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Gene action and heterosis for yield and yield components in maize (*Zea mays*)*

P BHAVANA [1], R P SINGH [2] and R N GADAG[3]

Indian Agricultural Research Institute, Pusa, New Delhi 110 012

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India's maize (*Zea mays* L.) production has grown annually by a robust 4.5% in last 10 years to a record 18.5 million tonnes in 2007–08 (Sud 2008). Bulk of this increase is due to cultivation of highly productive single cross hybrids owing to availability of superior inbred lines. This necessitates identification of superior inbreds for further enhancing productivity of hybrids. Estimates of combining ability provide information regarding usefulness of inbreds as parents for hybridization to generate segregating population which is expected to give superior segregates. Line × tester analysis is a very good approach to know nature and magnitude of gene action which ultimately determines the most appropriate and efficient breeding procedure. It also estimates combining ability effects and partitioning of the genetic variance. Magnitude and extent of heterosis in desired direction is of paramount importance in deciding as to whether or not heterosis is practically and economically feasible. Thus exploitation of heterosis and selection of parents on the basis of combining ability are important breeding approaches in crop improvement.

The experimental material comprised nine lines, viz 'DMB 5', 'DMB 9', 'DMB 12', 'DMB 14', 'DMB 16', 'DMB 17', 'DMB 18', 'DMB 22', 'DMB 23' and 5 testers, viz 'DMB 26', 'DMB 27', 'DMB 28', 'DMB 29' and 'DMB 30' (advance breeding lines of Maize Breeding Unit, New Delhi). Testers were selected based on diverse sources of origin and variability to yield and yield components. These parents were crossed in line × tester fashion during winter season of 2006 at Maize Research Station, Hyderabad to generate 45 F_1s. During rainy (*kharif*) season of 2007, 14 parents and their 45 F_1s were evaluated in a randomized block design with three replications at Maize Breeding Unit, Delhi. Row-to-row and plant-to-plant spacings were 50 cm × 20 cm, respectively. The data were recorded on five randomly selected plants for days to 50% pollenshed, days to 50% silking, plant height (cm), ears/plot, ear height (cm), yield/plot (kg), single cob weight (g), cob length (cm), cob girth (cm), number of rows/ear, number of kernels/row and 100-seed weight (g). Combining ability analysis was done according to the model given by Kempthorne (1957). Heterosis (%) of F_1 over better parent was computed following Turner (1953).

The *per se* performance of the genotypes revealed that there was substantial variability among them for all the characters. Analysis of variance indicated highly significant variance for parents vs hybrids for all traits except days to 50% silking and number of ears/plot indicating superior performance of hybrids over parents. Analysis of variance for combining ability indicated that variances due to females and males indicative of general combining ability variance were significant and higher in magnitude for days to 50% pollenshed, days to 50% silking, plant height, ears/plot, ear height, yield/plot, cob length, cob girth, number of rows/ear and 100-seed weight. This implied that these characters are predominantly governed by additive gene action. Therefore these parents can be used for the production of synthetics and composites which can further serve as base populations for effecting selections for individual traits. This result was in agreement with the reports of Katna *et al.* (2005) and Iqbal *et al.* (2007). Variance due to females × males, which is related to dominance variance was significant for days to 50% silking and number of kernels/row. Hence both additive and dominance gene action were important for days to 50% silking. Similar results were obtained by Jabeen *et al.* (2007). High predictability ratio indicating high relative importance of gca over sca was observed for all characters except single cob weight, number of kernels/row and 100-seed weight. The predictability ratio for yield/plot was high indicating predominance of gca over sca. For yield, the line × tester interaction was found to contribute more than lines and testers individually. Except for plant height, all the characters had high contribution from line × tester interaction.

