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Heterosis and combining ability analysis in newly developed inbred lines of maize (*Zea mays* L.)

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Abstract
The study aimed to assess heterosis and combining ability for grain yield (t ha^{-1}) in newly developed maize inbred lines. A hybridization program, including the L × T mating design, using 20 inbred lines and three testers. Resulted in 60 single cross experimental hybrids, evaluated across two seasons in a randomized block design. Results highlighted significant genetic variation among the genotypes, with lines contributing more to total hybrid variance than testers. Non-additive gene action, especially dominance variance, played a key role in trait expression. Inbred lines DIM-317 and DIM-304 showed notable general combining ability (gca) effects, indicating their potential as general combiners for grain yield. Cross combinations, including LC-8376, LC-8619, LC-8624, LC-8418, LC-8441, LC-8394, and LC-8630, exhibited high positive specific combining ability (sca) effects, suggesting their suitability as specific combiners. Heterosis assessment revealed variability in the extent of heterotic effects for grain yield, with crosses like LC-8634, LC-8636, LC-8411, LC-8616, LC-8617, and LC-8441 displaying significant mid-parent heterosis, indicating remarkable increases over mid-parental values. Standard heterosis showed numerical superiority in a few crosses, including LC-8634 and LC-8418. The findings emphasize the importance of selecting parents with complementary genetic backgrounds and high combining abilities for successful hybridization. The study provides insights into the genetic potential of newly developed maize inbred lines, contributing to ongoing efforts in breeding high-yielding hybrids and paving the way for further advancements in maize improvement programs.

Keywords: Line × tester, general combining ability, specific combining ability, heterosis, ANOVA

Introduction

The primary aim of maize breeding is to cultivate new hybrids characterized by elevated genetic potential for yield and advantageous traits that surpass those found in existing commercial hybrids. The successful production of these hybrids hinges on two crucial factors: the inherent characteristics of the individual line and its performance within a hybrid combination. The evaluation of a line's behavior in hybrid combinations is gauged through the estimation of general combining ability (gca) and specific combining ability (sca) effects.

Since the proposal of the inbred-hybrid concept by Shull in 1908, the emphasis on harnessing heterosis in maize breeding has persisted. Achieving superior hybrids relies on understanding the combining ability of the lines involved in hybrid production. The exploitation of hybrid vigor or heterosis is a pivotal method in crop improvement, particularly in cross-pollinated crops. The selection of appropriate parents, a crucial step in exploiting hybrid vigor, depends on factors such as the individual performance of the parents and their combining ability. The concept of general and specific combining ability, as introduced by Sprague and Tatum in 1942, aids breeders in evaluating lines for use as parents in hybrid production and identifying superior hybrids with both additive and non-additive gene effects.

The L × T mating design, as proposed by Kempthorne in 1957 [6], emerges as a suitable method to identify superior parents and hybrids based on gca and sca effects, respectively. The nature and magnitude of gene action represent additional critical factors in the development of an effective breeding program. Combining ability analysis proves invaluable in assessing potential inbred lines and identifying the nature of gene action involved in various quantitative characters. A comprehensive understanding of the genetic architecture of yield and its components necessitates systematic studies on heterosis, combining ability, and gene action.

The paramount objective of any maize breeder is the development of high-yielding hybrids to enhance productivity. Achieving this goal requires inbred lines with high productivity, necessitating the development or improvement of maize inbred lines with diverse genetic backgrounds.

The IARI Regional Research Center (RRC), Dharwad, has successfully developed new inbred lines with diverse features, yet untapped in breeding programs. As the initial step in a breeding program utilizing these new genetic materials, it is imperative to study genetic variation, gene action, and combining abilities of these newly developed inbred lines. The diverse maize inbred lines identified can serve as parents in harnessing heterosis. With these considerations in mind, the present study is designed with the objective of estimating heterosis and combining ability for yield in newly developed inbred lines of maize.

