

## Quantitative studies on heterosis and inbreeding depression in maize (*Zea mays* L.)

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**Abstract:** The present investigation was carried out for studying heterosis and inbreeding depression of twenty eight hybrids ( $F_1$ 's) and their  $F_2$ 's made by crossing of eight maize inbreds in all possible cross combinations excluding reciprocal. Observations were recorded on ten quantitative traits viz., plant height (cm), ear length (cm), ear girth (cm), number of kernel rows per ear, number of kernels per row, 100 kernels weight (g) yield per plant (g), days to 50 % tassel emergence, days to 50% silk emergence and days to 50% maturity. Variable magnitude of heterosis was observed for different cross combinations for all the traits. Based on higher mean performance (94.33 to 118.67 g/plant) and higher heterotic response (11.95 to 30.48%) eleven crosses were selected. Response of inbreeding depression was significant in positive direction for most of the traits. Among these eleven crosses five crosses CM 300 x CML 142, CM 300 x CML 144, CM 300 x CML 150, CM 300 x CML 176 and CML 150 x CML 144 were selected having high heterotic value (12.31 to 30.48%) and lower inbreeding depression (less than 15%) for their utilization in maize improvement programme for the development of superior inbred lines.

**Keywords:** Heterotic value, Inbreeding depression, Maize, Quantitative studies, *Zea mays*

### INTRODUCTION

Maize is the third most important cereal crop in India after rice and wheat. It accounts for ~9 per cent of total food grain production in the country. Its production in India has grown from 14 MnMT in 2004-05 to 23 MnMT in 2013-14 maintaining the growth rate of 5.6 per cent over the last ten years (Agricultural Statistics at a glance, 2014). Being a multipurpose crop as food, feed and having industrial value, it is also known as miracle crop or queen of the "cereals". In case of maize, a great scope for the genetic improvements are available, due to presence of variability in their germplasm (Om Prakash *et al.*, 2006). Knowledge on different traits of interest (qualitative and quantitative traits) and their genetic control is a pre-requisite for planning the genetic improvement strategies (Premlatha and Kalamani, 2009). For improving the genetic architecture of the crop through breeding efforts, utilization of heterosis is important for maximization of the yield in maize. Heterosis response is expressed as a deviation of the performance of  $F_1$  (cross) from either of the parents (better parents heterosis) or average of the parental value (mid parent heterosis). But for commercial exploitation of heterosis, known as standard heterosis was estimated as deviation of the

performance of hybrid from the standard variety using as check. Standard heterosis was mostly considered for release of new hybrids. Nowadays, the maize breeder are emphasizing on single cross hybrids for better grain yield, uniformity, low cost of hybrid seed production and availability of superior and diverse inbred lines (Premlatha and Kalamani, 2009; Singh *et al.*, 2010; Kumari *et al.*, 2016). Inbreeding involves mating together of individuals that are closely related by ancestry in comparison to random mating. Consequence of inbreeding is the reduction in mean phenotypic value of the characters related with reproductive capacity or physiological efficiency is termed as "inbreeding depression". The present investigation has been undertaken to study the heterosis in  $F_1$  over standard check (SC) and inbreeding depression over  $F_2$  segregating generation for yield and its related characters in maize. Since, inbreeding depression and heterosis are completely opposite in terms of their manifested effect. It is essentially required to generate precise information on heterosis and inbreeding depression with respect to characters, in order to assess the relative potential of experimental hybrids for extraction of inbred.

