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Heterosis and combining ability for yield and its contributing traits in yellow maize

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Abstract

Eight parents (5 lines and 3 testers) and their fifteen F_1 hybrids were evaluated by analyzing their ability to genetic behavior (combining abilities and heterosis) for yield and its contributing traits of maize. The results of analysis of variance indicated considerable genetic variation among the parental lines and testers as well as their hybrids, highlighting the importance of both additive and non-additive gene effects in the inheritance of yield and its components traits under study. The ratio of σ2GCA/σ2SCA was less than unity for all traits, indicating the predominant role of non-additive gene effects (dominance and epistasis) in the inheritance of all studied traits. The results showed that the majority of parental lines and testers by general combining ability effects and most hybrids by specific combining ability and heterosis effects had favorable significance for all studied traits. Based on mean performance and GCA effects, the testers; T_1 and T_2 and lines; L_2 and L_3 were the best general combiners for grain yield/plant and most evaluated traits. Desirable and significant SCA effects and heterosis estimates were observed by most crosses for all studied traits. The crosses: $L_3 \times T_3$ for earliness and $L_2 \times T_1$, $L_3 \times T_2$, $L_4 \times T_2$ and $L_4 \times T_3$ for yield and most studied traits showed the best mean performance and desirable estimates of SCA effects and heterosis. In order to improve the earliness and grain yield traits, the crosses mentioned above can generally be used in maize hybrid breeding programs in Egypt.

Keywords: yellow maize, heterosis, general and specific combining ability.

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1. Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops in the world following wheat and rice. It is widely used for food, feed, fuel and fiber in many parts of the world (Erenstein *et al.*, 2022). Maize has broad morphological variability and geographical adaptability due to its cross-pollinated nature. According to USDA in February 2023, 201.12 and 0.93 million hectares of land were covered by maize and produced 1,151.36 and 7.44 million metric tons with yield of 5.72 and 8.00 metric tons per hectare of maize grain in the world and Egypt, respectively (USDA, 2023). There is a critical need to increase the production of maize to face the gap between production and consumption. To establish a sound basis for any breeding program, aimed at achieving high yield, breeders must have information about the nature of the combining ability of parents, their behavior and hybrid combination performance (Chawla and Gupta, 1984). Line × Tester analysis was suggested by Kempthorne (1957) to analyze polygenic system. Line × Tester analysis is useful technique for screening a large number of lines for identifying the best combiner. Similarly, knowledge about nature of gene action governing the expression of various traits could help in predicting the effectiveness of selection. A line × tester analysis has been a popular mating system to assess the combining ability of parents and crosses in maize (Elmyhun *et al.*, 2020). In Egypt, the policy of the government is to increase maize production through the development of new genotypes with high productivity. The genetic parameter general combining ability (GCA) and specific combining ability (SCA) were defined by Sprague and Tatum (1942). Both GCA and SCA effects should be taken into consideration when planning maize breeding programs to produce and release new inbred lines and crosses. Knowledge about general (GCA) and specific (SCA) combing ability effects of genetic materials is of practical value in breeding programs. Both components play an important role in selecting superior parents for hybrid combinations (Duvick, 1999) and represent a powerful method to measure the nature of gene action involved in quantitative traits (Baker, 1978). GCA effects represent the fixable component of genetic variance and are important to develop superior genotypes. SCA represents the non-fixable component of genetic variation, it is important to provide information on hybrid performance (Begna, 2021). The concept of heterosis occurs when a hybrid outperforms its two parents (Lippman and Zamir, 2007). Because single-cross varieties of corn have significantly improved maize productivity over the past few decades, maize is the most effective example of using heterosis in crops to increase agricultural production, according to Hochholdinger and Baldauf (2018). The present investigation was conducted to identify desirable parents and cross combinations as well as to gather information on the genetic behaviour combining ability and heterosis involved in the improvement of yield and its contributing traits in yellow maize crosses.

