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Study of Gene Action and Heterosis Effects of Different Genotypes for Yield and Yield Attributing Traits in Maize (*Zea mays* L.)

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Authors' contributions

This work was carried out in collaboration between all authors. Authors RAG and PCP designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MPP and SMC managed the analyses of the study. Author NVS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

A study of Line × Tester analysis involving 8 lines and 5 tester of yellow maize was carried out to identify high heterotic crosses and their relationship in terms of general and specific combining ability effects (*gca* and *sca*) for yield and its component traits. Analysis of variance exhibited highly significant difference among all the parents for different traits under study. The ratio of $\sigma^2_{gca}/\sigma^2_{sca}$ was less than unity there by indicating the preponderance of non-additive gene action in the expression of majority of the characters studied. The line Z 488-4 and tester BLD 47 were identified as most promising parents due to having good general combining ability for grain yield and several other yields contributing traits. Among the crosses, HYN-10-RN 235-270 × IC 328963 and BLD 254 × BLD 47 proved as good specific combiner for kernel yield per plant and its component traits while

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for earliness cross BLD 254 × IMR 53 were found good specific combiner. On the basis of heterosis cross Z 488-4 × IMR 53 and BLD 266 × BLD 47 was found superior for kernel yield per plant, ear yield per plant, days to tasselling, days to silking, days to dry husk, ear girth and 100 kernel weights. Therefore, these crosses need to be further evaluation for genotype x environment interaction over different seasons and or locations.

Keywords: Line × Tester analysis; grain yield; gene action and heterosis.

1. INTRODUCTION

Maize (*Zea mays* L.; 2n=20) is one of the most important cereal crops as a food for human being and a feed for animals. It supplies raw materials for various industries for manufacturing starch, ethanol, acetic acid, glucose, synthetic rubber, dyes, resin etc. Due to diversified use of the maize it occupies the unique place as “Queen of Cereals” although maize ranked third amongst the food crops, next to rice and wheat in the world. It accounts 15 to 56 per cent of the total daily calories of the people in many developing countries. Being a C_4 plant, it is physiologically more efficient and resilient to climate change. It has wider genetic variability and able to grow successfully throughout the world over a wide range of environmental conditions covering tropical, subtropical and temperate agro-climatic regions. Maize belongs to the tribe Maydeae of the family *Poaceae*. Mexico is accepted as the centre of origin of this crop and evolved from teosinte (*Zea mexicana* L).

For effective selection of grain yield and other desirable traits, information on the magnitude of useful genetic variances in the population, in terms of combining ability and heterosis is essential. Heterosis and combining ability are prerequisites for developing good economically viable hybrid maize. Information on the heterotic patterns and combining ability among maize germplasm is essential in maximizing the effectiveness of hybrid development. In maize, appreciable percentage of heterosis for yield and combining ability were studied by several workers. Combining ability analysis is one of the powerful tools in identifying the best combiners that may be used in crosses either to exploit heterosis or to accumulate desirable genes. In maize, appreciable percentage of heterosis for grain yield have been reported [1]. The concept of combining ability has been widely adopted in maize improvement was suggested [2]. The success in commercial production of hybrid maize depends on extensive assessment of inbred lines. Therefore, the present investigation was undertaken to study the combining ability for grain yield and its component traits in single cross hybrids of yellow maize and their parents using the Line × Tester model.