The GCA effects of 'DMB 16' for days to 50% pollenshed and days to 50% silking were significant in desirable direction

*Short note

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[1]Scientist (Plant Breeding), (e mail: bhavanaraj2311@yahoo.co.in), ICAR RCER Research Centre, Ranchi, [2]Technical Officer, [3]Senior Scientist (e mail: rn_gadag@yahoo.com)

Table 1 Estimates of better parent heterosis for yield and yield components

Cross	Days to 50% pollenshed	Days to 50% silking	Plant height (cm)	Ears/plot	Ear height (cm)	Yield/ plot (kg)	Single cob weight (g)	Cob length (cm)	Cob girth (cm)	Rows/ ear	Kernels/ row	100 seed weight (g)
$L_1 \times T_1$	–2.98*	–1.14	8.82	153.33**	19.51	130.77**	221.82**	86.80**	88.17**	57.58**	122.94**	79.17**
$L_1 \times T_2$	–6.36**	–4.97**	20.00	153.33**	48.78**	103.23**	104.57**	11.77**	16.74**	23.08**	20.86**	20.19**
$L_1 \times T_3$	–10.61**	–10.16**	15.15	377.78**	66.67**	240.00**	2141.18**	409.74**	404.04**	568.75**	1519.35**	189.13**
$L_1 \times T_4$	–11.48**	–10.88**	3.45	372.73**	56.10**	217.39**	155.71**	95.74**	68.93**	79.13**	125.22**	43.48**
$L_1 \times T_5$	–8.52**	–8.15**	27.72	129.17**	65.85**	124.24**	116.00**	66.43**	47.34**	52.94**	75.00**	60.87**
$L_2 \times T_1$	–5.75**	–4.95**	28.43	153.33**	12.77	146.15**	255.55**	101.54**	92.75**	48.48**	115.15**	131.94**
$L_2 \times T_2$	–6.90**	–3.85**	28.57	213.33**	34.69*	135.48**	60.48**	33.09**	9.93**	22.58**	16.61**	19.67**
$L_2 \times T_3$	–7.82**	–5.35**	24.74	377.78**	100.00**	230.00**	1982.35**	364.61**	402.02**	581.25**	1467.74**	200.00**
$L_2 \times T_4$	–9.29**	–8.29**	8.62	336.36**	29.41*	213.04**	176.43**	103.10**	80.00**	73.91**	113.48**	73.91**
$L_2 \times T_5$	–6.82**	–5.98**	38.61*	119.05**	31.37*	114.71**	105.53**	44.09**	61.69**	58.82**	71.92**	58.70**
$L_3 \times T_1$	–2.98*	–1.14	–0.98	100.00**	6.38	65.38**	97.27**	44.90**	51.15**	32.95**	48.48**	62.50**
$L_3 \times T_2$	–4.05**	–3.87**	22.86	180.00**	39.58**	138.46**	134.93**	22.27**	29.08**	37.97**	81.95**	–2.31
$L_3 \times T_3$	–10.06**	–9.09**	37.65*	355.56**	96.97**	250.00**	2123.53**	423.06**	383.84**	568.75**	1696.77**	176.09**
$L_3 \times T_4$	–12.57**	–11.92**	4.31	390.91**	39.58**	217.39**	138.57**	99.07**	64.64**	86.09**	109.13**	47.83**
$L_3 \times T_5$	–9.09**	–7.61**	21.78	150.00**	52.08**	169.23**	130.82**	40.68**	46.08**	52.94**	70.08**	53.26**
$L_4 \times T_1$	–4.76**	–4.55**	16.67	213.33**	125.00**	153.85**	218.18**	91.50**	85.50**	59.09**	110.39**	98.61**
$L_4 \times T_2$	–4.05**	–4.97**	3.81	46.67**	110.71**	25.81**	91.50**	29.84**	21.00**	26.44**	54.45**	–0.73
$L_4 \times T_3$	–8.94**	–8.02**	55.13**	333.33**	96.43**	195.00**	2576.47**	481.31**	424.24**	590.62**	1703.23**	215.22**
$L_4 \times T_4$	–9.84**	–9.84**	3.45	254.55**	110.71**	186.96**	189.29**	95.66**	89.29**	87.83**	96.96**	64.13**
$L_4 \times T_5$	–7.95**	–8.15**	19.80	52.17**	103.57**	106.45**	133.17**	74.02**	63.95**	66.18**	60.96**	70.65**