Materials and Methods

Geographical location and Weather condition

In conducting the experiments aimed at assessing GCA, SCA, and heterosis extent, the research was carried out at the IARI Regional Research Centre in Dharwad. Positioned in the transitional tract of Karnataka State, the center is located at 15°27' north latitude, 75°13' east longitude, and at an altitude of 678 m above mean sea level. The average rainfall at the IARI Regional Research Centre, Dharwad, stands at 546 mm, with soils characterized as sandy loam and a pH of 7.2. Irrigation is sourced from a Tube well, and the crop was cultivated under rainfed conditions during kharif and irrigated during Rabi.

Genetic material

The experimental materials comprised 20 newly developed elite inbred lines of maize sourced from diverse origins such as CIMMYT, IIMR, and IARI Regional Research Centre, Dharwad. Three testers, namely DC-13 (MS heterotic pool), DC-14 (tuxpeno pool), and DC-17 (MS heterotic pool), were used. Additionally, 60 single cross experimental hybrids resulting from a line × tester design were evaluated, along with 20 parents and two checks (PMH-1 and PMH-3), during kharif-2017 and rabi-2017.

Hybridization programme

The crossing program was initiated at IARI Regional Research Centre, Dharwad, where 20 inbred lines and three testers were sown during summer-2017 with a spacing of 75 × 20 cm. Staggered sowing, arranged in ten rows for each male parent, followed the L × T mating design. The program included silk cutting, bagging, and pollination. Silks were cut back on shoots three to four days before pollination to ensure uniform silk emergence. Shoots were then bagged securely with silk bags. A day before pollination, bagging was performed using the tassel bag method, involving the coverage of the tassel with a bag made of heavy craft paper. Pollens were applied to silks after removing the silk bag, ensuring no contact or exposure of the silks. The tassel bag was then flipped upwards, allowing the pollen to fall onto the silk. The bag was pulled down and fastened to prevent contamination.

Evaluation of single cross experimental hybrids

The 60 single cross experimental hybrids resulting from the line × tester design were evaluated along with 20 parents and two checks (PMH-1 and PMH-3) during kharif-2017 and rabi-2017. The experimental design employed was a randomized complete block design, with two replications, totaling 85 entries per replication. The row length was 4 m, with two rows per plot, spaced at 75 cm between rows and 20 cm between plants within the row. The plot size was 4.0 m × 1.5 m, equaling 6.0 m².

After thorough land preparation, sowing was performed by hand dibbling with one seed per hill, followed by irrigation. Recommended doses of fertilizers (150 N, 75 P_2O_5, 37.5 K_2O, and 25 $ZnSO_4$ kg/ha) were applied, with P_2O_5, K_2O, $ZnSO_4$, and one-third of nitrogen as basal dose and the remaining two-thirds of nitrogen top-dressed in two equal splits at the fourth and seventh week after planting. Weeding, irrigation, and other recommended cultural practices were adhered to as per the maize crop's recommended package of practices to ensure a healthy crop.

Harvest and Yield Calculation

Upon reaching physiological maturity, the cobs were carefully dehusked and harvested within each designated net plot. To accurately gauge the yield, the harvested cobs underwent a systematic process: air drying, shelling, cleaning, and subsequent weighing. The recorded metric for each plot was the fresh ear weight at the time of harvest.

Grain yield per hectare was computed from yield per plot and expressed in t ha^{-1}.

$$F = e \frac{100 - d}{100}$$

Where,

e = corrected fresh ear weight on the basis of Av stand at harvest

e = ab/c

a = average stand per plot of the trial

b = fresh ear weight (g)

c = stand at harvest of the respective plot

d = average moisture (%)

F = corrected fresh ear weight at zero per cent moisture

At the time of harvesting, fresh ear weight was recorded in grams per plant. Moisture content in grain at maturity was recorded in shelled samples of five random ears of each plot with the help of electronic moisture meter. The fresh weight of ear data was used to work out the dry weight grain yield per plant at 15% moisture level. Corrected fresh ear weight at 0% moisture to be multiplied by correction factor (100/85) for calculation of plot yield at 15% moisture content.