2. MATERIALS AND METHODS

The present investigation was carried out at Maize Research Station, Sardarkrushinagar Dantiwada Agricultural University, Bhiloda (Gujarat). A line x tester experiment consisting of 8 lines *viz.*, Z 488-4, BLD-266, BLD-254, BLD-206, WNC-32067, IMR-156, WNC-40066 and HYN-10RN-235-270; 5 testers *viz.*, IMR-53, IC-328963, BLD-309, BLD-328 and BLD-47 and their 40 F_1 hybrids, were evaluated along with the standard check GAYMH-1 during *kharif* 2017. The five representative plants were taken from each plot and data were recorded for kernel yield and its component traits *viz.* plant height (cm), ear height (cm), ear length (cm), ear girth (cm), number of kernel rows per ear, number of kernels per row, 100 kernels weight (gm) and shelling (%). Whereas days to tasseling, days to silking, Anthesis Silking Interval (ASI) and days to dry husk were recorded on plot basis. The kernel yield for each genotype was estimated by using the method of Bhupender et al. [3], with a modification concerning reducing grain moisture content to 15 percent with stepwise formula. (a) grain yield at observed grain moisture content = [Ear yield gm/plant at harvest × shelling proportion (%)], (b) grain dry matter content = 1-moisture per cent at harvest, (c) grain yield at 15% grain moisture content = [(grain yield at observed grain moisture content x grain dry matter content)/0.85], (d) grain yield at 15% grain moisture content = [(grain yield at 15% grain moisture content)/100]. The mean data were subjected to statistical analysis. The analysis of variance was carried out as per the procedure suggested by Sukhatme [4], combining ability variance analysis was based on the method developed by Kempthorne [5] as well as estimation of heterobeltiosis and economic heterosis as per the method given by Fonseca and Peterson [6] and Meredith and Bridge [7], respectively.

3. RESULTS AND DISCUSSION

In the present investigation, analysis of variance revealed highly significant differences for all the characters studied (Table 1). The mean square due to line and tester were indicating presence of variability in genotypes for different characters under study. The variance due to line *vs* tester found significant for all the traits except for anthesis silking interval, day to dry husk, number of kernels per row and 100 kernel weight which indicating the presence of high heterosis response in the material studied. The variance due to general and specific combining ability was revealed that influence of both additive and non-additive effects in the expression of these characters. However the ratio of GCA and SCA variances ($\sigma^2_{gca}/\sigma^2_{sca}$) was found less than unity for days to tasseling, days to silking, anthesis silking interval (ASI), plant height, ear height, ear length, ear girth, number of kernel rows per ear, number of kernels per row, 100 kernel weight, ear yield per plant, kernel yield per plant and shelling per cent indicating the predominance of non additive gene action, where as for days to dry husk found influence of additive gene action. Therefore, predominance of *sca* effects over *gca* effects in the present study indicated the importance of non-aditive gene action for all the traits except days to dry husk. The influence of both types of gene effect in maize was also observed by [8,9] and [10].

The estimates of GCA effects (Table 2) revealed that, none of the parent was good general combiners for all the traits. Among the female parent, the parental line Z 488-4 was found good general combiner for days to tasseling, days to silking, days to dry husk, ear height, ear girth, number of kernel rows per ear, ear yield per plant and kernel yield per plant. Tester BLD 47 was reported good general combiner for kernel yield per plant, ear yield per plant and ear girth. The tester, IMR 53 for earliness while, IC 328963 and BLD 309 for plant height as well as ear height were proved to be a good general combiner. The present study revealed that line Z 488-4 and tester BLD 47 are the good general combiners for grain yield and several other yield components suggested that these parents might presume to have relatively greater number of favourable alleles for developing superior hybrid of maize and thus can be directly exploited in heterosis breeding.

Among the 40 crosses under study, cross HYN-10-RN 235-270 × IC 328963 was found good specific combiner for kernel yield per plant, plant height, ear height, ear length, ear girth, number of kernels per row and 100 kernel weight, whereas cross BLD 254 × BLD 47 was proved as good specific combiner for ear yield per plant, kernel yield per plant, ear length, 100 kernel weight and shelling per cent. For earliness cross BLD 254 × IMR 53 was found good specific combiner (Table 3). Similar results were reported for GCA effect as well as SCA effects [8,11] and [9].

