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PERFORMANCE, HETEROSIS AND HERITABILITY IN SINGLE, THREE-WAY AND DOUBLE CROSS HYBRIDS OF MAIZE (*Zea mays* L.).

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ABSTRACT

Performance, heterosis and heritability were studied in a set of single, three-way and double crosses involving seven inbreds for thirteen yield and yield contributing characters across three locations. Three-way crosses and double crosses were found to be more variable than single crosses for days to maturity, ear diameter, number of kernels row^{-1} and grain yield and are more advantageous when crop is grown under adverse climatic conditions and had shown stable and consistent performance. Heterosis estimates were low for majority of the traits studied in all the three classes of hybrids. Narrow sense heritability was moderate for 50 per cent tasseling, days to 50 per cent silking, number of kernel rows ear^{-1}, and shelling percentage and low for ear length, ear diameter, number of kernels row^{-1},grain and fodder yield at all the individual locations indicating predominance of dominant gene action. From all the three classes of crosses, one each of superior single [SC-2; BML-51 × BML-14], three-way [TWC-51; (BML-32 × BML-6) × BML-51] and double [DC-18; (BML-51 × BML-14) × (BML-10 × BML-7)] cross hybrids were identified based on high *per se* performance at least in two locations.

INTRODUCTION

Maize (*Zea mays* L.) is the most versatile crop among cereals with respect to its adaptability, types and uses. Among the maize growing countries India ranks 4th in area and 7th in production. Maize is majorly used for food and feed for poultry and live stock and raw material for industrial products. In India, maize sector had shown rapid growth in the last two decades due to extensive cultivation of single cross hybrids. However, during rainy season the crop is grown under unfavourable ecology in most parts of the country and it is likely that the single cross hybrids may succumb to weather aberrations. As against this, three-way and double crosses perform better due to population buffering and mitigate the yield losses to some extent. Hybrids are the progeny from hybridization between two or more pure line varieties or open pollinating cultivars. They can be single, double and three-way or crosses. Although, Cokerham (1961) reported that the expected genetic variance and predicted yield potential declined from single to three-way, to double, and to top crosses from the study of all possible hybrids from a given set of inbred lines, many other researchers (Otsuka *et al*., 1972; Dimchovski *et al*., 1979; Ivakhnenko and Zubko, 1986) had also found the superior performance of three-way and double crosses in a given set of environments. On the contrary, in his study on performance of 36 each of the single cross hybrids, three-way crosses and double crosses (Weatherspoon, 1970) observed that single crosses produced highest grain yields followed by three-way and double cross hybrids.

Heterosis or hybrid vigor refers to the superior performance of a hybrid relative to its parents. Shull (1908) suggested the concept of increase in performance of hybrids over mean of its two homozygous parents for growth and physiological characters in maize. Diversity among inbred source populations is an important factor in determining combining ability among inbred lines and heterosis revealed by the hybrids, where a more diverse combination is expected to produce more superior hybrids (Dhawan and Singh, 1961; Prasad and Singh, 1986).

Heritability, a measure of the genetic variation in a population relative to the total phenotypic variation of a trait, is very much influenced by the methods of determination and the genotypes used. Its estimation is normally specific to the materials used, and the place and time of the evaluation. Therefore, in the present investigation a set of newly synthesized inbred lines were used to produce single, three-way and double cross hybrids with a view to assess the performance and estimate heterosis and heritability of the three classes of hybrids and to identify the best hybrid combinations for future maize breeding programs.

MATERIALS AND METHODS

To study the performance, heterosis and heritability in single, three-way and double cross hybrids of maize, seven newly developed inbreds viz., BML-51, BML-32, BML-14, BML-13, BML-10, BML-7 and BML-6 at Maize Research Centre, Rajendranagar, Hyderabad were crossed in diallel fashion (Griffing, 1956 Method I Model II) and obtained twenty one single crosses (SC's) during kharif, 2014. Later these F1's were involved in crosses with inbreds such that no parent appeared twice in the same cross and obtained 105 three-way crosses (TWC's). Similarly, single crosses from diallel set were crossed with restriction that only unrelated crosses were involved in crossing programme and obtained 105 double crosses (DC's). Single crosses were obtained during *kharif* 2014 while three-way crosses and double crosses were obtained during *rabi* 2014-15 at ARS, Karimnagar.