$$\text{Grain yield (kg ha}^{-1}\text{) at 0\% moisture} = \frac{\text{Fresh ear weight} \times (100 - \text{AVM}) \times \text{S\%} \times 10000}{100 \times \text{plot area}}$$

$$\text{Grain yield (kg ha}^{-1}\text{) at 15\% moisture} = \frac{\text{Fresh ear weight} \times (100 - \text{AVM}) \times \text{S\%} \times 10000 \times 100/85}{100 \times \text{Plot area}}$$

Where,

AVM = Average moisture content

S% = Shelling Percentage

Statistical analysis

The statistical analysis involved applying Analysis of Variance (ANOVA) to the mean values of grain yield for both parents and hybrids, following the methodology outlined by Panse and Sukhatme (1962) [8]. Combining ability analysis included subjecting the mean values of each character in every entry to line × tester analysis, and the variance of general combining ability for various cross combinations was determined using Kempthorne's procedure (1957) [6].

Estimation of heterosis was integral, with percentages of increase or decrease of the F1 hybrid over different benchmarks calculated for each character using formulas from Turner (1953) [10] and Hayes *et al*. (1955) [5]. Standard heterosis, based on the mean performance of the best check for a given trait out of three checks, was calculated, and differences in the magnitude of heterosis were rigorously tested as per Panse and Sukhatme's procedure (1962) [8].

Results Discussion

Analysis of variance of parents and crosses for yield and yield attributes

The Randomized Complete Block Design analysis of variance conducted among the 85 entries revealed significant differences, as shown in Table 1, with respect to the mean sum of squares for grain yield per hectare. The ANOVA results pointed to highly significant variations among the genotypes, indicating the presence of substantial variability within both parents and hybrids. The analysis of variance for combining ability, as presented in Table 1 for both kharif and rabi seasons, demonstrated significant variations among the treatments for grain yield. The parents versus hybrids (crosses) mean sum of squares were highly significant, suggesting the presence of average heterosis due to significant differences in the mean performances of hybrids and parents. Mean sum of squares due to parents were non-significant during both kharif and rabi, while the mean squares due to lines vs. testers were also non-significant. Crosses exhibited highly significant mean sum of squares for grain yield per hectare in both kharif and rabi seasons. These results shed light on the existence of substantial genetic variability and combining ability effects, providing insights into the performance of parents and hybrids in terms of grain yield (t ha^{-1}). The table presents the proportionate contributions of lines, testers, and their interaction to the total hybrid variances (Table 1). The contribution of females to the total hybrid variance was higher than that of males but less than the contribution from the interaction between females and males, as indicated in Table 1, during both kharif and rabi seasons. This suggests that specific cross combinations interact significantly to enhance the *per se* values.

Table 1: Line × Tester analysis of variance for Grain yield per hectare in maize

Source of variation	d. f.	kharif-2017	rabi-2017
Replicates	1	7.18*	0.17
Treatments	82	13.36**	15.10**
Parents	22	1.23	1.19
Parents (Line)	19	1.21	1.07
Parents (Testers)	2	0.01	0.27
Parents (L vs T)	1	3.92	5.35
Parents vs Crosses	1	591.62**	888.79**
Crosses	59	8.08**	5.48**
Line × Tester	38	7.78**	5.96**
Error	82	1.6	1.4
Variance components			
σ^2_{GCA}		0.24	0.14
σ^2_{SCA}		3.09**	2.28**
$\sigma^2_{GCA}/\sigma^2_{SCA}$		0.08	0.06
σ^2_{A}		0.47	0.29
σ^2_{D}		3.09	2.28
$\sigma^2_{A}/\sigma^2_{D}$		0.15	0.13
Proportional contribution of female, male and female × male for hybrid yield			
Contribution of females%		35.85	26.9
Contribution of males%		2.14	3.05
Contribution of females □ males%		62	70.04

*, ** - Significant at 5% and 1% level of probability, σ^2_{GCA} = Variance GCA, σ2SCA= Variance SCA

Table 1 illustrates that, in both kharif and rabi seasons, the variance attributed to specific combining ability (SCA) exceeded that of general combining ability (GCA). The GCA to SCA variance ratio consistently fell below unity, highlighting the notable impact of non-additive gene action on trait expression. Similarly, the ratio of additive to dominance variance remained consistently below unity, indicating a predominant role of dominance over additive genetic effects. These findings underscore the importance of non-additive genetic factors in influencing the observed variations in the studied traits during both seasons.