Top three crosses based on the heterobeltiosis and economic heterosis presented in Table 3. Cross BLD 266 × BLD 47 was posses higher significant heterobeltiosis for kernel yield per plant, ear yield per plant, ear length, ear girth and 100 kernel weight. Crosses BLD 206 × BLD 328 and BLD 266 × BLD 328 were reported higher heterobeltiosis for days to tasselling as well as days to silking. The superiority of the cross over the commercial standard check considered as economic heterosis. Based on the economic heterosis estimated over the standard check GAYMH 1, cross Z 488-4 × IMR 53 was found superior kernel yield per plant, ear yield per plant, days to tasselling, days to silking, days to dry husk, ear girth and 100 kernel weight. Similarly hybrid WNC-40066 × BLD-47 recorded significant standard heterosis for ear yield per plant, kernel yield per plant , number of kernels per row, ear length and ear girth. The crosses with significant heterobeltiosis and standard heterosis for kernel yield and its components involving poor × good and good × poor general combiners parents respectively indicate dominance type of gene action, as previously reported by other researchers [8-11].

Table 1. Analysis of variance for combining ability of yield and its component traits in maize

Source	df	DT	DS	ASI	DDH	PH	EH	EL	EG	NKR/E	NK/R	TW	EY/P	KY/P	SP
Replications	2	3.36	1.16	6.93	3.36	21.79	7.28*	5.66	0.17	4.23	16.81	32.03	1478.42	1118.39	13.40
Crosses	39	11.63**	12.61**	1.14	12.67**	561.73**	301.77**	4.05**	1.86**	1.39*	20.35	15.37	1662.06**	888.72**	25.17
Line	7	37.88**	37.72**	0.53	34.53**	1182.06*	535.85	3.17	0.82	1.02	24.43	23.41	595.34	394.25	8.36
Tester	4	4.18	5.72	0.60	18.24*	556.87	177.06	3.73	1.43	0.30	21.88	9.83	1076.71	592.39	4.15
LinexTester	28	6.14**	7.31**	1.37	6.41	407.34**	261.06**	4.31**	2.19**	1.64**	19.11	14.15	2012.36**	1054.67**	32.37*
Error	78	1.80	1.65	1.63	5.09	9.99	2.29	1.86	0.41	0.77	14.22	12.58	496.54	217.89	18.82
δ^2 *Line*		2.41**	2.42**	-0.08	1.98**	77.89*	35.53	0.04	0.01	0.01	0.59	0.74	7.53	10.77	-1.46
δ^2 *Tester*		0.10	0.18	-0.04	0.56*	22.63	7.26	0.05	0.03	-0.02	0.26	-0.10	24.77	14.99	-1.09
δ^2 *GCA*		0.99**	1.04**	-0.06	1.11**	43.89**	18.13*	0.05	0.02	-0.01	0.39*	0.22*	18.14	13.37	-1.23
δ^2 *SCA*		1.49**	1.94**	-0.10	0.54	131.23**	86.08**	0.60*	0.50**	0.25*	1.19	0.62	510.01**	273.99**	0.71
δ^2 *GCA* / δ^2 *SCA*		0.67	0.53	0.58	2.04	0.33	0.21	0.08	0.05	-0.05	0.33	0.36	0.04	0.05	-1.72

*, ** Significant at 5% and 1% levels, respectively.; DT- Days to tasseling, DS- Days to silking, ASI- Anthesis silking interval, DDH- Days to dry husk, PH- Plant height, EH- Ear height, EL- Ear length, EG- Ear girth, NKR/E- Number of kernel rows per ear, NK/R- Number of kernels per row, TW- 100 kernel weight, EY/P- Ear yield per plant, KY/P- Kernel yield per plant and SP- Shelling percent

Table 2. General combining ability (*gca*) effects of parents for various characters in maize