$L_5 \times T_1$	–5.36**	–5.68**	20.35	206.67**	34.04*	180.77**	260.00**	82.62**	83.97**	62.12**	117.75**	105.56**
$L_5 \times T_2$	–5.20**	–4.97**	9.73	46.67**	25.00	41.94**	36.00**	8.85**	–1.49**	–3.50	7.38	–8.03*
$L_5 \times T_3$	–10.61**	–9.09**	8.85	477.78**	78.79**	310.00**	2488.23**	426.04**	411.11**	600.00**	1738.71**	191.30**
$L_5 \times T_4$	–12.02**	–12.44**	12.07	327.27**	45.83**	200.00**	158.57**	101.94**	73.93**	72.17**	106.52**	61.96**
$L_5 \times T_5$	–7.95**	–7.61**	21.24	100.00**	43.75**	117.14**	66.83**	44.86**	50.16**	41.18**	63.36**	55.43**
$L_6 \times T_1$	–1.79	–2.27*	22.55	213.33**	46.67**	176.92**	257.27**	77.13**	93.89**	62.12**	112.99**	100.00**
$L_6 \times T_2$	–1.73	–2.21	19.05	153.33**	48.89**	87.10**	64.91**	15.58**	13.07**	17.89**	25.09**	0.73
$L_6 \times T_3$	–10.06**	–6.95**	32.65	411.11**	118.18**	275.00**	2252.94**	396.62**	409.09**	562.50**	1483.87**	219.57**
$L_6 \times T_4$	–9.84**	–9.33**	8.62	290.91**	64.44**	239.00**	195.71**	105.89**	87.50**	82.61**	127.39**	61.96**
$L_6 \times T_5$	–7.95**	–7.61**	28.71	91.30**	42.22**	85.71**	71.86**	41.50**	48.90**	38.24**	66.44**	61.96**
$L_7 \times T_1$	–4.17**	–4.55**	30.39	253.33**	31.91*	219.23**	238.18**	79.77**	93.13**	60.61**	118.18**	94.44**
$L_7 \times T_2$	–4.62**	–3.31**	27.62	180.00**	40.82**	96.77**	64.84**	24.99**	12.03**	16.67**	34.73**	–4.55
$L_7 \times T_3$	–9.50**	–6.42**	41.05*	455.56**	103.03**	235.00**	1935.29**	339.36**	435.35**	550.00**	1209.68**	217.39**
$L_7 \times T_4$	–9.84**	–10.36**	21.55	363.64**	50.00**	239.13**	173.57**	91.86**	81.43**	70.43**	112.17**	65.22**
$L_7 \times T_5$	–7.39**	–7.07**	36.63*	100.00**	42.00**	145.71**	112.06**	56.26**	60.82**	41.18**	78.08**	78.26**
$L_8 \times T_1$	–8.00**	–6.04**	18.10	273.33**	31.91*	265.22**	248.18**	111.91**	87.79**	60.61**	128.37**	111.11**
$L_8 \times T_2$	–5.14**	–2.75*	18.10	206.67**	38.78**	252.17**	182.27**	95.06**	66.35**	77.94**	127.44**	46.67**
$L_8 \times T_3$	–12.29**	–12.30**	26.67	488.89**	93.94**	280.00**	2123.53**	430.02**	367.68**	525.00**	1612.90**	206.52**
$L_8 \times T_4$	–12.02**	–10.88**	16.38	381.82**	27.45*	278.26**	201.43**	122.45**	82.14**	66.96**	130.23**	93.33**
$L_8 \times T_5$	–6.25**	–6.52**	29.52	176.47**	47.06**	273.91**	194.33**	119.69**	30.45**	51.47**	119.53**	87.78**
$L_9 \times T_1$	–8.52**	–7.53**	25.49	318.18**	48.78**	233.33**	673.58**	178.08**	109.11**	133.53**	341.56**	108.33**
$L_9 \times T_2$	–3.98**	–4.84**	23.81	200.00**	65.75**	176.19**	662.26**	124.34**	121.12**	161.38**	327.23**	72.29**
$L_9 \times T_3$	–7.82**	–6.95**	14.71	244.44**	84.85**	160.00**	1947.06**	374.35**	367.68**	531.25**	1345.16**	219.57**
$L_9 \times T_4$	–10.93**	–9.84**	18.97	263.64**	70.73**	233.33**	671.70**	178.38**	107.04**	112.10**	348.72**	100.00**
$L_9 \times T_5$	–3.98**	–5.38**	32.35	336.36**	70.73**	328.57**	498.11**	153.13**	91.30**	112.10**	300.36**	83.13**
SEm±	1.15	1.10	16.37	2.59	12.95	0.40	0.021	2.39	0.46	2.07	4.87	3.75