Combining ability analysis for Grain yield per hectare

Combining ability estimates guide the selection of desirable parents based on test cross progeny performance obtained through various mating designs. The ultimate choice of parents for a breeding program relies on their individual performance and behavior in hybrid combinations. Hence, it is crucial to systematically assess the genetic potential of parents in hybrid combinations, particularly in relation to general and specific combining abilities. Tables 2 (gca) and 3 (sca) present the estimation of gca and sca effects for grain yield during both kharif and rabi seasons.

Kharif Season: GCA effects for grain yield varied from DIM-322 (-2.15) to DIM-317 (3.42), with only DIM-317 showing significant gca effects in a desirable direction. Among testers, none showed significant gca effects. SCA effects ranged from -3.14 (LC-8396) to 2.71 (LC-8376), with nineteen cross combinations displaying significant positive sca effects. Notably, crosses like LC-8376, LC-8619, LC-8624, LC-8418, LC-8441, LC-8394, and LC-8630 exhibited high positive sca effects.

Rabi Season: GCA effects ranged from DIM-333 (-1.83) to DIM-304 (1.25), with only DIM-304 showing significant gca effects in a desirable direction. Among testers, none showed positive significant gca effects, but tester DC-17 (-0.41) showed negative significant gca effects. SCA effects ranged from -2.91 (LC-8620) to 4.07 (LC-8418), with six crosses displaying significant positive sca effects. Notably, crosses like LC-8418, LC-8624, LC-8641, LC-8669, LC-8617, and LC-8619 exhibited high positive sca effects.

Among twenty lines, only DIM-317 during kharif and DIM-304 during rabi showed significant gca effects in a desirable direction, suggesting these lines are good general combiners for grain yield. Among sixty crosses, nineteen during kharif and six during rabi exhibited significant sca effects, with crosses like LC-8376, LC-8619, LC-8624, LC-8418, LC-8441, LC-8394, LC-8630, LC-8641, LC-8669, LC-8617, and LC-8619 displaying high significant sca effects. These crosses are considered the best specific combiners for grain yield per hectare, aligning with findings from previous studies by Gazal *et al*. (2017) [4], Avinash *et al*. (2017) [2], Dar *et al*. (2018) [3], and Kharim *et al*. (2018) [7].

Extent of heterosis for Grain yield per hectare

Heterosis was assessed in 60 hybrids for grain yield per hectare and expressed as an increase or decrease over mid-parental values (mid-parent/relative heterosis) and over standard checks (standard heterosis/economic heterosis). Standard heterosis for grain yield and yield-contributing characters was evaluated against the best commercial check PMH-3, and the results of mid-parent heterosis and standard heterosis are presented in Table 4.

Kharif Season: Heterosis expression over mid-parental values for grain yield per hectare ranged from -3.98 (LC-8484) to 250.31% (LC-8634). Forty-seven crosses displayed positive significant mid-parent heterosis, with the top three hybrids LC-8634 (250.31%), LC-8636 (222.07%), LC-8411 (197.97%), LC-8616 (196.68%), LC-8617 (188.56%), and LC-8441 (181.92%) showing highly significant mid-parent heterosis. Standard heterosis estimates varied from -60.68% (LC-8667) to 13.83% (LC-8634). While none of the sixty hybrids recorded positive significant standard heterosis over the commercial check, six crosses exhibited numerical superiority, with the highest magnitude displayed by hybrids LC-8634 (13.83%), LC-8636 (3.27%), and LC-8441 (1.13%).