### MATERIALS AND METHODS

The experiment was conducted at the Research farm of

Tirhut College of Agriculture, Dholi, under Rajendra Agricultural University, Bihar, Pusa. Materials for the present investigation were generated from eight inbred lines, including five quality protein maize (QPM) inbreds (CML 142, CML 144, CML 150, CML 176, CML 186) and three non-QPM inbreds (CM 300, CM 400 and CM 600) obtained from AICRP on maize, Dholi Centre. These parental lines were planted in crossing block on different dates with an interval of three days for synchronization of flowering period in order to facilitate crossing programme. Each plot consisted of three rows of five meter length with row to row and plant to plant spacing of 60 and 20 cm respectively. The inbreds were crossed in all possible combinations excluding reciprocals and 28 crosses were made. F<sub>2</sub> seeds were generated by selfing the F<sub>1</sub> plants. The 28 crosses obtained together with the eight parental inbreds, 28F<sub>2</sub>'s and a QPM check Shaktiman-4 were evaluated in randomized block design (RBD) with three replication under timely (19<sup>th</sup> November) and late sown conditions (17<sup>th</sup> December). Entries were grown at a spacing of 60 cm x 20 cm in rows of five meter length in plots having three rows per plot for parents and F<sub>1</sub>'s whereas, F<sub>2</sub>'s were grown in plots having five rows per plot. Recommended package of practices was followed to raise a good crop. To obtain the estimates of heterosis and inbreeding depression of 28 crosses ten agronomic traits were assessed. Observations were recorded on whole plot basis for days to 50 per cent tassel emergence, days to 50 per cent silk emergence and days to 50% maturity by counting the number of days from sowing to the issuance of tassel, silk and maturity of cob in 50 per cent plants. Five randomly selected plants in each plot were used for recording observations on plant height, ear length, ear girth, number of kernel rows per ear, number of kernels per row, 100 kernel weight, yield per plant for parents and F<sub>1</sub>'s. While, in case of F<sub>2</sub>'s observations were recorded on twenty five plants chosen randomly in each plot. Statistical analysis was calculated by the mean of individual data recorded for each character in each replication separately for each cross. To make the result more precise and manageable, the result on pooled data basis (across the environment) were presented in order to generate generalized information regarding the extent of heterosis and inbreeding depression in different characters of hybrids evaluated in the present study. Heterosis was calculated over standard check (SC) as percentage increases or decrease of the performance of the traits over standard check variety in desirable direction was calculated using the following formula:

Standard heterosis (SH); (Meredith and Bridge, 1972)

$$SH = \frac{F_1 - SC}{SC} \times 100 \dots\dots\dots(Eq.1)$$

Where, F<sub>1</sub> = Mean performance of F<sub>1</sub> hybrid  
 SC = Mean performance of standard check  
 Inbreeding depression (ID) was calculated by using following formula:

$$ID = \frac{F_1 - F_2}{F_2} \times 100 \dots\dots\dots(Eq. 2)$$

Where, F<sub>1</sub> = Mean performance of F<sub>1</sub> hybrid  
 F<sub>2</sub> = Mean performance of F<sub>2</sub>  
 Significance of heterosis and inbreeding depression were determined with a t test.

## RESULTS AND DISCUSSION

Analysis of variance revealed (Table 1) highly significant differences among the treatment for most of the traits. Variance is partitioned in to different sources in order to test the significance of these sources of variation. Highly significant variance for parents Vs F<sub>1</sub>'s were observed for all the characters with the exception of days to 50% tassel emergence and days to 50% silk emergence indicating superior performance of hybrids over parents. The mean sum square due to F<sub>1</sub>'s Vs F<sub>2</sub>'s was found to be significant for all the characters indicating the occurrence of inbreeding depression in expression of all the characters (Table 1). The effect due to variation in the form of date of sowing was non-significant in most of the cases. On the perusal of data in Table 1 showed the relative ranking of the genotypes across the date of sowing was influenced to a considerably greater extent for most of the traits including yield per plant. The *per se* performance of the genotypes revealed that there was substantial variability among them for all the characters. Variable magnitude of heterosis as exhibited by different cross combinations for all the characters indicated sufficient divergence in parental material for these traits. Genetic variability among experimental material was also reported by Marker and Krupaker (2009), Oliboni *et al.* (2012), Kumar *et al.* (2013), Kumari *et al.* (2013) and other workers.

