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GENETICS

Heterosis studies in diallel crosses of maize for yield and yield attributing traits in maize (*Zea mays* L.) over locations

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Abstract

A study was undertaken to estimate the heterotic, heterobeltiotic and standard heterotic effects of 11 characters of 45 maize hybrids developed by ten parents in maize during *rabi*, 2011-12 over three locations *viz.*, College Farm, Rajendranagar (Hyderabad), Agricultural Research Station, Karimnagar and Agricultural Research Station, Kampasagar, Nalgonda District, T.S. The pooled analysis of variance (Diallel) revealed significant differences among locations and genotypes for all the characters studied. The crosses exhibited significant differences, indicating varying performance of cross combinations. The parent *vs* crosses which indicates average heterosis, for all the traits, thus considerable amount of average heterosis was reflected in hybrids. Negative standard heterosis was observed for days to 50 per cent tasseling, days to 50 per cent silking and days to maturity due to earliness in three hybrids over checks DHM-117 and 900 M Gold were BML-2782 X BML-5233-5, CM-211 X BML-5233-5 and BML-2486 X BML-2. Five crosses *viz.* BML-15 X BML-2910, BML-7 X BML-3044, CM-211 X BML-7, BML-6 X BML-2 and BML-2782 X BML-6 were identified as potential hybrids with more than 12% standard heterosis for grain yield over better yielding commercial hybrid check DHM-117. Testing of these hybrids in all India coordinated trials across the different states of the country may result in identification of better hybrids in the near future for commercial exploitation.

Highlights

- The overall results of heterosis, heterobeltiosis and standard heterosis indicated that the parents involved in the crossing should have one high *per se* performing parent and over dominance may be the cause of heterosis.
- The five hybrids *viz.*, BML-15 X BML-2910, BML-7 X BML-3044, CM-211 X BML-7, BML-6 X BML-2 and BML-2782 X BML-6 were recorded more standard heterosis for grain yield over commercial check DHM 117 and offers great scope for exploitation of the hybrid vigour on commercial scale.

Keywords: Heterosis, maize, multilocation testing, yield attributes

Maize (*Zea mays* L.) is one of the most important cereal crop and occupies a prominent position is global agriculture after wheat and rice. In India, maize ranks third next to rice and wheat (Centre for Monitoring Indian Economy 2014). Maize grain is gaining popularity in our country very fast due to huge demand, particularly for poultry feed industry; besides maize has diversified uses as food and industrial raw materials. Maize acreage and production have an increasing trend with introduction of hybrids due to their high yield potential.

Maize is a highly cross pollinated crop and the scope for the exploitation of hybrid vigour depend on the direction and magnitude of heterosis provides information on extent of genetic diversity of parents in developing superior F_1s so as to exploit. Hybrid vigour and has direct bearing on the breeding methodology to be adapted for varietal improvement (Shull 1908).

Basic knowledge on the genetic potential of base populations, either *per se* or in crosses are important information in breeding programs for the development of outstanding cultivars. The diallel mating scheme has been widely used to provide information on the performance of parental populations and their heterotic pattern in crosses (Hallauer and Miranda 1995). Diallel crosses also allow the identification of heterotic groups and the prediction of the performance of new populations derived from population crosses. Therefore, the present investigation was carried out to know the direction and magnitude of heterosis in maize.

Materials and Methods

Forty five hybrids, ten parents and two checks (DHM-117 and 900 M Gold) were evaluated during *rabi,* 2011-12 at three different locations *viz.,* College Farm, Rajendranagar, Hyderabad, Agricultural Research Station, Karimnagar and Agricultural Research Station, Kampasagar, Nalgonda Districts of Andhra Pradesh (Now in Telangana State), India. Each entry was sown in a row of 4 meters length with a spacing of 75 cm between rows and 20 cm between the plants. One plan per hill was maintained. The recommended fertilizers of Nitrogen, Phosphorus and Murate of Potash were applied in the ratio of 120:80:60 kg ha-^{1}. The entire phosphorus and murate of potash and half dose of nitrogen was applied as basal, while remaining half dose of nitrogen in two equal split doses at knee height stage and tasseling stages. Intercultural operations like weeding and irrigation schedules were taken to protect the crop from pests and diseases, so as to raise a healthy crop. At flowering and maturity stages, observations were recorded on days to 50 per cent tasseling, days to 50 per cent silking, days to maturity, plant height (cm), ear height (cm), ear girth (cm), ear length (cm), number of kernel rows per ear, number of kernels per row, 100-seed weight (g) and grain yield per plant (g). The analysis of variance for each trait was calculated as per Panse and Sukhatme (1978). The pooled mean value over three locations for each parent and hybrid was taken for computation of heterosis, heterobeltiosis and standard heterosis over DHM-117 and 900 M Gold according to the method of Fonseca and Patterson (1968).