Rabi Season: The extent of heterosis exhibited by hybrids over their corresponding mid-parent for this trait ranged from -7.39 (LC-8630) to 311.56% (LC-8418). Among the 60 hybrids studied, fifty-two crosses showed positive significant mid-parent heterosis. The hybrids LC-8418, LC-8394, LC-8619, LC-8635, and LC-8641 (311.56%, 207.11%, 198.56%, 192.97%, and 183.75%, respectively) recorded highly significant relative heterosis. Standard heterosis recorded values ranging from -62.77% (LC-8484) to 19.88% (LC-8418). While none of the sixty hybrids recorded positive significant economic heterosis over the commercial check, only one cross, LC-8418 (19.88%), revealed numerical superiority over commercial check PMH-3.

Among the sixty hybrids, none recorded significant positive economic heterosis, but six and one crosses revealed numerical superiority over commercial check PMH-3 during both kharif and rabi, respectively. Forty-seven crosses during kharif and fifty-two crosses during rabi exhibited relative heterosis. Consistent findings were reported by Gazal *et al*. (2017) [4], Anilkumar *et al*. (2018), and Kharim *et al*. (2018) [7].

Table 2: Estimates of general combining ability effects of lines and testers for Grain yield per hectare during *kharif*-2017 and *rabi*-2017

Sl. No.	Lines	Yield per hectare	
		kharif-2017	rabi-2017
1	DIM-320	-0.22	-0.23
2	DIM-330	0.72	-0.32
3	DIM-327	0.87	0.09
4	DIM-317	3.42**	0.44
5	PDM-79-1	-0.14	0.73
6	PDM-71-2	-0.46	0.75
7	DIM-322	-2.15**	-0.47
8	DIM-348	-0.37	0.12
9	PDM-95	0.71	-1.18*
10	DIM-311	-0.18	0.71
11	PDM-201	0.87	0.66
12	PDM-4281	0.98	0.76
13	DIM-333	-0.68	-1.83**
14	PDM-198	-0.8	0.91
15	DIM-342	-0.44	-0.7
16	DIM-346	-1.67**	0.74
17	PDM-4641	-0.67	-0.9
18	DIM-337	0.82	0.01
19	DIM-304	0.89	1.25*
20	DIM-336	-1.51**	-1.53**
Testers			
1	DC-13	-0.02	0.22
2	DC-14	-0.35	0.18
3	DC-17	0.37	-0.41*
S.Em. ±		0.67	0.52
C.D. at 5% female		1.34	1.03
C.D. at 1% female		1.78	1.38
S.Em. ±		0.26	0.2
C.D. at 5% male		0.52	0.4
C.D. at 1% male		0.69	0.53

Table 3: Estimates of specific combining ability effects of crosses for Grain yield per hectare during kharif-2017 and rabi-2017