Particular	Days to tasseling	Days to silking	ASI	Days to dry husk	Plant height	Ear height	Ear length	Ear girth	Number of kernel rows per ear	Number of kernels per row	100 kernal weight	Ear yield per plant	Kernel yield per plant	Shelling (%)
Line (Female)														
Z 488-4	-2.13**	-2.28**	-0.15	-3.36**	-1.72	-3.40**	0.17	0.50*	0.56*	-0.60	-1.00	13.96*	12.31**	1.15
BLD-266	-0.39	-0.14	0.25	-1.03	-15.51**	-11.26**	-0.70	-0.04	-0.11	-1.25	-0.80	-5.24	-2.70	0.75
BLD-254	2.21**	2.26**	0.05	0.91	5.57**	5.83**	0.48	-0.14	-0.03	-0.09	-0.87	-4.32	-2.98	-0.01
BLD-206	0.48	0.13	-0.35	0.44	4.44**	3.56**	-0.08	-0.20	0.04	-2.13*	-0.13	-0.09	-1.54	-0.79
WNC 32067	-0.79*	-0.81*	-0.02	0.71	14.29**	7.87**	0.12	-0.23	-0.19	1.29	-1.40	2.60	0.06	-0.91
IMR156	1.68**	1.66**	-0.02	0.91	1.01	-0.32	-0.26	0.12	-0.24	0.49	1.67	0.54	0.10	-0.40
WNC 40066	0.88*	0.93**	0.05	0.24	-7.16**	-0.55	0.69	0.04	-0.18	0.72	1.80	-2.76	-2.42	-0.33
HYN-10-RN 235-270	-1.93**	-1.74**	0.18	1.18*	-0.92	-1.72**	-0.42	-0.05	0.16	1.57	0.73	-4.70	-2.82	0.55
S. Em ±	0.33	0.31	0.33	0.56	0.95	0.43	0.41	021	0.24	1.02	0.91	5.67	3.93	1.42
Tester (Male)														
IMR 53	-0.66*	-0.78**	-0.13	-1.14*	0.85	1.01**	0.21	-0.10	-0.01	0.38	0.90	-0.89	-1.19	-0.32
IC 328963	0.18	0.26	0.08	0.73	-2.91**	-4.09**	0.13	-0.18	0.01	-1.51	0.11	-0.25	-0.91	-0.49
BLD-309	-0.16	-0.08	0.08	-0.73	-6.69**	-0.93**	-0.61	-0.06	-0.04	-0.26	-0.14	-7.03	-4.87	0.13
BLD-328	0.34	0.51*	0.17	0.44	3.83**	3.20**	-0.15	-0.08	-0.14	0.38	-0.89	-2.84	-1.45	0.56
BLD-47	0.30	0.09	-0.21	0.69	4.92**	0.80*	0.42	0.43*	0.17	1.01	0.03	11.01*	8.41**	0.11
S. Em ±	0.26	0.24	0.26	0.44	0.75	0.34	0.32	0.16	0.19	0.81	0.71	4.48	3.11	1.12

*, ** Significant at 5% and 1% levels, respectively

Table 3. The three top ranking crosses with respect to SCA effects, heterosis over better parent and check GAYMH-1