Results and Discussion

Exploitation of heterosis or hybrid vigour is an important method of crop improvement adopted in many of the crops especially in cross pollinated crops. This phenomenon of heterosis was attracted the attention of plant breeders due to its conspicuous effect on economic characters especially grain yield and also maturity, quality traits. This heterosis has been successfully exploited in many cross pollinated crops among which maize is the major one.

Analysis of variance

The pooled analysis of variance (Diallel analysis) over three locations revealed significant differences for locations for all the characters studied (Table 1). Significant differences for replications x locations were recorded only for days to 50 per cent tasseling. The differences among the parents, parent vs crosses and crosses were observed to be significant for all the characters studied. The parents exhibited significant differences for all the characters indicating greater diversity in the parental lines. The crosses exhibited significant differences, indicating varying performance of cross-combinations. The parent vs crosses which indicates average heterosis, was also significant for all the traits, thus considerable amount of average heterosis was reflected in hybrids. The interaction effect of (parent vs hybrid) x environment was significant for ear length, number of kernels per row, 100-seed weight and grain yield per plant. While the interaction effects of parent x environment and hybrid x environment were significant for ear

Table 1. Pooled analysis of variance for combining ability (Diallel) for yield and yield components in maize

Source of variation	d.f.	Days to 50% tasseling	Days to 50% silking	Days to maturity	Plant height (cm)	Ear height (cm)	Ear girth (cm)
Replicates	2.00	15.07**	6.93	2.14	395.83*	281.03**	1.74
Environments	2.00	867.30**	497.84**	369.02**	2388.83**	461.55**	12.24**
Replication x Environments	4.00	10.56**	0.41	2.83	18.17	8.07	0.18
Treatemnts	54.00	151.17**	147.58**	229.90**	8089.02**	3151.65**	17.69**
Parents	9.00	269.86**	244.04**	227.62**	4804.52**	2189.77**	16.27**
Hybrids	44.00	125.91**	124.96**	159.88**	5828.76**	2796.36**	10.21**
Parents vs.Hybrids	1.00	194.37**	274.88**	3331.17**	137101.13**	27441.09**	359.74**
Treatment x Environments	108.00	3.21	2.31	3.33	43.89	18.06	2.35**
Parent x Environments	18.00	3.38	0.8	1.21	31.74	25.67	3.10**
Hybrids x Environments	88.00	3.21	2.43	3.81	47.06	16.9	2.25**
Parent vs.Hybrids x Env.	2.00	1.57	10.57	0.99	13.96	0.84	0.14
Error	324.00	3.16	3.79	5.03	102.43	26.08	0.5
Total	494.00	22.94	21.17	30.7	972.06	368.8	2.83

Table 1 (cont.)

Source of variation	d.f.	Ear length (cm)	Number of kernel rows per ear	Number of kernels per row	100- Seed weight (g)	Grain yield per plant (g)
Replicates	2.00	3.06	4.76	19.62	4.67	112.78
Environments	2.00	22.96**	15.62**	237.07**	440.40**	40696.17**
Replication x Environments	4.00	3.91	0.80	4.09	0.93	27.14
Treatemnts	54.00	50.34**	8.57**	299.28**	111.46**	8556.84**
Parents	9.00	62.83**	5.80**	331.09**	115.18**	1961.60**
Hybrids	44.00	28.34**	7.83**	162.26**	83.43**	5804.86**
Parents vs.Hybrids	1.00	905.93**	66.32**	6041.57**	1311.67**	189001.41**
Treatment x Environments	108.00	6.43**	4.82**	50.57**	48.61**	1404.17**
Parent x Environments	18.00	4.39**	4.27**	20.43**	44.57**	1211.23**
Hybrids x Environments	88.00	6.49**	5.00**	56.60**	50.48**	1318.73**
Parent vs.Hybrids x Env.	2.00	22.24**	1.63	56.31**	2.66**	6899.94**
Error	324.00	0.73	0.63	3.59	0.55	36.19
Total	494.00	7.52	2.49	47.22	24.99	1431.62

* Significant at 5% level; ** Significant at 1% level

girth, ear length, number of kernel rows per ear, number of kernels per row, 100-seed weight and grain yield per plant.

The data regarding heterosis, heterobeltiosis and standard heterosis for yield and yield components in maize were presented in Tables 2, 3 and 4 respectively.