Reduction in plant height is desirable trait in maize and five crosses estimates significantly lesser plant height in comparison to check among 28 crosses developed. The cross CM 600 x CML 144 (-16.52%) displayed the most negative heterosis for plant height hence can be used to produce short stature hybrids which can be useful where lodging is a problem. Bhatnagar *et al.* (2004), Killaria and Sharma (2006) and Oliboni *et al.* (2012) earlier reported significant heterosis for dwarfness. None of the crosses appeared to be shorter than the respective shorter parent. Six crosses exhibited significant standard heterosis for earliness in respect of days to 50% tassel emergence and days to 50% silk emergence. Out of six crosses, two crosses, CM 600 x CML 186 and CM 600 x CM 300 also exhibited significant standard heterosis for earliness in terms of days to 50% maturity. Manpreet *et al.* (2007), Kumar *et al.* (2008) and Premlatha and Kalamani (2009) observed

**Table 1.** Pooled analysis of variance for different characters across two dates of sowing.

Sources of Variation	D.F.	Mean sum of Squares									
		Plant height (cm)	Ear length (cm)	Ear girth (cm)	Number of kernel rows per ear	Number of kernels per row	100 Kernel weight (g)	Days to 50% tassels emergence	Days to 50% silk emergence	Days to 50% maturity	Yield per plant (g)
Replication	2	1773.53**	0.05	0.19	0.19	20.03*	2.65	0.15	0.05	0.62	7.13
Environments	1	40174.11**	66.87**	19.78**	17.24**	300.33**	318.55**	5309.54**	5192.13**	14720.04**	4529.37**
Rep. × Env.	2	738.66**	0.01	0.11	0.01	16.05	1.10	0.3873	0.13	0.13	8.86
Entries	64	1381.68**	20.15**	8.56**	8.23**	144.17**	91.19**	33.94**	34.33**	53.21**	2266.57**
Parents	7	2740.22**	10.78**	8.35**	7.91**	105.56**	22.48**	47.13**	51.33**	14.43	554.16**
F <sub>1</sub>	27	652.38**	10.67**	4.74**	4.21**	76.95**	49.05**	34.30**	32.85**	64.30**	1219.27**
F <sub>2</sub>	27	377.75**	9.14**	2.43**	1.93**	57.99**	28.08**	24.04**	25.01**	16.50**	1163.76**
F <sub>1</sub> + Check	28	639.62**	10.34**	4.58**	4.08**	74.29**	49.58**	32.22**	31.81**	62.01**	1179.29**
Parents Vs F <sub>1</sub>	1	34946.77**	564.55**	273.43**	302.16**	3865.39**	3559.04**	1.52	1.11	409.65**	72811.79**
F <sub>1</sub> Vs F <sub>2</sub>	1	16237.98**	318.20**	89.14**	51.79**	2442.69**	638.58**	248.57**	255.50**	348.11**	21498.88**
Ent. X Env.	64	253.22**	0.83	0.19	0.46	3.81	7.60*	11.19**	11.55**	22.04**	29.07
Parents × Env.	7	267.16*	0.07	0.09	0.03	0.55	0.29	11.43	9.81	7.52	7.89
F <sub>1</sub> × Env.	27	282.31**	0.52	0.23	0.16	1.62	3.28	13.27**	13.85**	34.91**	21.26
F <sub>2</sub> × Env.	27	194.38**	1.22	0.20	0.90	7.10	10.72**	9.64	10.24	9.18	38.51
F <sub>1</sub> + Check × Env.	28	274.84**	0.51	0.22	0.15	1.58	3.42	13.20**	13.76**	33.67**	20.55
Parents Vs F <sub>1</sub> × Env.	1	332.75	0.11	0.00	0.02	3.35	51.88**	2.45	2.92	162.50**	115.72
F <sub>1</sub> Vs F <sub>2</sub> × Env.	1	1232.03**	5.33*	0.04	0.51	2.43	68.14**	1.86	3.24	37.33*	138.45
Error	256	103.60	1.27	0.87	0.90	5.50	5.28	7.13	7.40	6.64	52.24