Characters	Hybrids with high sca effects		Hybrids with highest heterobeltiosis		Hybrids with highest economic heterosis	
Days to tasselling	IMR156 × IMR 53	-2.68**	BLD-206 × BLD-328	-7.23**	Z 488-4 × IMR 53	-5.88
	BLD-254 × IMR 53	-2.54**	BLD-266 × BLD-328	-5.49**	Z 488-4 × IC 328963	-4.58
	BLD-206 × BLD-309	-1.64*	Z 488-4 × IC 328963	-3.95	HYN-10-RN 235-270 × IMR 53	-3.92
	S. Em ±	**0.73**	**S. Em ±**	**1.06**	**S. Em ±**	**1.06**
Days to silking	IMR156 × IMR 53	-3.62**	BLD-206 × BLD-328	-6.47**	Z 488-4 × BLD-309	-6.79
	BLD-254 × IMR 53	-2.88**	BLD-266 × BLD-328	-5.88**	Z 488-4 × IMR 53	-6.17
	BLD-206 × BLD-309	-1.46*	Z 488-4 × BLD-309	-5.03**	Z 488-4 × IC 328963	-6.17
	S. Em ±	**0.70**	**S. Em ±**	**0.99**	**S. Em ±**	**0.99**
ASI	Z 488-4 × BLD-309	-1.02	WNC 32067 × BLD-47	-57.14	Z 488-4 × BLD-309	-66.67
	WNC 32067 × BLD-47	-0.86	IMR156 × IMR 53	-57.14	BLD-206 × IC 328963	-66.67
	BLD-266 × BLD-328	-0.83	WNC 32067 × IMR 53	-50.00	WNC 32067 × BLD-47	-66.67
	S. Em ±	**0.75**	**S. Em ±**	**1.06**	**S. Em ±**	**1.06**
Days to dry husk	BLD-254 × IMR 53	-3.33*	Z 488-4 × IMR 53	-7.42**	Z 488-4 × IMR 53	-6.70**
	WNC 40066 × BLD-309	-2.74*	Z 488-4 × IC 328963	-6.25**	Z 488-4 × IC 328963	-5.52**
	HYN-10-RN 235-270 × BLD-309	-2.68*	BLD-254 × IMR 53	-4.33*	BLD-254 × IMR 53	-4.33**
	S. Em ±	**1.26**	**S. Em ±**	**1.79**	**S. Em ±**	**1.78**
Plant height	HYN-10-RN 235-270 × IC 328963	-22.15**	WNC 40066 × BLD-309	-27.29**	BLD-266 × IC 328963	-36.19**
	WNC 40066 × BLD-309	-21.59**	HYN-10-RN 235-270 × IC 328963	-19.23**	WNC 40066 × BLD-309	-33.53**
	IMR156 × BLD-47	-15.67**	WNC 40066 × IMR 53	-17.93**	HYN-10-RN 235-270 × IC 328963	-31.43**
	S. Em ±	**2.13**	**S. Em ±**	**3.02**	**S. Em ±**	**3.02**
Ear height	HYN-10-RN 235-270 × IC 328963	-20.58**	BLD-266 × IC 328963	-33.02**	BLD-266 × IC 328963	-53.02
	IMR156 × BLD-47	-18.40**	IMR156 × BLD-328	-30.43**	HYN-10-RN 235-270 × IC 328963	-52.19
	WNC 40066 × IMR 53	-14.72**	HYN-10-RN 235-270 × IC 328963	-29.34**	IMR156 × BLD-47	-41.69
	S. Em ±	**0.97**	**S. Em ±**	**1.38**	**S. Em ±**	**1.38**
Ear length	HYN-10-RN 235-270 × IC 328963	2.59**	BLD-266 × BLD-47	47.68**	WNC 40066 × BLD-47	32.10**
	WNC 40066 × BLD-47	1.53	HYN-10-RN 235-270 × IC 328963	46.24**	HYN-10-RN 235-270 × IC 328963	29.63**
	BLD-254 × BLD-47	1.35	BLD-206 × BLD-47	34.81**	BLD-254 × BLD-47	29.14**
	S. Em ±	**0.91**	**S. Em ±**	**1.29**	**S. Em ±**	**1.29**
Ear girth	WNC 32067 × BLD-309	1.49**	BLD-206 × BLD-328	23.22**	WNC 40066 × BLD-47	10.71
	BLD-206 × BLD-328	1.44**	BLD-266 × BLD-47	19.46*	Z 488-4 × IMR 53	9.74
	HYN-10-RN 235-270 × IC 328963	1.09**	BLD-206 × IMR 53	18.03*	WNC 32067 × BLD-309	9.74
	S. Em ±	**0.48**	**S. Em ±**	**0.67**	**S. Em ±**	**0.67**