2. Materials and methods

In this investigation, two trials were conducted at the Experimental Farm of the Faculty of Agriculture, Al-Azhar University, Nassr city, Cairo, Egypt in the 2016 growing season and Fackous, Sharkia Governorate, Egypt in the 2017 growing season. The experimental material consisted of 8 parental inbred lines including five female lines (Inb-155, Inb-162, Inb-171, Inb-203 and Inb-176) and three testers (Inb-210, Inb-215 and Inb-234) parents representing a wide range of diversity for several agronomic traits. All these inbred lines were obtained from Maize Research Department, Field Crop Research Institute, Agricultural Research Center, Giza, Egypt. In the 2016 season, the female parental lines and male parental lines (testers) were planted and crossed according to line × tester mating design to produce 15 F_1 hybrids, according to Kempthorne (1957). As for the 2017 season, the genetic materials (five lines, three testers and their fifteen F_1 crosses) were evaluated in a randomized complete blocks design with four replications. Each plot area was 6.3 m^2, which consisted of 3 ridges, each of 3 m long and 70 cm apart, for each genotype under study. The distance between hills was 25 cm. The agricultural practices of irrigation, fertilization, weeds and pest control were used as normally recommended for maize production. Samples of ten guarded plants were taken at random from the middle ridge of each plot to determine the following traits i.e. days to 50% tasseling (days), days to 50% silking (days), plant height (cm), ear height (cm), ear length (cm), ear diameter in (cm), 100-kernel weight (g) and grain yield/plant (g), adjusted to 15.5% moisture content. The recorded data were subjected to the ordinary analysis of variance (Steel and Torrie 1980) to determine the significant differences among hybrids and parents. Differences between means were tested using the least significant difference (L.S.D.) test at the 5% and 1% levels of probability. Combining ability analysis was done using line x tester method (Kempthorne, 1957). The variances for general and specific combining abilities were tested against their respective error variance. Significance test for GCA and SCA effects were performed using t-test. Mid- and better parents heterosis estimates were determined as outlined by Falconar and Mackay (1996) and t-test was performed.

3. Results and Discussion

3.1 Analysis of variance

The results of ANOVA by line × tester mating design for all studied traits are illustrated in Table (1). The variances due to genotypes, parents (P), crosses (C), P vs. C, GCA (Lines; L), GCA (Testers; T) and SCA (L × T) showed highly significant differences ($p<0.01$) for all studied traits. These findings suggested that the analyzed genotypes were genetically varied and responded to the study conditions. These results show that there is sufficient genetic variation among lines, testers, and their hybrids and emphasize the importance of both additive and non-additive gene actions in regulating the traits under study. Therefore, the selection is possible to identify the most desirable maize hybrids in this study. According to ANOVA of the line × tester mating design, multiple researchers found the occurrence of significant differences among the maize genotypes for all traits under examination, which is consistent with this study (Belay, 2022; Habiba *et al*., 2022; Ramadan and Husain, 2022; Sedhom, 2022). The existence of genetic variations in earliness, grain yield and its components traits provide an additional pathway for maize breeders mainly those who are interested to heterosis breeding (Mideska *et al*., 2022). The mean squares of lines, testers, and their interactions made up the crosses variance. The highest mean squares of testers were observed for days to 50% tasseling and silking as well as ear diameter traits. While the mean squares of lines were the highest for grain yield/plant and other investigated traits. Belay (2022) reported that the variability among the set of lines suggests a great potential for identifying superior parental inbreds with high general combining abilities for hybrid variety development.

Table (1): Analysis of variance for the studied traits of 15 yellow maize hybrids and their parents.

S.O.V.	df	Days to 50% tasseling	Days to 50% silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	100- kernel weight (g)	Grain yield/plant (g)
Replications	3	7.23*	5.68	180.65*	87.03**	3.13**	0.32*	158.82**	80.62**
Genotypes	22	92.01**	87.45**	2823.02**	1180.98**	28.42**	1.28**	111.71**	5569.78**
Parents (P)	7	97.43**	87.00**	1841.50**	283.64**	24.87**	0.81**	140.68**	1157.00**
Crosses (C)	14	432.05**	446.01**	12603.77**	12612.32**	329.56**	10.81**	1071.14**	80487.36**
P *vs*. C	1	65.01**	62.07**	2615.15**	813.13**	8.69**	0.84**	28.69**	2424.91**
GCA (Female)	4	25.78**	43.94**	8338.48**	2423.71**	19.29**	0.36**	39.99**	4848.51**
GCA (Tester)	2	144.35**	89.62**	306.95**	70.42**	14.56**	1.85**	7.68**	1241.53**
SCA	8	64.79**	64.24**	330.53**	193.52**	1.92**	0.83**	28.29**	1508.96**
Error	66	1.93	2.50	48.00	15.91	0.55	0.09	1.07	15.91
σ^2GCA/ σ^2SCA		0.00038	0.00037	0.85761	0.36999	0.52339	0.00	0.0016	0.0650

* and ** denote significant at 0.05 and 0.01 levels of probability, respectively.