Maturity is an important attribute of a given genotype, which directly or indirectly affects economic yield. Maturity itself is expressed by several components such as days to 50 per cent tasseling, days to 50 per cent silking and days to maturity. In pooled analysis the average negative heterosis for days to 50 per cent tasseling was found to be in the range of -10.71 to 10.89 per cent with 23 crosses registered significant negative heterosis. Heterobeltiosis in 31 hybrids registered with a range of -20.52 to 5.24 percent. However, standard heterosis in 15 hybrids over DHM-117 registered with a range of -17.66 to 2.69 and 23 hybrids over 900 M Gold, range of -19.12 to 0.88. Twenty four, 27, 13 and 18 hybrids recorded significant negative heterosis, heterobeltiosis and standard heterosis over DHM-117 and 900 M Gold, respectively for days to 50 per cent silking. While, 36 hybrids for days to maturity had average heterosis with a range, -11.57 to 6.92, 43 hybrids heterobeltiosis with range of -15.97 to 3.03, 30 hybrids for standard heterosis over DHM-117, with range of -16.04 to 1.68 and 29 hybrids with a range of -15.62 to 2.30 over 900 M Gold. The best crosses for earliness with high stand heterosis, heterobeltiosis, average heterosis and *per se* performance were BML-2782 X BML-5233-

Table 2: Average heterosis for yield and yield components in maize

S.No.	Characters	Range	No. of desirable heterotic hybrids	Best hybrid combinations
1	Days to 50 per cent tasseling	-10.71** to 10.89**	23	BML-2782 X BML-5233-5, CM-211 X BML-5233-5 and BML-2486 X BML-2
2	Days to 50 per cent silking	-12.04** to 10.74**	24	BML-2782 X BML-5233-5, CM-211 X BML-5233-5, BML-2486 X BML-2
3	Day to maturity	-11.57** to 6.92**	36	CM-211 X BML-5233-5, BML-2486 X BML-2910 and BML-5233-5 X BML-2910
4	Plant height (cm)	-10.31*to 78.98**	37	BML-15 X BML -2910, CM-211 X BML-15 and BML-2782 X BML-3044
5	Ear height (cm)	-19.37** to 103.04**	31	BML-6 X BML-2910,CM-211 X BML-3044 and CM-211 X BML-15
6	Ear girth (cm)	-7.10 to 38.75**	38	BML-2486 X BML-6, BML-7 X BML-3044 and BML-6 X BML-7
7	Ear length (cm)	0.15 to 74.07**	38	BML-2486 X BML-2, BML-15 X BML-2910 and BML-7 X BML-3044
8	Number of kernel rows per ear	-6.10 to 28.98**	18	BML-2782 X BML-5233-5, CM-211 X BML-5233-5 and BML-5233-5 X BML-2910
9	Number of kernels per row	-3.65 to 101.15**	42	BML-6 X BML-3044, BML-2486 X BML-2 and BML-15 X BML-2910
10	100-seed weight (g)	-19.66** to 60.15**	37	BML-5233-5 X BML-7, BML-15 X BML-2910 and CM-211 X BML-5233-5
11	Grain yield per plant (g)	-16.75** to226.21**	43	BML-15 X BML-2910, BML-2782 X BML-7 and BML-2782 X BML-6

Table 3: Heterobeltiosis for grain yield and yield components in maize

S.No.	Character	Range	No. of desirable heterotic hybrids	Best hybrid combinations
1	Days to 50 per cent tasseling	-20.52** to 5.24**	31	BML-2782 X BML-5233-5, CM-211 X BML-5233-5 and BML-5233-5 X BML-2910
2	Days to 50 per cent silking	-21.82** to 3.64	27	BML-2782 X BML-5233-5, CM-211 X BML-5233-5 and BML-5233-5 X BML-2910
3	Day to maturity	-15.97** to 3.03	43	BML-2782 X BML-5233-5, BML-5233-5 X BML-2910 and CM-211 X BML-5233-5
4	Plant height (cm)	-16.69** to 54.60**	29	CM-211 X BML-15, BML-2782 X BML-3044 and BML-15 X BML-2910
5	Ear height (cm)	-26.33** to 92.82**	24	CM-211X BML-3044, CM-211 X BML-15 and BML-2 X BML-3044
6	Ear girth (cm)	-9.99* to 32.82**	26	BML-7 X BML-3044, BML-6 X BML-7 and BML-2486 X BML-6
7	Ear length (cm)	-20.72** to 59.14**	24	BML-15 X BML-2910, BML-2486 X BML-2 and BML-7 X BML-2910
8	Number of kernel rows per ear	-14.10** to 27.08**	9	CM-211 X BML-5233-5, BML-2782 X BML-5233-5 and BML-5233-5 X BML-2910
9	Number of kernels per row	-29.33** to 83.84**	29	BML-6 X BML-3044, BML-15 X BML-2910 and BML-2486XBML-2
10	100-seed weight (g)	-22.67** to 53.79**	27	BML-5233-5 X BML-7, BML-15 X BML-2910 and CM-211 X BML-5233-5
11	Grain yield per plant (g)	-38.94** to 205.13**	41	BML-15 X BML-2910, BML-6 X BML-3044 and BML-2782 X BML-7