Sl. No.	Lines	Hybrids	Yield per hectare	
			K-17	R-17
1	DIM-320	LC-8658	0.7	0.19
		LC-8659	-1.81*	0.58
		LC-8660	1.11	-0.77
2	DIM-330	LC-8610	0.95	0.18
		LC-8611	-0.33	-1.31
		LC-8612	-0.63	1.14
3	DIM-327	LC-8619	2.43**	1.76*
		LC-8620	-2.76**	-2.91**
		LC-8621	0.33	1.16
4	DIM-317	LC-8634	1.31	-0.91
		LC-8635	-1.07	0.11
		LC-8636	-0.24	0.8
5	PDM-79-1	LC-8418	2.27*	4.07**
		LC-8419	-2.07*	-1.48
		LC-8420	-0.2	-2.59**
6	PDM-71-2	LC-8394	2.15*	0.96
		LC-8395	0.99	-0.09
		LC-8396	-3.14**	-0.88
7	DIM-322	LC-8667	-1.35	-2.09*
		LC-8668	-0.28	-0.05
		LC-8669	1.63	2.14*
8	DIM-348	LC-8640	-1.11	-2.91**
		LC-8641	1.86*	2.20*
		LC-8642	-0.76	0.71
9	PDM-95	LC-8439	-1.98*	1.42
		LC-8440	-0.26	-1.73*
		LC-8441	2.24*	0.31
10	DIM-311	LC-8622	-2.82**	-1.82*
		LC-8623	0.5	-0.5
		LC-8624	2.32*	2.32**
11	PDM-201	LC-8409	-1.1	-0.88
		LC-8410	0.66	1.65
		LC-8411	0.44	-0.76
12	PDM-4281	LC-8517	0.66	-0.73
		LC-8518	0.83	-0.42
		LC-8519	-1.48	1.15
13	DIM-333	LC-8625	-0.13	-0.29
		LC-8626	-0.43	0.12
		LC-8627	0.56	0.17
14	PDM-198	LC-8484	-2.92**	-0.64
		LC-8485	1.19	0.78
		LC-8486	1.73	-0.15
15	DIM-342	LC-8628	-2.70**	1.49
		LC-8629	0.65	0.61
		LC-8630	2.04*	-2.10*
16	DIM-346	LC-8637	0.64	0.99
		LC-8638	-0.14	0.4
		LC-8639	-0.49	-1.39
17	PDM-4641	LC-8376	2.71**	0.25
		LC-8377	0.36	0.19
		LC-8378	-3.07**	-0.44
18	DIM-337	LC-8661	-2.18*	-1.58
		LC-8662	0.85	0.02
		LC-8663	1.34	1.56
19	DIM-304	LC-8616	1.12	0.25
		LC-8617	1.33	1.88*
		LC-8618	-2.46**	-2.13*
20	DIM-336	LC-8643	1.35	0.28
		LC-8644	-0.08	-0.05
		LC-8645	-1.27	-0.23
S.Em. ±			0.71	1.16
C.D. at 5%			1.41	2.31
C.D. at 1%			1.88	3.08

*, ** - Significant at 5% and 1% level of probability

Table 4: Estimates of heterosis over mid parent and commercial check for Grain yield per hectare during *kharif* - 2017 and *rabi* – 2017