The ratio of σ^2 GCA / σ^2 SCA was lower than unity for all evaluated traits, which indicated the predominant effect of non-additive gene actions (dominance and epistasis) for the control of these traits under study. Similar results were reported by El-Badawy (2013), Attia *et al*. (2013) and Anees *et al*. (2019). On the other hand, Akbar *et al*. (2008) and Hefny (2010) reported that both additive and non-additive were important in the genetic expression of yield and its components in maize.

3.2 Mean performance of yellow maize genotypes

The mean values of lines, testers and their F_1 hybrids for all the studied traits are summarized in Table (2). The mean performance of lines, testers, and their hybrids differed significantly for all studied traits. Significantly, the parental line L_3 and tester T_1 recorded the lowest values (desirable) for days to 50% tasseling (54.25 and 63.00, respectively) and silking (57.00 and 65.25, respectively) traits. While the highest values of these traits were observed by line L_4 and tester T_3 (undesirable). The line L_4 and tester T_3 were significantly higher than other parental genotypes in plant height (215.00 and 187.50 cm) and ear height (101.50 and 92.50 cm), respectively. While the shortest plant was noticed by the line L_5 and tester T_2 with values of 158.50 and 153.75cm, respectively. Also, the lowest ear height registered by line L_3 and tester T_2 with values of 79.25 and 75.25 cm, respectively. The highest values for ear length (21.67 cm), ear diameter (4.78 cm) and grain yield/plant (192.00 g) were detected by line L_2, and the highest 100- kernel weight (23.43 g) were obtained by line L_1 were noticed. While the lowest ear length (15.07 cm), ear diameter (3.45 cm), 100-kernel weight (15.90 g) and grain yield/plant (151.87 g) were observed by lines L_5, L_4, L_3 and L_1, respectively.

Table (2): Mean performance of parents and F_1's for all the studied traits in maize.

Genotype	Days to 50% tasseling	Days to 50% silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	100- kernel weight (g)	Grain yield/plant (g)
Inb-155 L1	64.75	67.50	194.25	90.50	17.47	4.10	23.43	151.87
Inb-162 L2	60.50	63.25	192.00	87.00	21.67	4.78	20.03	192.00
Inb-171 L3	54.25	57.00	166.25	79.25	17.23	4.08	15.90	153.75
Inb-176 L4	69.25	70.75	215.00	101.50	17.17	3.45	21.03	155.75
Inb-203 L5	68.00	69.75	158.50	82.00	15.07	4.55	23.00	162.80
Inb-210 T1	63.00	65.25	163.75	82.00	20.80	4.07	32.90	182.80
Inb-215 T2	64.00	66.75	153.75	75.25	16.71	4.18	29.67	192.87
Inb-234 T3	68.25	71.00	187.50	92.50	14.57	3.53	30.80	173.03
Inb-155 × Inb-210	56.75	60.00	236.75	122.00	22.27	4.90	35.10	203.57
Inb-155 × Inb-215	63.00	66.00	231.00	126.50	21.10	5.12	33.00	204.00
Inb-155 × Inb-234	63.25	68.00	240.75	131.25	20.27	4.51	28.83	192.90
Inb-162 × Inb-210	60.25	62.50	228.00	133.00	24.47	5.34	35.87	263.25
Inb-162 × Inb-215	57.75	60.00	226.50	114.00	23.10	4.93	29.10	222.90
Inb-162 × Inb-234	56.25	58.00	221.25	119.00	23.77	3.58	32.93	212.80
Inb-171 × Inb-210	64.25	66.75	198.00	108.25	22.57	5.25	32.07	253.50
Inb-171 × Inb-215	63.25	65.25	186.75	115.25	21.27	4.39	34.83	261.90
Inb-171 × Inb-234	51.25	53.75	173.75	99.50	19.84	4.95	35.00	249.25
Inb-176 × Inb-210	62.50	63.25	180.75	95.75	21.13	5.19	31.20	203.60
Inb-176 × Inb-215	58.75	59.75	162.50	87.75	22.03	4.87	32.03	258.93
Inb-176 × Inb-234	52.25	56.75	178.25	88.00	19.83	5.10	28.50	242.97
Inb-203 × Inb-210	60.75	63.50	190.00	106.00	21.73	4.75	28.03	244.10
Inb-203 × Inb-215	62.75	63.00	188.75	105.25	20.07	4.99	28.87	252.80
Inb-203 × Inb-234	58.75	60.25	208.75	111.00	19.93	4.29	31.03	224.20
LSD 0.05	1.96	2.23	9.78	5.63	1.05	0.42	1.45	5.63
LSD 0.01	2.60	2.96	12.99	7.48	1.39	0.56	1.93	7.48