Characters	**Hybrids with high sca effects**		**Hybrids with highest heterobeltiosis**		**Hybrids with highest economic heterosis**	
Number of kernel rows per Ear	Z 488-4 × IC 328963	1.19*	BLD-206 × IMR 53	15.03*	Z 488-4 × IC 328963	8.28
	WNC 32067 × BLD-309	1.18*	WNC 32067 × BLD-309	11.86	BLD-206 × IMR 53	2.60
	BLD-206 × IMR 53	1.00	BLD-206 × BLD-328	11.11	HYN-10-RN 235-270 × IC 328963	2.60
	S. Em ±	**0.54**	**S. Em ±**	**0.77**	**S. Em ±**	**0.77**
Number of kernels per row	WNC 40066 × BLD-47	4.41	WNC 32067 × IMR 53	39.22**	WNC 40066 × BLD-47	39.78**
	HYN-10-RN 235-270 × IC 328963	3.00	WNC 40066 × BLD-47	31.32*	WNC 32067 × IMR 53	30.25**
	BLD-206 × BLD-328	2.88	BLD-266 × IMR 53	23.99	HYN-10-RN 235-270 × IC 328963	26.89**
	S. Em ±	**2.28**	**S. Em ±**	**3.22**	**S. Em ±**	**3.22**
100-kernal weight	BLD-254 × BLD-47	3.58	BLD-266 × BLD-47	25.84*	WNC 40066 × IMR 53	25.50**
	WNC 32067 × IMR 53	2.90	BLD-254 × BLD-47	22.34*	HYN-10-RN 235-270 × IC 328963	20.40**
	HYN-10-RN 235-270 × IC 328963	2.89	HYN-10-RN 235-270 × IC 328963	20.41*	Z 488-4 × IMR 53	17.33**
	S. Em ±	**2.02**	**S. Em ±**	**2.86**	**S. Em ±**	**2.86**
Ear yield per plant	WNC 40066 × BLD-47	43.67**	BLD-266 × IC 328963	64.05**	WNC 40066 × BLD-47	50.56**
	BLD-206 × BLD-328	35.26**	BLD-266 × BLD-47	61.27**	BLD-266 × BLD-47	37.68**
	WNC 32067 × BLD-309	32.21**	WNC 32067 × IC 328963	60.09**	Z 488-4 × IMR 53	35.52**
	S. Em ±	**12.68**	**S. Em ±**	**17.93**	**S. Em ±**	**17.93**
Kernel yield per plant	WNC 40066 × BLD-47	32.30**	WNC 32067 × BLD-328	78.42**	WNC 40066 × BLD-47	53.06**
	HYN-10-RN 235-270 × IC 328963	26.68**	BLD-266 × IC 328963	73.03**	BLD-254 × BLD-47	42.36**
	BLD-254 × BLD-47	22.86**	BLD-266 × BLD-47	73.03**	Z 488-4 × IMR 53	41.58**
	S. Em ±	**8.81**	**S. Em ±**	**12.46**	**S. Em ±**	**12.46**
Shelling (%)	WNC 32067 × IMR 53	5.11	WNC 32067 × BLD-328	12.48	BLD-254 × BLD-47	6.98**
	BLD-206 × BLD-309	4.30	HYN-10-RN 235-270 × BLD-328	6.89	Z 488-4 × IC 328963	6.95**
	BLD-254 × BLD-47	4.04	HYN-10-RN 235-270 × BLD-309	6.11	BLD-266 × BLD-328	6.82**
	S. Em ±	**3.17**	**S. Em ±**	**4.49**	**S. Em ±**	**4.49**

4. CONCLUSION

The present study indicated that the parent Z 488-4 and BLD-47 were most promising parent for yield and its components traits. While the cross WNC40066 × BLD-47, Z 488-4 × IMR 53 and BLD-266 × BLD-47 found to be most promising for kernel yield and other desirable traits, the results need to be further strengthening for the genotype x environment interaction of these cross over different seasons and or locations to exploit the heterosis in yellow maize.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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