Table 4. Standard heterosis for yield and yield components in maize

S. No.	Characters	Range		No. desirable heterotic hybrids		Best hybrid Combinations	
		DHM-117	900 M Gold	Over DHM-117	Over 900M Gold	Over DHM-117	900 M Gold
1	Days to 50% tasseling	-17.66** to 2.69	-19.12 to 0.88	15	23	BML-2782 X BML-5233-5, CM-211 X BML-5233-5 and BML-5233-5 X BML-2910	BML-2782 X BML-5233-5, CM-211 X BML-5233-5 and BML-5233-5 X BML-2910
2	Days to 50% silking	-17.61** to 3.49	-18.56** to 2.30	13	18	BML-2782 X BML-5233-5, CM-211 X BML-5233-5 and BML-5233-5 X BML-2910	BML-2782 X BML-5233-5, CM-211 X BML-5233-5 and BML-5233-5 X BML-2910

3	Day to maturity	-16.04** to 1.68	-15.62** to 2.30	30	29	CM-211 X BML-5233-5, BML-5233-5 X BML-2910 and BML-2782 X BML-5233-5	CM-211 X BML-5233-5, BML-5233-5 X BML-2910 and BML-2782 X BML-5233-5
4	Plant height (cm)	-35.17** to 22.32**	-32.68** to 27.02**	3	4	CM-211 X BML-15, BML-7 X BML-3044 and BML-2 X BML-3044	CM-211 X BML-15, BML-7 X BML-3044 and BML-2 X BML-3044
5	Ear height (cm)	-35.92** to 32.36**	-21.71** to 61.70**	16	24	CM-211 X BML-3044, CM-211 X BML-6 and BML-6 X BML-2910	CM-211 X BML-3044, CM-211 X BML-6 and BML-6 X BML-2910
6	Ear girth (cm)	-21.48** to 9.49*	-21.05** to 10.09*	2	2	CM-211 X BML-6 and BML-7 X BML-3044	CM-211 X BML-6 and BML-7 X BML-3044
7	Ear length (cm)	-28.60** to 19.07**	-29.33** to 17.85**	6	5	BML-2486 X BML-2, BML-15 X BML-2910 and BML-7 X BML-2910	BML-2486 X BML-2, BML-15 X BML-2910 and BML-7 X BML-2910
8	Number of kernel rows per ear	7.44 to 21.04**	-9.51* to 18.33**	7	6	CM-211 X BML-5233-5, BML-2782 X BML-5233-5 and BML-2486 X BML-3044	CM-211 X BML-5233-5, BML-2782 X BML-5233-5 and BML-2486 X BML-3044
9	Number of kernels per row	-22.69** to 40.37**	-29.38** to 28.22**	19	9	BML-15 X BML-2910, BML-7 X BML-3044 and BML-2486 X BML - 2	BML-15 X BML-2910, BML-7 X BML-3044 and BML-2486 X BML - 2
10	100-seed weight (g)	-40.16** to 3.37	-39.53** to 4.46*	0	1	------	BML-6 X BMl-2
11	Grain yield per plant (g)	-61.39** to 42.79**	-66.90 ** to 22.40**	9	2	BML-15 X BML2910 and BML-6 X BML-3044	BML-15 X BML2910 and BML-6 X BML-3044

Table 5. Standard heterosis, heterobeltiosis and average heterosis for top five crosses for each trait in maize