The parental tester T_1 for Ear length (20.80 cm) and 100- kernel weight (32.90 g) as well as the parental tester T_2 for ear diameter (4.18 cm) and grain yield/plant (192.87 g) displayed the highest performance than other parental testers under study. The tester T_2 gave highest values for ear length, ear diameter and grain yield/plant, while the tester T_3 exhibited the lowest performance for grain yield/plant (16.71 cm, 4.18 cm, 192.87 g and 173.03 g, respectively). Based on mean performances, line L_2 and tester T_2 are often the best parental genotypes for grain yield and most studied traits, making them potentially useful in a maize breeding program for enhancing and improving grain productivity. The means of crosses were higher than those of parents, suggesting the presence heterotic effects in the F_1 generation for all evaluated traits, as shown in Table (2). Out of 15 F_1 hybrids studied, the three crosses; $L_3 \times T_3$, $L_4 \times T_3$ and $L_2 \times T_3$ were the earliest for days to 50% tasseling (51.25, 52.25, 56.25 days, respectively) and silking (53.75, 56.75 and 58.00 days, respectively), where their parents Inb-162, Inb-176 and Inb-234 showed good performance for days to 50% tasseling and silking traits. The three crosses $L_4 \times T_2$, $L_3 \times T_3$, and $L_4 \times T_3$ showed the lowest mean values for plant height with values of 162.50, 173.75, and 178.25 cm, respectively. As for the ear height, the highest values were recorded by the cross combination L_2 x T_1 with the value of 133.00 cm, followed by L_1 x T_3 (131.25 cm) and L_1 x T_2 (126.50 cm). The highest values of ear length were observed in the crosses; $L_2 \times T_1$, $L_2 \times T_3$ and $L_2 \times T_2$ with the values of 24.47, 23.77 and 23.10 cm, respectively. The maximum values of ear diameter were observed by the crosses; $L_2 \times T_1$ (5.34 cm), $L_3 \times T_1$ (5.25 cm) and $L_4 \times T_1$ (5.19 cm), while the crosses; $L_2 \times T_1$, $L_1 \times T_1$ and $L_3 \times T_3$ gave the highest values for 100- kernel weight (35.87, 35.10 and 35.00 g, respectively). Regarding grain yield/plant, the three crosses; $L_2 \times T_1$ (263.25 g), $L_3 \times T_2$ (261.90 g), and $L_4 \times T_2$ (258.93 g) gave the highest mean performances, which included intermediate yielding parental genotypes with grain yield/plant. The higher-yielding capability of these crosses obtained may be primarily due to their higher yield potential and maximized production of their main yield components. Compared with other crosses, the cross $L_2 \times T_3$ was an earliness genotype, while the cross $L_2 \times T_1$ showed significantly higher values for grain yield and most yield components under study.

3.3 Combining ability effects

Estimates of GCA effects of the individual parental lines and testers for all studied traits are given in Table (3). The results revealed that the parental lines and testers exhibited highly significant positive or negative GCA values for most studied traits. These findings suggest that the measured traits varied widely across all parental lines and testers under study. With comparing parental lines, L_2 showed negative and significant GCA effects (desirable) for days to 50% tasseling (p<0.05) and silking (p<0.01), while it had positive and significant GCA effects (desirable) for ear length and 100- kernel weight (p < 0.01). Line L_4 had negatively significant GCA effects (desirable) for days to 50% tasseling, days to 50% silking, plant height and ear height (p<0.01), and it had positively significant GCA effects (desirable) for ear diameter (p<0.01) and grain yield/plant (p<0.05). Highly significant and desirable GCA effects were observed for grain yield/plant, plant height and ear height by two lines L_3 and L_5, and for 100- kernel weight by line L_3. With respect to the parental testers, tester T_3 gave highly significant and negative GCA effects for number of days to 50% tasseling and silking traits (desirable). While the tester T_2 displayed highly significant GCA effects in the desirable direction for plant height and grain yield/plant. Also, ear length, ear diameter and 100- kernel weight (p<0.01) showed positively significant GCA effects by the tester T_1. Desirable GCA effects were observed for grain yield and other traits in parental lines (Habiba *et al*., 2022; Keno *et al*., 2017), indicating that they are desirable parents for maize hybrids development and involvement in maize program (Hussain *et al*., 2021; Ramadan and Husain, 2022). In this study, the lines L_3 and L_4 and the testers T_3 and T_2 were generally effective general combiners for earliness and grain yield. Therefore, they may be useful in the development of early and dwarf genotypes with their capacity to raise maize grain yield in the hybrids under study.