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

**Table 2.** Selected best crosses on the basis of per se performance and heterosis (%) for yield.

Hybrid Combinations	Per se performance	Heterosis (%)
CM 300 x CML 144	131.75	30.48**
CM 300 x CML 142	131.50	30.20**
CM 400 x CML 142	127.00	25.74**
CM 142 x CML 186	119.42	18.23**
CM 300 X CML 150	118.67	17.49**
CM 400 x CML 186	116.08	14.93**
CM 400 X CML 176	115.00	13.86**
CM 150 X CML 144	114.05	12.92**
CM 300 X CML 176	113.43	12.31**
CM 186 X CML 144	113.43	12.31**
CM 400 X CML 144	113.27	11.95**

significant heterosis for earliness in terms of days to 50% tasseling and days to 50% silking in the case of hybrids included in their studies. Heterosis for earliness in terms of days to 50% maturity was also reported earlier by Nigussie and Zelleke (2001) and Bhatnagar *et al.* (2004). Two crosses CM 600 x CML 186 and CM 600 x CM 300 exhibited significant heterosis for earliness as compared to their respective early maturing parent and hence can be used to produce early maturing hybrids. Thirteen crosses were found to have significant standard heterosis for ear length. Cross CM 300 x CML 144 (31.65%) indicating highest value of heterosis in positive direction. A positive heterotic value, 12.36% and 10.66% were observed for two crosses CM 300 x CML 142 and CM 300 x CML 144 respectively which demonstrated a desirable increase in ear girth. Four crosses (CM 400 x CML 176, CM 400 x CML 142, CM 300 x CML 142 and CM 300 x CML 144) exhibit significant standard heterosis ranged from 11.57% to 15.98% for number of kernels row per ear revealed increased number of grain rows in a cob. Similar results indicating the manifestation of significantly positive heterosis in these characters have been reported earlier by Kumar *et al.* (2008), Dubey *et al.* (2009), Singh *et al.* (2010) and Kumari *et al.* (2016) in maize crop. The eleven crosses recorded significantly positive heterosis for number of kernels per row, cross CM 300 x CML 144 showed maximum (23.07%) heterosis. Significant standard heterosis for 100 kernel weight were recorded to be 9.79% to 33.24% in the crosses CM 600 x CML 142 and CM 400 x CM 300, respectively. The eleven crosses registered significant positive standard heterosis, CM300 x CML 142 recorded highest (30.48%) value. Similar results indicating the manifestation of significantly positive heterosis in these characters in case of maize have been reported earlier by Kumar *et al.* (2008), Dubey *et al.* (2009), Singh *et al.* (2010), Oliboni *et al.* (2012) and Kumari *et al.* (2016).

Based on the findings of earlier research, the per se performance of hybrids and the extent of heterosis, in addition to specific combining ability effect are important considerations for commercial exploitation of heterosis. Selection of parents based on any one of

**Table 3.** Heterotic effect and estimates of inbreeding depression of eleven crosses for yield and other component characters.