Character / Cross	Standard heterosis		Heterobeltiosis	Average Heterosis	Mean Performance
	Over DHM-117	Over 900 M Gold			
1. Days to 50 per cent tasseling					
BML-2782 X BML-5233-5	-17.66**	-19.12**	-20.52**	-10.71**	61.11
CM-211 X BML-5233-5	-16.62**	-18.09**	-18.69**	-9.06**	61.89
BML-5233-5 X BML-2910	-16.32**	-17.79**	-13.87**	-5.97**	62.11
BML-5233-5 X BML-2	-11.68**	-13.24**	-3.12	2.70	65.56
BML - 2486 X BML-2	-10.63**	-12.21**	-13.85**	-8.29**	66.33
2. Days to 50 per cent silking					
BML-2782 X BML-5233-5	-17.61**	-18.56**	-21.82**	-12.04**	62.89
CM-211 X BML-5233-5	-17.03**	-17.99**	-18.80**	-9.88**	63.33
BML-5233-5 X BML-2910	-13.54**	-14.53**	-14.16**	-5.34**	66.00
BML-5233-5 X BML-2	-11.79**	-12.81**	-6.19**	0.25	67.33
BML- 2486 X BML-2	-9.46**	-10.50**	-11.52**	-7.78**	69.11
3. Days to maturity					
CM-211 X BML-5233-5	-16.04**	-15.62**	-15.20**	-11.57**	94.22
BML-5233-5 X BML-2910	-12.77**	-12.34**	-15.37**	-10.06**	97.89
BML-2782 X BML-5233-5	-10.89**	-10.45**	-15.97**	-9.50**	100.00
BML-2486 X BML-2910	-10.30**	-9.85**	-12.97**	-10.78**	100.67
BML-2486 X BML- 2	-9.70**	-9.25**	-8.71**	-8.30**	101.33
4. Plant height (cm)					
CM-211 X BML-15	22.32**	27.02**	54.60**	63.31**	279.06
BML-7 X BML-3044	7.32**	11.45**	42.82**	55.37**	244.83
BML-2 X BML-3044	7.30**	11.43**	37.89**	52.39**	244.80
BML-15 X BML-2910	5.68	9.75**	49.52**	78.98**	244.11
BML-2782 X BML-3044	2.99	6.95	54.31**	58.76**	234.97
5. Ear height (cm)					
CM-211 X BML-3044	32.36**	61.70**	92.82**	94.49**	127.92
CM-211 X BML-6	28.86**	57.42**	43.14**	62.42**	124.53
BML-6 X BML-2910	23.52**	50.90**	37.22**	103.04**	119.38
CM-211 X BML-15	19.42**	45.88**	65.48**	69.61**	115.41
BML-2 X BML-3044	17.29**	43.29**	57.95**	65.52**	113.36
6. Ear girth (cm)					
CM-211 X BML-6	9.49*	10.09*	19.93**	28.31**	15.63
BML-7 X BML-3044	8.02*	8.61*	32.82**	33.59**	15.42
BML-6 X BML-7	6.23	6.81	32.14**	32.98**	15.17
BML-2486 X BML-6	4.12	4.69	31.18**	38.29**	14.87
CM-211 X BML-3044	3.89	4.46	13.79**	20.37**	14.83

Table 5 (cont.)

Character / Cross	Standard heterosis		Heterobeltiosis	Average Heterosis	Mean Performance
	Over DHM-117	Over 900 M Gold			
7. Ear length (cm)					
BML-2486 X BML-2	19.07**	17.85**	30.04**	67.81**	19.29
BML-15 X BML-2910	15.64**	14.46**	41.21**	45.41**	18.73
BML-7 X BML-2910	11.11**	9.98**	10.88**	22.03**	18.00
CM-211 X BML-7	10.77**	9.64**	10.54**	31.57**	17.94
BML-7 X BML-3044	9.88**	8.76**	9.65*	36.51**	17.80
8. No. kernel rows per ear					
CM-211 X BML-5233-5	21.04**	18.33**	27.08**	28.79**	17.00
BML-2782 X BML-5233-5	18.67**	16.01**	24.58**	28.98**	16.67
BML-2486 X BML-3044	14.08**	11.52**	14.99**	16.10**	16.02
BML-5233-5 X BML-2910	13.92**	11.37*	19.60**	22.09**	16.00
CM-211 X BML-3044	11.55**	9.05*	12.44**	16.24**	15.67
9. No. kernels per row					
BML-15 X BML-2910	40.37**	28.22**	57.41**	70.84**	40.49
BML-7 X BML-3044	37.79**	25.86**	40.22**	61.13**	39.74
BML-2486 X BML-2	34.36**	22.73**	45.27**	87.17**	38.76
BML-6 X BML-3044	28.31**	17.21**	76.34**	101.15**	37.01
BML-7 X BML-2910	28.12**	17.03**	30.38**	36.70**	36.96
10. 100-seed weight (g)					
BML-6 X BML-2	3.37	4.46*	9.28**	15.28**	29.66
BML-6 X BML-7	2.14	3.22	20.53**	37.93**	29.30
CM-211 X BML-5233-5	0.35	1.41	29.08**	47.89**	28.79
BML-15 X BML-2910	-1.28	-0.23	53.64**	56.96**	28.32
BML-5233-5 X BML-7	-2.56	-1.53	53.79**	60.15**	27.96
11. Grain yield per plant (g)					
BML-15 X BML-2910	42.79**	22.40**	205.13**	226.21**	161.89
BML-6 X BML-3044	27.80**	9.55*	113.72**	141.68**	144.90
BML-2782 X BML-7	24.71**	6.9	113.18**	191.59**	141.39
BML- 7 X BML-3044	20.50**	3.29	106.00**	130.72**	136.62
CM-211 X BML-7	12.52**	-3.55	92.36**	138.61**	127.58

