study. The hybrids also showed significant differences, highlighting the varying performance of the cross combinations. The significant differences between parents and hybrids for all traits suggest that a considerable amount of average heterosis is present in hybrids for these characters.

3.2 *GCA* and *SCA* Effects

The estimates of GCA effects revealed that the parents' *viz.*, Based on significant *GCA* effect, the parents KML-122, KML-7, KML-6 were identified as good general combiners for grain yield and yield contributing traits like days to 50 per cent anthesis, days to 50 per cent silking, days to maturity, plant height, were proved to be good general combiner for yield and yield contributing characters [9,10].

In this study, the CA to SCA variance ratio was less than one for days to 50 percent anthesis, 50 percent silking, anthesis-silking interval, days to maturity, plant height, ear height, and grain yield per plant, as ear length, ear girth, number of kernel rows per ear, number of kernels per row, and 100 kernel weight, moisture suggesting these traits are governed by non-additive gene action.

These results align with previous findings by Mousa et al*.* [11].

4. CONCLUSION

Based on significant *GCA* effect, the parents KML-122, KML-7, KML-6 were identified as good general combiners for grain yield and yield contributing traits like days to 50 per cent anthesis, days to 50 per cent silking, days to maturity, plant height. Based on *sca* effects, the hybrids, KML124×LM13, KML131×LM14, KML136×LM13 were identified as specific combiners for yield and yield attributing traits.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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