Table (3): Estimates of general combining ability (GCA) effects of the 8 Maize parents (5 lines and 3 testers) evaluated for the studied traits.

Parents	Days to 50% tasseling	Days to 50% silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	100- kernel weight (g)	Grain yield/plant (g)
Lines								
Inb-155 L1	1.550*	2.88**	32.72**	15.75**	-0.35*	0.03	0.55	-32.56**
Inb-162 L2	-1.367*	-1.62**	21.80**	11.17**	2.22**	-0.20*	0.87**	0.27
Inb-171 L3	0.133	0.13	-17.28**	-3.17**	-0.33	0.05	2.21**	22.17**
Inb-176 L4	-1.617**	-1.87**	-29.62**	-20.33**	-0.56**	0.24**	-1.18**	2.45*
Inb-203 L5	1.300*	0.47	-7.62**	-3.42**	-0.98**	-0.13	-2.45**	7.66**
SE (gi)	0.40	0.46	2.00	1.15	0.21	0.09	0.30	1.15
Tesers								
Inb-210 T1	1.450**	1.42**	3.25*	2.17*	0.87**	0.28**	0.69**	0.89
Inb-215 T2	1.650**	1.02**	-4.35**	-1.08	-0.05	0.05	-0.19	7.39**
Inb-234 T3	-3.100**	-2.43**	1.10	-1.08	-0.83**	-0.33**	-0.50*	-8.29**
SE(gi)	0.31	0.35	1.54	0.89	0.17	0.07	0.23	0.89

* and ** denote significant at 0.05 and 0.01 levels of probability, respectively.

Promising lines with good line performance and the best GCA effects on targeted traits are preferred (Wasuwatthanakool *et al*., 2022). The inbred lines with high GCA effects for maize traits displayed the same effects for one or more of the traits influencing grain yield, indicating that these lines could be regarded as effective combiners for enhancing grain yield and may contribute favorable alleles in the creation of new crosses (Habiba *et al*., 2022). According to GCA, the inbred lines with advantageous allele sources for the establishment of heterotic populations as well as high-yielding synthetic varieties and hybrids as well as other agronomic qualities could result in superior segregants in the F_2 and subsequent generations. Completely agreed with the points of view which were reported by Anees *et al*. (2019) and Saeid *et al*. (2019). According to statistics, the SCA effects for F_1 hybrids were positively and negatively significant for all investigated traits, as shown in Table (4). Two crosses for days to 50% silking and ear length traits, three crosses for plant height, ear height and ear diameter traits, four crosses for days to 50% tasseling, five crosses for grain yield/plant and six crosses for 100-kernel weight were showed significant and desirable SCA effects ($p<0.05$ or 0.01). In this study, none of the combinations consistently outperformed the others for all traits taken into consideration, according to estimate of SCA effects. According to Griffing (1956), highly significant SCA effects of the crosses indicate that significant deviation from what would have been predicted based on the GCA effects of the respective parents. Significant and desirable SCA effects for grain yield and other traits using line x tester analysis were found, indicating the tendency of the hybrids to improve grain yield and early maturity (Habiba *et al*. 2022; Mogesse and Zeleke, 2022; Mousa *et al*. 2021).

Table (4): Estimates of specific combining ability (SCA) effects of 15 crosses of maize evaluated for the studied traits.