During *kharif* 2015, the experimental material comprising of seven parents, twenty one single crosses and 105 each of three-way and double crosses and eighteen public /private checks were evaluated at three locations *viz*., MRC, ARI, Rajendranagar, ARS, Karimnagar and RARS, Palem. All these 256 entries were laid out in balanced lattice (16 × 16) in two replications at each location and crop was managed in accordance with the recommended schedule (Vyavasaya panchangam, 2015) to raise a good crop. All the three classes of hybrids were serially numbered to denote single cross as SC-1 to SC-21, three-way cross as TWC-1 to TWC-105 and double cross as DC-1 to DC-105.However, in the present paper results pertaining to only top ranking hybrids were discussed. The data was recorded on ten randomly selected plants for plant height (cm), ear height (cm), ear length (cm), ear diameter (cm), number of kernel rows ear^{-1}and number of kernels row^{1}, whereas for days to 50 per cent tasseling, days to 50 per cent silking, days to maturity, test weight (100-grain weight (g)), shelling percentage (%), grain yield (kg ha^{-1}) and fodder yield (kg plot^{-1}) data was recorded on plot basis. Grain yield and fodder yield (kg plot^{-1}) were corrected for stand variation using the methodology of covariance (Mendes, 2015). In case of grain yield, hand harvested shelled corn of each entry was adjusted to 15.5 moisture in kg ha^{-1} similar to grain yield in bushels per acre at 15.5 moisture (Lauer, 2002).

Data from individual location was subjected to analysis of variance (ANOVA) to determine the effects of the genotypes evaluated. Standard errors were computed to compare mean performances of the hybrids with popular checks. Heterosis was estimated by the method of Turner (1953) and significance was tested using t-test suggested by Wynne *et al*. (1970). Broad-sense heritability was estimated according to Becker *et al*. (1982) and estimation and prediction of genetic ratio was done as per Baker (1978).

The formulae used were as follows:

Heterosis (SC) (%) = (F1-SC/ SC) × 100

where F1 = performance of F1, SC = performance of standard check

Significance of heterosis was tested by't' test as follows

t = F1-SC /SE of heterosis over check

SE = [2Me/r]1/2

$h^2B = \sigma^2G/\sigma^2P$

where

$\sigma^2G = [(r\,\sigma^2G + \sigma^2e) - \sigma^2e]/ r$

$\sigma^2P = \sigma^2G + \sigma^2e$

$= (MSG - MSe)r + MSe$

and h^2B = broad-sense heritability, σ^2G = genotypic variance, σ^2P = phenotypic variance, σ^2e = environmental variance, MSG = mean squares for genotypes in ANOVA, MSe = mean squares for error in ANOVA and r = number of replications.

Genetic ratio = $2\,\sigma^2gca/ (2\,\sigma^2gca + \sigma^2sca)$

where, σ^2gca = gca variance, σ^2sca = sca variance

Degree of dominance was estimated by adopting the formula:

$$\sqrt{\frac{\sigma^2\ sca}{2\sigma^2 gca}}$$

RESULTS AND DISCUSSION

Analysis of variance revealed highly significant variation ($P < 0.01$) among the genotypes of parents and crosses at all three locations indicating that the genotypes were genetically

Table 1: ANOVA for grain yield (kg ha^{-1}) at three locations

Source	d.f.	Karimnagar	Hyderabad	Palem
Replicates	1	227176	643392	9186.77
Varieties	242	2249385**	2904540**	2164733**
Double	104	1001953**	1969411**	1411619**
Triple	104	1603903**	1725177**	1901749**
Single	20	1847246**	1689209**	1473536**
Parent	6	596310	132623	478155
Cross	4	1753355**	1830028**	2299516**
Double Vs Triple	1	4544592**	8411043**	242833
Double Vs Single	1	5226962**	6398607**	813562
Double Vs Parent	1	224424016**	255195680**	135077648**
Double Vs Cross	1	92675	4880915**	3775
Triple Vs Single	1	1113989	17673332**	381269
Triple Vs Parent	1	202409856**	223486848**	131058232**
Triple Vs Cross	1	114472	1781804	7593
Single Vs Parent	1	147549392**	245668816**	98034952**
Single Vs Cross	1	669534	10545583**	141964
Parent Vs Cross	1	95047128**	79616784**	59292548**
Error	242	489323	510618	498574

*, **: Significant at 5% and 1% level, respectively

Table 2: Mean performance of top ten high yielding hybrids for yield and yield contributing characters at individual locations