Table 6. The top hybrids identified based on overall performance in the present investigation

Hybrid	Average Heterosis	Hetero beltios	Standard Heterosis		Mean performance	*sca* effect an	Stability
			Over DHM-117	Over 900M Gold			
BML- 15 X BML-2910	226.21**	205.13**	42.79**	22.40**	161.89	75.53**	Stable
BML-6 X BML-3044	141.68**	113.72**	27.80**	9.55**	144.90	38.91**	Stable
BML-2782 X BML-7	191.59**	113.18**	24.71**	6.90	141.39	35.63**	Stable
BML-7 X BML-3044	130.72**	106.00**	20.50**	3.29	136.62	30.66**	Stable
CM-211 X BML-7	138.61**	92.36**	12.52**	-3.55	127.58	29.43**	Stable
CM-211 X BML-6	133.08**	86.35**	11.44**	-4.48	126.34	28.16**	Stable
BML-5322-5 X BML-3044	101.00**	70.52**	12.49**	-3.58	127.53	28.10**	Stable
BML-6 X BML -2	99.43**	88.12**	12.50**	-3.57	127.54	20.51**	Stable
BML -2782 X BML-6	158.19**	87.46**	12.10**	-3.91	127.10	21.31**	Stable

5, CM- 211 X BML-5233-5 and BML-2486 X BML-2. These results are in confirmation with findings of Kalsy and Sharma (1970), Murthy *et al.* (1981), Appunu *et al.* (2007), Bhavana *et al.* (2011), Ram Reddy *et al.* (2011) and Rajesh *et al.* (2014) and Ruswandi *et al*. (2015).

Plant height (cm)

For plant height the range of heterosis, heterobeltiosis and standard heterosis varied from -10.31 to 78.98, -16.69 to 54.60, -35.17 to 22.32 per cent over DHM-117 and -32.68 to 27.02 per cent over 900 M Gold respectively, with 37, 29, 3 and 4 crosses exhibiting positive significant heterosis, heterobeltiosis and standard heterosis over DHM-117 and 900 M Gold respectively. The hybrids, CM-211 X BML-15, BML-7 X BML-3044 and BML-2 X BML-3044 recorded high standard heterosis over two checks, DHM-117 and 900 M Gold. Whereas the hybrid BML-15 X BML-2910 recorded high average heterosis along with *per se* performance (Table 5). The best hybrid for heterobeltiosis recorded was CM-211 X BML-15. The results were in comparable with findings of Chattopahdyay and Dhiman (2005), Muraya *et al.* (2006), Appunu *et al.* (2007), Devi *et al.* (2007), Frascaroli *et al.* (2007), Ram Reddy *et al.* (2011), Melkamu *et al.* (2013) and Asif *et al.* (2014).

Ear height (cm)

Higher ear height is a desirable feature of maize hybrids. For this trait as many as 31 hybrids recorded significant positive heterosis with range of -19.37 to 103.04 per cent and 24 hybrids for heterobeltiosis with a range of -26.33 to 92.82. However, 16 hybrids registered significant positive standard heterosis over check DHM-117 with a range of -35.92 to 32.36 per cent and -21.71 to 61.70 per cent over 900 M Gold. The hybrid BML-6 X BML-2910 recorded high average heterosis for this trait. Whereas the hybrid CM-211 X BML-3044 recorded high heterobeltiosis, high standard heterosis over DHM-117 and 900 M Gold along with high *per se* performance. The performance of the hybrid, CM-211 X BML-6 was stable over locations. These results are comparable with findings Muraya *et al.* (2006), Bhavana *et al.* (2011), Ram Reddy *et al.* (2011), Farhan *et al.* (2012) and Abdel *et al*. (2014).

Ear girth (cm)

Out of 45 hybrids, 38 hybrids for heterosis, 26 for heterobeltiosis and two hybrids over DHM-117 and 900 M Gold for ear girth was observed in the range of -7.10 to 38.95, -9.99 to 32.82, -21.48 to 9.49 and -21.05 to 10.09 per cent, respectively. The promising hybrids for this trait are CM-211 X BML-6 and BML-7 X BML-3044 with high standard heterosis and *per se* performance. Whereas the hybrid BML-7 X BML-3044 recorded high heterobeltiosis and stable over locations. In addition to this the hybrids BML-2486 X BML-6 and BML-6 X BML-7 recorded high heterosis along with *per se* performance. Heterotic pattern of ear girth was also observed by Saidaiah *et al.* (2008), Bhavana *et al.* (2011), Ram Reddy *et al.* (2011), Farhan *et al.* (2012) and Abdel *et al*. (2014).