Crosses	Days to 50% tasseling	Days to 50% silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear diameter (cm)	100- kernel weight (g)	Grain yield/plant (g)
Inb-155 × Inb-210	-5.70**	-6.083**	-2.67	-6.75**	0.18	-0.22	2.10**	2.52
Inb-155 × Inb-215	0.35	0.317	-0.82	1.00	-0.07	0.22	0.88	-3.55
Inb-155 × Inb-234	5.35**	5.767**	3.48	5.75**	-0.11	0.00	-2.98**	1.03
Inb-162 × Inb-210	0.72	0.917	-0.50	8.83**	-0.19	0.45**	2.54**	29.37**
Inb-162 × Inb-215	-1.98**	-1.183	5.60	-6.92**	-0.63	0.26	-3.34**	-17.48**
Inb-162 × Inb-234	1.27	0.267	-5.10	-1.92	0.82*	-0.71**	0.80	-11.90**
Inb-171 × Inb-210	3.22**	3.417**	8.58*	-1.58	0.47	0.11	-2.59**	-2.28
Inb-171 × Inb-215	2.02**	2.317**	4.93	8.67**	0.09	-0.52**	1.06*	-0.38
Inb-171 × Inb-234	-5.23**	-5.733**	-13.52**	-7.08**	-0.55	0.41**	1.53**	4.65*
Inb-176 × Inb-210	3.22**	1.917*	3.67	3.08	-0.74	-0.14	-0.07	-32.46**
Inb-176 × Inb-215	-0.73	-1.183	-6.98*	-1.67	1.08**	-0.23	1.65**	16.37**
Inb-176 × Inb-234	-2.48**	-0.733	3.32	-1.42	-0.34	0.37*	-1.58**	16.09**
Inb-203 × Inb-210	-1.45*	-0.167	-9.08*	-3.58	0.28	-0.20	-1.97**	2.84
Inb-203 × Inb-215	0.35	-0.267	-2.73	-1.08	-0.47	0.27	-0.25	5.04*
Inb-203 × Inb-234	1.10	0.433	11.82**	4.67*	0.19	-0.06	2.22**	-7.88**
SE(sij)	0.69	0.79	3.46	1.99	0.37	0.15	0.52	1.99

* and ** denote significant at 0.05 and 0.01 levels of probability, respectively.

The highest significant and negative SCA effects ($p<0.01$) were observed by the cross combination $L_1 \times T_1$ for days to 50% tasseling (-5.70) and silking (-6.08), with significant and positive SCA effects ($p<0.01$) for 100- kernel weight (2.10). Therefore, this cross is the best combination for improving the early maturity of maize. The cross $L_3 \times T_3$ recorded negative and highly significant desirable SCA effects for plant height (-13.52) and ear height (-7.08), indicating that this cross is the best combination for improving the shortness of stature trait in maize. Highly Significant and positive SCA effects ($p<0.01$) were observed by the cross combination $L_2 \times T_1$ for ear diameter, 100- kernel weight and grain yield/plant, with values of 0.45, 2.54 and 29.37, respectively. As for ear length, highly significant and positive SCA effect ($p<0.01$) was noticed by the cross combination $L_4 \times T_2$ (1.08), with significant and desirable SCA effects for plant height (-6.98), 100- kernel weight (1.65), and grain yield/plant (16.37). Generally, the cross combinations $L_2 \times T_1$, $L_3 \times T_3$, $L_4 \times T_2$ and $L_4 \times T_3$ had the most favorable SCA effects for earliness and grain productivity of maize. These results are in confidence with those of Wani *et al*. (2017), Hassan *et al.* (2019) and Raihan *et al*. (2019).