Hybrid Combination	Plant height	Ear length	Ear girth	Kernels per ear	Kernels row	Kernels per row	100 kernels weight	Days to 50% tassal emergence	Days to 50% silk emergence	Days to 50% maturity	Yield per plant
1. CM 300 x CML 144	H 8.56	31.65**	12.36**	15.98**	23.07**	32.30**	-1.19	-1.16	1.02	30.48**	
	ID 15.74**	13.63**	16.90**	12.31**	22.62**	26.44**	-4.65**	-4.53**	-0.34	10.63**	
2. CM 300 x CML 142	H 0.65	27.22**	10.66**	12.87**	15.03**	32.82**	0.45	0.02	0.68	30.20**	
	ID 11.66**	8.57**	4.30	10.78**	15.56**	12.20**	-1.92	-2.31	-2.36*	9.76**	
3. CM 400 x CML 142	H 2.12	24.26**	6.16	14.32**	16.49**	21.91**	-1.19	-1.16	-0.79	25.74**	
	ID 12.80**	17.06**	12.52**	4.20	26.31**	8.25*	-4.35**	-4.09**	-2.85*	16.80**	
4. CM 142 x CML 186	H -4.97	16.48**	4.47	1.95	14.99**	16.13**	1.34	1.30	0.68	18.23**	
	ID 4.92	12.76**	8.55*	0.74	13.12**	4.98	0.29	0.29	0.00	16.61**	
5. CM 300 X CML 150	H -6.55	16.76**	2.30	3.34	13.03**	16.85**	0.59	0.58	-0.11	17.49**	
	ID 11.96**	11.03**	7.78*	7.39*	16.76**	8.13*	-1.33	-1.87	-1.47	2.46	
6. CM 400 x CML 186	H -13.45**	17.16**	5.92	6.45	13.48**	22.00**	-1.04	-0.58	-1.02	14.93**	
	ID 4.54	17.85**	8.75**	9.98**	19.67**	13.06**	-1.65	-1.16	1.71	17.95**	
7. CM 400 X CML 176	H -1.69	15.22**	2.50	11.57**	13.76**	21.36**	-2.23	-1.73	-1.02	13.86**	
	ID 11.71**	15.38**	10.57**	20.04**	16.63**	6.27	-4.55**	-4.26**	-3.42*	16.74	
8. CM 150 X CML 144	H 2.78	15.23**	-4.28	1.37	14.57**	20.85**	0.30	-0.29	1.24	12.92**	
	ID 11.60	12.54**	5.19	4.42	25.57**	10.57**	-1.18	-1.74	-0.78	14.07**	
9. CM 300 X CML 176	H -10.38**	15.35**	2.17	4.20	12.49**	26.35**	0.45	0.43	-0.34	12.31**	
	ID 8.19	13.38**	7.45*	15.31**	15.55**	8.69*	-1.48	-1.87	-3.51*	13.66**	
10. CM 186 X CML 144	H -7.90	15.44**	-6.52	-2.05	11.43**	15.03**	2.52	2.89*	1.69	12.31**	
	ID 3.06	24.66**	3.75	-1.40	19.55**	25.97**	1.16	1.54	0.56	16.39**	
11. CM 400 X CML 144	H -14.00**	12.99**	4.89	7.42	13.03**	27.25**	-0.74	-1.16	0.68	11.95**	
	ID -0.13	16.25**	8.71**	3.70	14.73**	18.55**	-1.79	-2.34	0.34	15.86**	

\*, \*\* Significant at 5% and 1%, respectively, H - Heterotic effect, ID - Inbreeding depression

**Table 4.** Hybrid combinations showing higher mean value and lesser inbreeding depression in F<sub>2</sub> generation.

Hybrid combinations	Mean mance	perfor-	Inbreeding depression
CM 300 x CML 142	118.67		9.76**
CM 300 x CML 144	117.75		10.63**
CM 300 x CML 150	115.75		2.46
CM 400 x CML 142	105.67		16.80**
CML 142 X CML 186	99.58		16.61**
CM 300 x CML 176	97.93		13.66**
CML 150 X CML 144	97.50		14.07**
CM 400 X CML 176	95.75		16.74**
CM 400 X CML 186	95.25		17.95**
CML 186 X CML 144	94.84		16.39**
CM 400 X CML 144	94.33		15.86**

these criteria alone, therefore, may not be purposefully effective. Accordingly, in the present study, for commercial exploitation of heterosis eleven crosses were identified as the best cross combination based on their *per se* performance and the magnitude of heterosis in trait(s) of economic importance (Table 2). The eleven cross combinations, namely, CM 300 x CML 144, CM 300 x CML 142, CM 400 x CML 142, CML 142 x CML 186, CM 300 x CML 150, CM 400 x CML 186, CM 400 x CML 176, CML 150 x CML 144, CM 300 x CML 176, CM 400 x CML 144 and CML 186 x CML 144 were recorded significantly higher mean performance and significantly positive standard heterosis for yield (Table 3). The result, therefore, revealed that *per se* performance for yield of hybrids reflected the degree of heterosis manifestation in the hybrids. This is in agreement with the earlier reports made by Dubey *et al.* (2009), Premlatha and Kalamani (2009), Singh *et al.* (2010) and Oliboni *et al.* (2012) in case of maize crop. Among different characters studied, the extent of positive heterosis for yield and associated traits of selected crosses are presented in Table 3. Heterosis for yield is being manifested as the cumulative effect of heterosis of component traits. In the present investigation, the study of selected crosses on their *per se* revealed that the most of crosses that showed positive and significant heterosis for yield also showed heterosis for ear length, ear girth, kernels row per ear, kernels per row and 100 kernels weight. Similar findings have been reported for these characters in maize crop earlier by Kumar *et al.* (2008), Premlatha and Kalamani (2009) and Singh *et al.* (2010). The characters like ear girth, 100 seed weight and number of kernel row per ear are known to exhibit highest correlation with grain yield in maize reported by Sofi *et al.* (2007) and Kumari *et al.* (2016). The *per se* performance were in general related to the heterotic response for majority of characters were also reported in rice (Kumari *et al.*, 2014) and in tomato (Kumar and Singh, 2016).