**P* = 0.01 and **P* = 0.05

L_1, 'DMB 5'; L_2, 'DMB 9'; L_3, 'DMB 12'; L_4, 'DMB 14', L_5, 'DMB 16'; L_6, 'DMB 17'; L_7, 'DMB 18'; L_8, 'DMB 22'; L_9, 'DMB 23'; T_1, 'DMB 26'; T_2, 'DMB 27'; T_3, 'DMB 28'; T_4, 'DMB 29'; T_5, 'DMB 30' and hence can be used to produce early maturing hybrids. Significant negative specific combining ability (SCA) effect was detected in 'DMB 22' × 'DMB 28' for days to 50% silking. It was observed that this hybrid did not show any desirable SCA effect for yield and yield components, emphasizing the difficulty in combining earliness and yield. 'DMB 12' and 'DMB 14' had significant negative gca effects and hence can be used to produce short stature hybrids which may be useful where lodging is a problem. For ear height, 'DMB 14' and 'DMB 26' were significant in desirable direction.

In line× tester crosses, all the lines and testers were found to have significant gca effects for one or the other traits under study. Therefore these parents could be used for production of synthetics or composites as they possessed high additive gene effects. The estimates of GCA effects indicated that 'DMB 14' was best general combiner for plant height, ear height, single cob weight, cob length, cob girth and number of rows/ear, 'DMB 22' for ears/plot, yield/plot, single cob weight and 100 seed weight, 'DMB 18' for ears/plot and 'DMB 9', 'DMB 23' for 100-seed weight. Among the testers, 'DMB 26' for ear height, 'DMB 27' for number of rows/ear and 'DMB 29' and 'DMB 30' for 100-seed weight recorded significant positive GCA effects. To sum up 'DMB 22' was good general combiner. None of the parents displayed desirable GCA effects for all the traits. This means that there is scope for improving GCA of parents.

'DMB 12' × 'DMB 26' showed significant negative SCA effect for plant height and ear height. A highly significant SCA effect was observed in the cross 'DMB 16' × 'DMB 28' for ears/plot, yield/plot, single cob weight, number of rows/ear and number of kernels/row, 'DMB 9' × 'DMB 27' for days to 50% pollenshed, ears/plot and yield/plot, 'DMB 12' × 'DMB 28' for single cob weight, cob length and number of kernels/row and 'DMB 23' × 'DMB 26' for single cob weight and cob length. Other notable crosses with desirable effect include 'DMB 9' × 'DMB 26' for cob length and 100 seed weight, 'DMB 14' × 'DMB 26' for ears/plot, 'DMB 14' × 'DMB 30' for single cob weight, 'DMB 22' × 'DMB 29' for 100 seed weight, 'DMB 5' × 'DMB 30' for cob length, 'DMB 12' × 'DMB 27' for number of kernels/row and 'DMB 23' × 'DMB 30' for yield/plot. These hybrids with higher effects are useful for deriving high performing inbreds.

Majority of the hybrids expressed more than 100% better parent heterosis with 'DMB 16' × 'DMB 28' and 'DMB 23' × 'DMB 30' expressing more than 300% better parent

Table 2 SCA effects, GCA status and heterobeltosis for yield and yield components