3.4 Heterosis estimates

Crop seed breeding has made extensive use of heterosis (or hybrid vigor) to enhance a number of crucial economic traits (Liu *et al*., 2022), especially the earliness and grain yield of maize. The amount of heterosis over the mid-parents (MP) and better parent (BP) for evaluated traits are presented in Table (5). The results showed that most F_1 hybrids under study were significant and negative/ positive MP and BP for all studied traits. One cross for ear height, ten crosses for days to 50% silking, eleven crosses for days to 50% tasseling, thirteen crosses for ear diameter, fourteen crosses for 100- kernel weight and all crosses for ear length and grain yield/plant were showed significant MP in desirable direction ($p<0.05$ or 0.01). While significant BP in a desirable direction ($p<0.05$ or 0.01) was observed by seven crosses for 100- kernel weight, eight crosses for days to 50% tasseling and silking, thirteen crosses for ear length and diameter and all crosses for grain yield/plant. These results underline the dominance effect's crucial role in the inheritance of earliness and grain yield traits under study. Our findings are generally comparable to the results of Mogesse *et al*. (2020), Mogesse and Zeleke (2022), Sang *et al*. (2022) and Mideksa *et al*. (2022), who reported the presence of significant and desirable heterosis for early maturity and high yield of maize. The lowest heterosis compared with MP and BP (desirable) were obtained by the cross combination $L_4 \times T_3$ for days to 50% tasseling (-24.00 and -23.44) and silking (-19.93 and -19.79), plant height (-11.43 and -4.93) and ear height (-9.28 and -4.86), respectively. This finding implies that the development of the early and dwarf genotype of maize may benefit from this cross. While the cross $L_5 \times T_3$ for ear length (34.53 and 32.30, respectively), the cross $L_4 \times T_3$ for ear diameter (46.24 and 47.83, respectively), the cross $L_3 \times T_2$ for 100- kernel weight (52.89 and 17.42, respectively) and the cross $L_3 \times T_3$ for grain yield/plant (52.55 and 44.05) showed highly significant heterosis of MP and BP heterotic effects, respectively. According to MP and BP heterosis estimates, certain cross combinations, such as $L_2×T_1$, $L_2×T_3$, $L_3×T_2$, $L_3×T_3$, $L_4×T_2$ and $L_5×T_3$, were preferred for one or more earliness and yield traits as well as positive estimations for grain yield/plant in this study. These results suggest that there is a significant level of heterosis for enhancing earliness, grain yield, and characteristics associated to yield. Positive and significant heterosis is desirable for the grain yield as it suggests more grain yield potential than the current parental genotypes, therefore we can improvement of maize grain yield by exploiting maximum heterosis (Mogesse and Zeleke, 2022). Similar results were reported by Sedhom *et al*. (2016) and Turkey *et al*. (2018).

Table (5): Heterosis as percentage of mid-parent (M.P) and better parent (B.P) for the studied traits.

Crosses	Days to 50% tasseling		Days to 50% silking		Plant height (cm)		Ear height (cm)	
	MP	BP	MP	BP	MP	BP	MP	BP
Inb-155 × Inb-210	-11.15**	-9.92**	-9.60**	-8.05**	32.26**	44.58**	41.45**	48.78**
Inb-155 × Inb-215	-2.14	-1.56	-1.68	-1.12	32.76**	50.24**	52.64**	68.11**
Inb-155 × Inb-234	-4.89**	-2.32	-1.81	0.74	26.13**	28.40**	43.44**	45.03**
Inb-162 × Inb-210	-2.43	-0.41	-2.72	-1.19	28.18**	39.24**	57.40**	62.20**
Inb-162 × Inb-215	-7.23**	-4.55**	-7.69**	-5.14**	31.02**	47.32**	40.52**	51.50**
Inb-162 × Inb-234	-12.62**	-7.02**	-13.59**	-8.30**	16.60**	18.00**	32.59**	36.78**
Inb-171 × Inb-210	9.59**	18.43**	9.20**	17.11**	20.00**	20.92**	34.26**	36.59**
Inb-171 × Inb-215	6.98**	16.59**	5.45**	14.47**	16.72**	21.46**	49.19**	53.16**
Inb-171 × Inb-234	-16.33**	-5.53**	-16.02**	-5.70**	-1.77	4.51	15.87**	25.55**
Inb-176 × Inb-210	-5.48**	-0.79	-6.99**	-3.07	-4.55	10.38**	4.36	16.77**
Inb-176 × Inb-215	-11.82**	-8.20**	-13.09**	-10.49**	-11.86	5.69	-0.71	16.61**
Inb-176 × Inb-234	-24.00**	-23.44**	-19.93**	-19.79**	-11.43	-4.93	-9.28**	-4.86
Inb-203 × Inb-210	-7.25**	-3.57*	-5.93**	-2.68	17.92**	19.87**	29.27**	29.27**
Inb-203 × Inb-215	-4.92**	-1.95	-7.69**	-5.62**	20.90**	22.76**	33.86**	39.87**
Inb-203 × Inb-234	-13.76**	-13.60**	-14.39**	-13.62**	20.66**	31.70**	27.22**	35.37**
Crosses	Ear length (cm)		Ear diameter (cm)		100- kernel weight (g)		Grain yield/plant (g)	
	MP	BP	MP	BP	MP	BP	MP	BP
Inb-155 × Inb-210	16.38**	7.05**	19.99**	20.47**	24.62**	6.69**	21.65**	11.36**
Inb-155 × Inb-215	23.48**	20.80**	23.63**	24.76**	24.29**	11.24**	18.35**	5.77**
Inb-155 × Inb-234	26.53**	16.03**	18.36**	28.01**	6.33**	6.39	18.74**	11.48**
Inb-162 × Inb-210	15.23**	12.92**	20.78**	31.28**	35.52**	9.02**	40.47**	37.11**
Inb-162 × Inb-215	20.39**	6.62**	10.06*	17.96**	17.10**	1.91	15.83**	15.57**
Inb-162 × Inb-234	31.19**	9.69**	13.86**	1.42	29.57**	6.93**	16.59**	10.83**
Inb-171 × Inb-210	18.67**	8.49**	28.95**	29.07**	31.42**	2.53	50.65**	38.68**
Inb-171 × Inb-215	25.31**	23.40**	6.48	7.79	52.89**	17.42**	51.12**	35.79**
Inb-171 × Inb-234	24.80**	15.15**	30.13**	40.28**	49.89**	13.64**	52.55**	44.05**
Inb-176 × Inb-210	11.33*	1.60	38.01**	50.36**	15.70**	5.17	20.28**	11.38**
Inb-176 × Inb-215	30.08**	28.35**	27.80**	41.23**	26.36**	7.98**	48.54**	34.25**
Inb-176 × Inb-234	25.00**	15.53**	46.24**	47.83**	9.97**	7.47	47.80**	40.42**
Inb-203 × Inb-210	21.19**	4.49	10.24*	16.78**	0.30	14.79	41.26**	33.53**
Inb-203 × Inb-215	26.30**	20.09**	14.38**	19.52**	9.62**	2.70	42.16**	31.08**
Inb-203 × Inb-234	34.53**	32.30**	6.13	21.56**	15.37**	0.76	33.52**	29.57**