Ear length (cm)

In respect to ear length, the heterosis was ranged from 0.15 to 74.07 per cent with 38 crosses registering significant positive heterosis. Whereas heterobeltiosis in 24 hybrids with a range of -20.72 to 59.14 per cent. However, six crosses over DHM-117 and 5 over 900 M Gold exhibited positive and significant standard heterosis which ranged from -28.60 to 19.07 and -29.33 to 17.85 percent. The crosses, BML-2486 X BML-2, BML-15 X BML-2910, BML-7 X BML-2910, CM-211 X BML-7 and BML-7 X BML-3044 exhibited high standard heterosis, heterobeltiosis, average heterosis and along with *per se* performance. Three hybrids BML-15 X BML-2910, BML-7 X BML-3044 and CM-211 X BML-7 were found to be highly consistent over locations. The present results were comparable with findings of Saidaiah *et al.* (2008), Bhavana *et al.* (2011), Ram Reddy *et al.* (2011), Rajesh *et al.* (2014) and Ruswandi *et al*. (2015).

Number of kernel rows per ear

The character number of kernel rows per ear recorded positive significant average heterosis in 18 hybrids and it ranged from -6.10 to 28.98 per cent. The significant heterobeltiosis was observed in nine hybrids with a range from -14.10 to 27.08 per cent. However, the positive significant standard heterosis was observed in seven hybrids ranging from 7.44 to 21.04, six hybrids ranging from -9.51 to 18.33 per cent over DHM-117 and 900 M Gold, respectively. The highest standard heterosis was recorded in CM-211 X BML-5233-5 along with *per se* and high heterobeltiosis. The hybrids BML-2782 X BML-5233-5, BML-2486 X BML-3044, BML-5233-5 X BML-2910 and CM-211 X BML-3044 also recorded high standard heterosis along with *per se* performance. Similar kind of heterotic pattern was observed by Singh *et al.* (2010), Bhavana *et al.* (2011), Ram Reddy *et al.* (2011), Melkamu *et al.* (2013) and Abdel *et al*. (2014).

Number of kernels per row

Out of 45 crosses, 42 crosses recorded positive significant average heterosis and it ranged from -3.65 to 101.15 per cent while, the significant heterobeltiosis was ranged in 29 hybrids, with a range of -29.33 to 83.84 per cent. However, the significant standard heterosis was recorded in 19 hybrids, over DHM-117 and nine hybrids over 900 M Gold with a range of -22.69 to 40.37 percent and -29.38 to 28.22 per cent, respectively. The cross BML-6 x BML-3044 registered high heterosis and heterobeltiosis. However the high standard heterosis with *per se* performance was observed in the crosses were BML-15 X BML- 2910, BML-7 X BML-3044, BML- 2486 X BML-2 and BML-6 X BML-3044. These results are comparable with findings of Chattopadhyay and Dhiman (2005), Ram Reddy *et al.* (2011), Melkamu *et al.* (2013), Abdel *et al*. (2014) and Imdad *et al*.(2014).

100-seed weight (g)

100-seed weight is one of the important grain characters. Grains, the ultimate economic product from the maize plant are the net result of various components. The total yield in maize is influenced by several grain component characters. 100-seed weight in pooled analysis recorded positive significant average heterosis in 37 hybrids and it ranged from -19.66 to 60.15 per cent. The significant heterobeltiosis was observed in 27 hybrids, with a range from -22.67 to 53.79 per cent. Positive significant standard heterosis was observed in none of the hybrids, ranging from -40.16 to 3.37 per cent when compared with check DHM-117. While over 900 M Gold check, only one hybrid recorded positively significant standard heterosis with a range of -39.53 to 4.46 per cent. None of the hybrid was observed with significant standard heterosis over DHM-117 and only one hybrid exhibited high significant standard heterosis over 900 M Gold. The hybrids with high heterosis, heterobeltiosis and *per se* performance are BML-5233-5 X BML-7, BML-15 X BML-2910, CM-211 X BML-5233-5, BML-6 x BML-7 and BML-6 X BML-2. These results are in comparable with findings of Singh *et al.* (2010), Bhavana *et al.* (2011), Ram Reddy *et al.* (2011), Sumalini and Shobha Rani (2011), Farhan *et al.* (2012) and Abdel *et al*. (2014).