Character	Crosses	SCA effects	GCA status	Heterobeltosis
Days to 50% pollenshed	'DMB 9'×'DMB 27'	–1.57**	L×L	–6.90**
	'DMB 22'×'DMB 28'	–1.17*	H×H	–12.29**
	'DMB 23'×'DMB 26'	–1.08*	L×H	–8.52**
Days to 50% silking	'DMB 18'×'DMB 26'	–1.03*	L×H	–4.55**
	'DMB 22'×'DMB 28'	–2.19**	H×H	–12.30**
Plant height (cm)	'DMB 12'×'DMB 26'	–22.74**	H×L	–0.98
Ears/ plot	'DMB 9'×'DMB 27'	3.25*	L×L	213.33**
	'DMB 14'×'DMB 26'	3.29*	L×L	213.33**
	'DMB 16'×'DMB 28'	2.87*	L×L	477.78**
Ear height (cm)	'DMB 12'×'DMB 26'	–14.48*	L×H	6.38
Yield/ plot (kg)	'DMB 9'×'DMB 27'	0.43*	L×L	135.48**
	'DMB 16'×'DMB 28'	0.47*	L×L	310.00**
	'DMB 23'×'DMB 30'	0.51*	L×L	328.57**
Single cob weight (g)	'DMB 12'×'DMB 28'	0.02**	L×L	2123.53**
	'DMB 14'×'DMB 30'	0.02**	H×L	133.17**
	'DMB 16'×'DMB 28'	0.02**	L×L	2488.23**
	'DMB 23'×'DMB 26'	0.02**	L×L	673.58**
Cob length (cm)	'DMB 5'×'DMB 30'	1.43*	L×L	66.43**
	'DMB 9'×'DMB 26'	1.58**	L×L	101.54**
	'DMB 12'×'DMB 28'	1.41*	L×L	423.06**
	'DMB 23'×'DMB 26'	1.54*	L×L	178.08**
Rows/ear	'DMB 16'×'DMB 28'	1.32*	L×L	600.00**
Kernels/row	'DMB 12'×'DMB 27'	3.73*	L×L	81.95**
	'DMB 12'×'DMB 28'	4.30*	L×H	1696.77**
	'DMB 16'×'DMB 28'	4.46*	L×H	1738.71**
100-seed weight (g)	'DMB 9'×'DMB 26'	2.73**	H×L	131.94**
	'DMB 22'×'DMB 29'	2.07*	H×H	93.33**

**P=0.01 and *P=0.05, L and H, Low and high general combiners heterosis for grain yield (Table 1). The crosses 'DMB 14' × 'DMB 28', 'DMB 18' × 'DMB 28', 'DMB 22' × 'DMB 28' and 'DMB 23' × 'DMB 28' showed high positive heterosis for yield and yield components. This indicates high heterosis for grain yield had contribution from high heterosis of yield attributes. High and significant heterosis for grain yield accompanied by significant heterosis for one or more yield components was earlier reported by several workers (Moneam *et al*. 2009).

The results obtained with regard to grain yield have proved the validity of the fact that inbreds derived from the geographically and genetically diverse maize populations but improved through half sib and full sib method of selection for few cycles, when crossed, would provide substantial heterosis to surpass the yield level of the best heterotic released hybrids under cultivation.

All crosses recorded negative heterosis for days to 50% pollenshed and days to 50% silking indicating early maturity of crosses. The highest negative better parent heterosis for days to 50% silking was observed in 'DMB 16' × 'DMB 29' (–12.44), followed by 'DMB 22' × 'DMB 28' (–12.30). The hybrids 'DMB 12' × 'DMB 29', followed by 'DMB 22' × 'DMB 28' exhibited high better parent heterosis indicating operation of negative over dominance for days to 50% flowering. Under Indian conditions early maturing hybrids are of prime importance and hence negative heterosis for this trait is desirable. Existence of negative heterosis for days to 50% silking was reported by Iqbal *et al*. (2010). Best crosses among 45 crosses having significant desired specific combining ability effects, GCA status and heterobeltosis are presented in Table 2. This study indicated that promising crosses with high sca effects involved not only high × high parents but also high × low and low×low gca effects.

The cross 'DMB 16' × 'DMB 28' with high sca effects and better parent heterosis was identified for selection for ears/plot, yield/plot, single cob weight, number of rows/ear and number of kernels/row.

SUMMARY

Fortyfive maize (*Zea mays* L.) hybrids developed by crossing divergent parents in line×tester design were evaluated for studying the genetic effects of yield and yield components and to identify the parents with good general combining ability. The comparative variances due to gca and sca indicated predominance of additive gene action for almost all the characters except for number of kernels/row. Estimates of general combining ability effects revealed that the genotype 'DMB 22' was good general combiner. The best specific crosses with high sca effects in desirable direction were 'DMB 16' × 'DMB 28', 'DMB 9' × 'DMB 27', 'DMB 12' × 'DMB 28' and 'DMB 23' × 'DMB 26'. Majority of the hybrids expressed more than 100% better parent heterosis for grain yield. High negative heterosis for days to 50% pollenshed and days to 50% silking indicated early maturity of hybrids. Cross 'DMB16' × 'DMB 28' with high specific combining ability effects and better parent heterosis was identified for selection for ears/plot, yield/plot, single cob weight, number of rows/ear and number of kernels/row.

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