One of the characteristics of heterosis is that the increase in vigour is confined to F<sub>1</sub> generation. There is considerable depression from F<sub>1</sub> to F<sub>2</sub> and later gener-

ation. Shull (1914) reported that high inbreeding depression (positive) is the reflection of higher heterosis especially in cross-pollinated crop like maize. It may be seen from the present study that hybrid combinations that showed higher estimates of heterosis in general found to show substantial inbreeding depression (Table 3). In maize, inbreeding is accompanied by a reduction in the mean phenotypic value of most of the traits of economic importance simply because of reduction in fitness. Value of significantly positive inbreeding depression for plant height varied between 11.60% to 15.74%. Low inbreeding depression for plant height in positive direction was also reported earlier in maize by Maldonado and Miranda Filho (2002) and Kllaria and Sharma (2006). The F<sub>2</sub> population derived from these crosses recorded positive estimate of inbreeding depression for plant height hence helpful in screening of transgressive segregants from F<sub>2</sub> population having reduced plant height. The F<sub>2</sub> population derived from the cross CML 186 x CML 144 recorded positive and useful estimate of inbreeding depression for days to 50% silking indicating earliness for days to silking. The results, therefore, suggested that formation of new gene combination as a result of segregation and recombination may lead to increase in the degree of expression of a trait in the F<sub>2</sub> population. The statistically significant values of inbreeding depression for ear length, ear girth, number of kernel rows per ear, number of kernels per row, 100 kernels weight and grain yield per plant ranged between 8.51 to 24.66, 7.45 to 16.90, 7.39 to 20.04, 13.12 to 25.57, 8.13 to 26.44 and 9.76 to 17.95%, respectively. Less inbreeding depression for yield attributing traits viz., ear diameter, number of rows per ear and number of kernels per row was reported earlier by San Vicente and Hallauer (1993). High inbreeding depression for yield in maize was reported by many workers (Singh and Khalidi, 2002; Aramendiz *et al.*, 2004; Simon *et al.*, 2004; Andreoli *et al.*, 2006; Kumari, 2013).

Hybrids are considered to possess a high degree of biological fitness for a given situation. Inbreeding tends to disrupt this fitness. Crosses which tolerate this stress are desirable from the stand point of forming a heterotic group. Inbreeding tolerant base population could be used to generate inbred lines extract inbred lines as well as for the development of commercially promising single cross hybrids. In the present study, five crosses, namely, CM 300 x CML 142, CM 300 x CML 144, CM 300 x CML 150, CM 300 x CML 176 and CML 150 x CML 144 having higher heterosis, inbreeding depression less than 15% and high mean performance in F<sub>2</sub> generation were identified for their further utilization in recombination breeding programmes (Table 4).

## Conclusion

It was concluded that among 28 crosses which were generated from all possible cross combinations exclud-

ing reciprocal from eight genetically diverse parents, the eleven cross combinations were recorded significantly higher mean performance and significantly positive standard heterosis for yield. It was observed that in most of the cases, heterosis manifestation in grain yield was found to be associated with simultaneous heterosis in ear length, number of kernels per row and 100 kernel weight. Keeping greater magnitude of heterosis, higher mean performance and lesser inbreeding depression (less than 15%) into consideration, five crosses, namely, CM 300 x CML 142, CM 300 x CML 144, CM 300 x CML 150, CM 300 x CML 176 and CML 150x CML 144 were identified. These five crosses may be further used in maize improvement programme for the development of superior inbred lines.

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