Sl. No.	Hybrids	Heterosis for grain yield per hectare over			
		Mid parent		PMH-3	
		K-17	R-17	K-17	R-17
1	LC-8658	106.85**	146.49**	-24.63*	-23.61*
2	LC-8659	34.36	145.43**	-50.43**	-20.47
3	LC-8660	129.09**	81.16**	-17.51	-37.84**
4	LC-8610	173.78**	170.04**	-13.83	-24.55*
5	LC-8611	124.01**	110.24**	-28.48*	-38.29**
6	LC-8612	142.51**	150.83**	-24.72*	-21.59*
7	LC-8619	166.63**	198.56**	0.91	-6.73
8	LC-8620	32.86	56.15	-49.12**	-49.01**
9	LC-8621	128.12**	138.05**	-14.65	-17.73
10	LC-8634	250.31**	175.30**	13.83	-27.47*
11	LC-8635	170.89**	192.97**	-10.75	-18.67
12	LC-8636	222.07**	177.16**	3.27	-17.77
13	LC-8418	135.36**	311.56**	-9.75	19.88
14	LC-8419	23.44	128.07**	-52.11**	-30.34**
15	LC-8420	88.28**	67.63*	-28.62*	-45.60**
16	LC-8394	129.14**	207.11**	-13.7	-7.85
17	LC-8395	90.72**	162.14**	-27.30*	-17.64
18	LC-8396	12.3	109.97**	-58.19**	-30.03**
19	LC-8667	-3.29	57.22*	-60.68**	-46.23**
20	LC-8668	11.75	101.51**	-54.06**	-28.23*
21	LC-8669	73.28**	129.43**	-30.29*	-13.91
22	LC-8640	36.27	57.35*	-42.40**	-48.34**
23	LC-8641	90.66**	183.75**	-18.55	-2.83
24	LC-8642	53.50*	117.13**	-35.78**	-21.50*
25	LC-8439	63.90*	178.32**	-40.50**	-21.05
26	LC-8440	95.93**	68.95*	-27.98*	-49.69**
27	LC-8441	181.92**	99.72**	1.13	-36.71**
28	LC-8622	22.62	77.23**	-56.24**	-33.26**
29	LC-8623	95.98**	100.34**	-29.16*	-21.72*
30	LC-8624	165.98**	139.87**	-6.21	-1.71
31	LC-8409	134.39**	119.23**	-23.59*	-31.07**
32	LC-8410	174.11**	118.55**	-5.9	-18.14
33	LC-8411	197.97**	68.69*	-15.18	-13.65
34	LC-8517	142.72**	92.47**	-19.39	-14.2
35	LC-8518	135.47**	95.48**	-0.13	-15.69
36	LC-8519	100.13**	49.13*	-20.95	-30.11*
37	LC-8625	73.96**	30.87	-38.33**	-36.37**
38	LC-8626	56.28*	79.66**	-34.88**	-42.13**
39	LC-8627	102.76**	75.65**	-20.95	-26.71*
40	LC-8484	-3.98	66.47*	-59.66**	-62.77**
41	LC-8485	82.20**	51.52*	-9.66	-28.53*
42	LC-8486	116.09**	62.83**	-17.75	-17.14
43	LC-8628	4.45	15.53	-37.39**	-57.41**
44	LC-8629	69.64**	54.72*	-29.61**	-30.07*
45	LC-8630	120.69**	-7.39	0.25	-10.98
46	LC-8637	83.65**	138.81**	-5.9	-38.37**
47	LC-8638	51.47	95.69**	-45.61**	-48.48**
48	LC-8639	65.50*	74.15**	-41.03**	-45.17**
49	LC-8376	163.07**	34.68	-4.64	-10.52
50	LC-8377	89.08**	28.03	-25.97*	-34.83**
51	LC-8378	20.59	5.28	-58.09**	-59.50**
52	LC-8661	68.49*	57.97*	-36.51**	-41.32**
53	LC-8662	135.48**	85.20**	0.82	-16.92
54	LC-8663	173.30**	102.41**	-6.4	-5.99
55	LC-8616	196.68**	126.48**	-10.23	-10.79
56	LC-8617	188.56**	84.34**	-13.86	-11.93
57	LC-8618	103.06**	27.92	-34.76**	-39.82**
58	LC-8643	112.91**	67.74*	-23.09*	-30.43*
59	LC-8644	61.81*	61.04*	-45.29**	-46.39**
60	LC-8645	52.74	71.79**	-44.67**	-50.75**

*, ** - Significant at 5% and 1% level of probability

The top ten hybrids based on grain yield per se their heterosis over mid parent and commercial check and combining ability status were presented in Table 5 and Table 6 during kharif and rabi, respectively. The mid parental heterosis revealed that the hybrids had high heterotic effect for all the characters studied. Table 5 and Table 6 provide a overview of the heterosis and combining ability status of the top ten crosses selected based on grain yield per se during the kharif-2017 and rabi-2017 seasons, respectively. In both seasons, several crosses exhibited significant mid-parent heterosis, standard heterosis, and specific combining ability effects. Notably, the crosses LC-8622, LC-8630, LC-8624, LC-8611, LC-8659, LC-8518, LC-8519, LC-8418, LC-8612, and LC-8396 during kharif, and LC-8519, LC-8485, LC-8518, LC-8642, LC-8619, LC-8611, LC-8394, LC-8395, LC-8628, and LC-8396 during rabi, demonstrated significant improvements in grain yield over their parents. It is evident that certain crosses consistently outperformed others, suggesting the stable and superior performance of these hybrids across different seasons. The varying GCA statuses of parents (L × H, or H × L and H x H) underscore the importance of selecting parents with complementary genetic backgrounds and high GCA background for successful hybridization. This indicate that specific cross combinations contribute significantly to the improvement of per se values. The consistent presence of significant mid-parent across different crosses further supports the notion that these hybrids possess desirable traits for grain yield improvement.