Grain yield per plant (g)

Grain yield per plant is the important yield characters. Grain yield is a complex quantitative character which is influenced by other ancillary and component characters. Hence all changes in the components would not be expressed as changes in yield but all changes in yield would be accompanied by changes in one or more components. The present investigation revealed a high order of heterosis for grain yield per plant. Forty three hybrids manifested significant positive heterosis ranging from -16.75 (BML-15 X BML-3044) to 226.21 per cent (BML-15 X BML-2910). The significant heterobeltiosis was recorded in 41 hybrids, with a range of -38.94 (BML-5233-5 X BML-2486) to 205.13 per cent (BML-15 X BML-2910). Nine hybrids over DHM-117 and two over 900 M Gold registered significant positive standard heterosis in pooled analysis. The hybrid which exhibited highest heterosis over DHM-117 and 900 M Gold, was BML-15 X BML-2910 (42.79% and 22.40%) followed by BML-6 X BML-3044 (27.80% and 9.55%), but only on DHM-117 was BML-2782 X BML-7 (24.71%), BML-7 X BML-3044 (20.50) and CM-211 X BML-7 (12.52). These results are in comparable with findings of Devi and Prodhan (2004), Premalatha, and Kalamani (2010), Singh *et al.* (2010), Sultan *et al.* (2010), Bhavana *et al.* (2011), Ram Reddy *et al.* (2011), Farhan *et al.* (2012), Melkamu *et al.* (2013), Abdel *et al*. (2014), Asif *et al.* (2014), Imdad *et al*.(2014), Rajesh *et al.* (2014) and Ruswandi *et al*.(2015).

Grain yield per plant is a multiplicative product of several basic components of yield. The increased grain yield is definitely because of increase in one or more than one yield components. The major reason of high degree of heterosis was due to genetic divergence in the parents, though the predominance of dominant gene action was operating in the inheritance of traits. Among these top five crosses, BML-15 X BML-2910 also registered significant positive standard heterosis for number of kernels per row. This indicates the yield attributes helped the hybrids to get high heterosis for grain yield per plant. Similarly other hybrids which manifested significant standard heterosis for this trait were BML-6 X BML-2, BML-5233-5 X BML-3044, BML-2782 X BML-6, CM-211 X BML-6 and BML-6 x BML-7 and were also supported by different quantitative traits with significant standard heterosis over DHM-117.

The cross BML-15 X BML-2910 possessed high *per se* performance (161.89g), significant positive high *sca* effect (75.53), significant standard heterosis (42.79%), significant average heterosis (226.21%) and significant heterobeltiosis (205.13%) over the check DHM-117 for grain yield per plant. Besides grain yield, the cross also showed high *per se* performance, significant positive *sca* effects and standard heterosis for other yield contributing characters like number of kernels per row. This hybrid was stable over locations for grain yield per plant. The next best hybrid was BML-7 X BML-3044 early maturing with high grain yield per plant of 136.62 g, with *sca* effect (30.66), significant standard heterosis (20.50%) over DHM-117, significant average heterosis (130.72%) and significant heterobeltiosis (106.00%) over the check DHM-117 and this hybrid was stable over locations for grain yield, number of kernels per row, plant height, number of kernel rows per ear, ear length and ear girth. The another hybrid, CM-211 X BML-7 with high grain yield per plant of 127.58 g, with *sca* effect (29.43), significant standard heterosis (12.52%), significant average heterosis (138.61%) and significant heterobeltiosis (92.36%) and this hybrid was stable was over locations for grain yield per plant, and ear girth. The hybrid, BML-6 X BML-2 with grain yield per plant of (127.54), with *sca* effect (20.51), significant standard heterosis (12.50%), significant average heterosis (99.43%) and significant heterobeltiosis (88.12%) and this hybrid was stable over locations for grain yield and 100-seed weight. Whereas the hybrid, BML-2782 X BML-6 with gain yield per plant (127.1), with *sca* effect (21.31), significant standard heterosis over DHM-117(12.10%), significant average heterosis (158.19%) and significant heterobeltiosis (87.46%) and this hybrid was stable over locations for grain yield per plant and ear girth (Table 6).

Conclusion

The overall results of heterosis, heterobeltiosis and standard heterosis indicated that the parents involved in the crossing should have one high *per se* performing parent and over dominance may be the cause of heterosis. The main reason ascribed in diversified parents involved in the cross combinations or uncommon genes for a trait is the cause to exploit the maximum exploitable level of heterosis in maize. It can be clearly brought out that the five cross combinations *viz.,* BML-15 X BML-2910, BML-7 X BML-3044, CM-211 X BML-7, BML-6 X BML-2 and BML-2782 X BML-6 with more than 12% standard heterosis for grain yield over high yielding commercial check DHM-117 offers greater scope for exploitation of the hybrid vigour on commercial scale. The large scale testing of these hybrids in All India Coordinated Maize Improvement Project (AICMIP) trials may result in commercial release in near future and thereby help in accelerating the rate of adoption of maize hybrids in the India.

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