* and ** denote significant at 0.05 and 0.01 levels of probability, respectively.

A high level of heterosis in maize is a prerequisite for the development of commercial hybrids maize. It is worthy to note that the most of crosses exhibited the highest useful heterosis for grain yield and most yield components under study. Therefore, these crosses offer good possibility for improving yield and its contributing traits. The level of heterosis expressed in this study reflects a high degree of genetic diversity among parents. Raut (2010) reported that genetic diversity is important for heterotic expression. $L_2 \times T_1$, $L_3 \times T_3$, $L_4 \times T_2$ and $L_4 \times T_3$ are promising hybrids for varietal improvement purpose, as they showed high useful heterosis, high specific combining ability effects and involved at least one parent as good general combiner. In such crosses, desirable transgressive segregates would be expected in the subsequent segregating generations, if the additive genetic system present in the good combiner and the complementary epistatic effects in the F_1 acted in the same direction to maximize the yielding ability. Thus, the interaction of crosses should be evaluated with locations to identify the most single cross hybrids for increasing productivity in yellow maize. Grain yield suggests that the parents' genes interacted positively in a major way; as a result, such gene interactions result in the manifestation of heterosis, which can be used to generate hybrid varieties (Belay, 2022). In hybrid breeding, the value of any inbred line ultimately hinges on its capacity to successfully unite with another line to yield superior hybrids (Bayoumi *et al*., 2018; Ramadan and Husain, 2022).

4. Conclusion

Statistically, ANOVA of line × tester indicates the existence of a clear variability between the evaluated genotypes for all traits under study. The line L_4 and the tester T_3 were discovered to be the best general combiners for earliness and grain yield of maize, according to GCA impacts. Based on heterosis compared with MP, BP, and SCA effects, the cross combinations; $L_2 \times T_1$, $L_3 \times T_3$, $L_4 \times T_2$ and $L_4 \times T_3$ were preferred for one or more earliness and yield traits as well as positive estimations for grain yield/plant. Finally, this result is confirmed by favorable highly significant SCA effects of these hybrids. These crosses could be considered the best hybrids, and they can be used in breeding program for improving these traits using hybrid $L_2 \times T_1$, $L_3 \times T_3$, $L_4 \times T_2$ and $L_4 \times T_3$ of maize to produce more early maturity and high-yielding varieties of maize.

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