Table 5: Heterosis and combining ability status of top ten crosses selected based on grain yield per se during kharif-2017

Sl. No.	Parentage	Hybrids	*Per se* (t ha^{-1})	Mid parent heterosis	Standard heterosis	sca effects	gca status of parents
1	DIM-311 × DC-13	LC-8622	12.55	22.62	-56.24 **	-2.82**	L × H
2	DIM-342 × DC-17	LC-8630	11.39	120.69 **	0.25	2.04*	L × H
3	DIM-311 × DC-17	LC-8624	11.15	165.98 **	-6.21	2.32*	L × H
4	DIM-330 × DC-14	LC-8611	11.12	124.01 **	-28.48 *	-0.33	H × L
5	DIM-320 × DC-14	LC-8659	10.37	34.36	-50.43 **	-1.81*	L × L
6	PDM-4281 × DC-14	LC-8518	10.34	135.47 **	-0.13	0.83	H × L
7	PDM-4281 × DC-17	LC-8519	9.95	100.13 **	-20.95	-1.48	H × H
8	PDM-79-1 × DC-13	LC-8418	9.87	135.36 **	-9.75	2.27*	L × H
9	DIM-330 × DC-17	LC-8612	9.84	142.51 **	-24.72 *	-0.63	H × H
10	PDM-71-2 × DC-17	LC-8396	9.84	12.3	-58.19 **	-3.14**	L × H

*, ** - Significant at 5% and 1% level of probability

Table 6: Heterosis and combining ability status of top ten crosses selected based on grain yield per se during rabi-2017

Sl. No.	Parentage	Hybrids	*Per se* (t ha^{-1})	Mid parent heterosis	Standard heterosis	sca effects	gca status of parents
1	PDM-4281 × DC-17	LC-8519	13.35	49.13*	-30.11*	1.15	H × L
2	PDM-198 × DC-14	LC-8485	11.64	51.52*	-28.53*	0.78	H x H
3	PDM-4281 × DC-14	LC-8518	10.95	95.48*	-15.69	-0.42	H × H
4	DIM-348 × DC-17	LC-8642	10.82	117.13**	-21.50*	0.71	H × L
5	DIM-327 × DC-13	LC-8619	10.81	198.56**	-6.73	1.76*	H × H
6	DIM-330 × DC-14	LC-8611	10.39	110.24**	-38.29**	-1.31	L × H
7	PDM-71-2 × DC-13	LC-8394	10.28	207.11**	-7.85	0.96	H × H
8	PDM-71-2 × DC-14	LC-8395	10.27	162.14**	-17.64	-0.09	H × H
9	DIM-342 × DC-13	LC-8628	10.2	15.53	-57.41**	1.49	L × H
10	PDM-71-2 × DC-17	LC-8396	10.05	109.97**	-30.03**	-0.88	H × L

*, ** - Significant at 5% and 1% level of probability

Conclusion

The study aimed to evaluate heterosis and combining ability in newly developed maize inbred lines to contribute insights to breeding programs. Using 47 inbred lines and three testers, the research followed a rigorous hybridization program, including the L × T mating design, resulting in 60 single cross experimental hybrids, evaluated across two seasons in a randomized block design. Conducted at the IARI Regional Research Centre in Dharwad, Karnataka. Statistical analyses revealed significant genetic variability in grain yield among genotypes. The contributions of females, males, and their interaction emphasized the importance of specific cross combinations. Non-additive gene action played a predominant role, guiding the need for strategic parent selection. Estimates of general combining ability (GCA) and specific combining ability (SCA) effects for grain yield during kharif and rabi seasons aided in identifying potential parents based on their combining abilities. Heterosis analysis demonstrated significant mid-parent heterosis in the majority of crosses during both seasons. Standard heterosis comparisons with commercial checks highlighted specific crosses, such as LC-8634, LC-8636, LC-8418, LC-8619, LC-8624, showing high heterosis and combining abilities. The findings underscore the importance of selecting parents with complementary genetic backgrounds and high combining abilities for successful hybridization. The research offers information about the genetic potential of new developed maize inbred lines, adding to the continuous endeavors in creating high-yielding hybrid varieties and facilitating progress in maize improvement programs.

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