Location: Karimnagar Hybrid No. & Parentage		DT	DS	DM	PLHT (cm)	EHT (cm)	EL (cm)	ED (cm)	NKRE	NKRR	TW (g)	Sh (%)	GY(kg ha^{-1})	FY (kg plot^{-1})
SC-2 (BML-51	Mean	52	55	88	195	98.5	18.8	4.16	12.7	31.55	36.985	81.8	8553	3.259
× BML-14)	Het (%)	-0.95	1.85	-1.12	9.55	22.36*	-14.74**	-7.56	-8.63	-20.73**	40.92**	-1.51	8.74	30.68*
DC-53 (BML-51	Mean	51	52.5	84.5	219	123.5	19.85	4.24	12.9	35.25	35.275	81.35	8549	4.226
× BML-6) × (B	Het (%)	-2.86	-2.78	-5.06	23.03**	53.42**	-9.98	-5.78	-7.19	-11.43*	34.41**	-2.05	8.69	69.47**
ML-32 × BML-10)														
TWC-20 (BML-51	Mean	51.5	54	88.5	184	99.5	19.15	4.465	14	33.85	33.41	80.1	8313	3.492
× BML-10) × BML-6	Het (%)	-1.9	0	-0.56	3.37	23.6	-13.15**	0.78	0.72	-14.95*	27.3	-3.55	5.68	40.01*
TWC-52 (BML-32	Mean	51.5	53	83	195	101.5	23.1	4.54	13.3	36.9	35.355	81.9	8284	3.6
× BML-6) × BML-14	Het (%)	-1.9	-1.85	-6.74	9.55	26.09*	4.76	0.89	-4.32	-7.29	34.71*	-1.38	5.31	44.36*
TWC-2 (BML-51	Mean	53.5	55	81.5	186	89	20.7	4.145	13	33.9	33.195	81.9	8240	3.451
× BML-32) × BML-13	Het (%)	1.9	1.85	-8.43*	4.49	10.56	-6.12	-7.89	-6.47	-14.82*	26.48	-1.38	4.76	38.37
TWC-67 (BML-14	Mean	56.5	57	89.5	187.5	83	21.7	4.4	13.2	34.55	32.885	81.3	8222	3.465
× BML-7) × BML-32	Het (%)	7.62*	5.56	0.56	5.34	3.11	-1.59	-2.22	-5.04	-13.19*	25.3	-2.11	4.53	38.95*
DC-17 (BML-51 ×	Mean	48.5	52	81	175.5	91	19.6	4.475	14.4	33.8	31.865	80.55	8157	3.124
BML-14) × (BML	Het (%)	-7.62*	-3.7	-8.99*	-1.4	13.04	-11.11*	-0.56	3.6	-15.08**	21.41*	-3.01	3.71	25.26*
-13 × BML-6)														
DC-22 (BML-51	Mean	52.5	53.5	88.5	191.5	92	19.6	4.18	13.6	35.25	29.94	81.35	8046	3.195
× BML-13) × (B	Het (%)	0	-0.93	-0.56	7.58	14.29	-11.11*	-7.11	-2.16	-11.43*	14.08	-2.05	2.29	28.12*
ML-32 × BML-10)														
DC-7 (BML-51 ×	Mean	51.5	53.5	82	182.5	92.5	19.75	4.215	13.6	36.2	30.875	81.05	8040	3.458
BML-32) × (BM	Het (%)	-1.9	-0.93	-7.87*	2.53	14.91	-10.43*	-6.33	-2.16	-9.05	17.64	-2.41	2.21	38.65**
L-13 × BML-6)														
TWC-51 (BML-	Mean	52.5	55	84	207	105	20.9	4.315	13	34.9	31.04	80	8028	3.612
32 × BML-6) ×	Het (%)	0	1.85	-5.62	16.29**	30.43*	-5.22	-4.11	-6.47	-12.31*	18.27	-3.67	2.06	44.82*
BML-51														
Ekka 2288	Mean	52.5	54	89	178	80.5	22.05	4.5	13.9	39.8	26.245	83.05	7866	2.494
S.E. ±		1.2	1.1	2.3	7.1	7	0.8	0.1	0.4	1.6	2.5	1.3	494.6	0.3

Table 2: Continued

Location: Karimnagar Hybrid No. & Parentage		DT	DS	DM	PLHT (cm)	EHT (cm)	EL (cm)	ED (cm)	NKRE	NKRR	TW (g)	Sh (%)	GY (kg ha^{-1})	FY (kgplot^{-1})
SC-2 (BML-51 × BML-14)	Mean	52	55	88	195	98.5	18.8	4.16	12.7	31.55	36.985	81.8	8553	3.259
	Het (%)	-0.95	1.85	-1.12	9.55	22.36*	-14.74**	-7.56	-8.63	-20.73**	40.92**	-1.51	8.74	30.68*
DC-53(BML-51 × BML-6) × (BML-32 × BML-10)	Mean	51	52.5	84.5	219	123.5	19.85	4.24	12.9	35.25	35.275	81.35	8549	4.226
	Het (%)	-2.86	-2.78	-5.06	23.03**	53.42**	-9.98	-5.78	-7.19	-11.43*	34.41**	-2.05	8.69	69.47**
TWC-20 (BML-51 × BML-10) × BML-6	Mean	51.5	54	88.5	184	99.5	19.15	4.465	14	33.85	33.41	80.1	8313	3.492
	Het (%)	-1.9	0	-0.56	3.37	23.6	-13.15**	0.78	0.72	-14.95*	27.3	-3.55	5.68	40.01*
TWC-52 (BML-32 × BML-6) × BML-14	Mean	51.5	53	83	195	101.5	23.1	4.54	13.3	36.9	35.355	81.9	8284	3.6
	Het (%)	-1.9	-1.85	-6.74	9.55	26.09*	4.76	0.89	-4.32	-7.29	34.71*	-1.38	5.31	44.36*
TWC-2 (BML-51 × BML-32) × BML-13	Mean	53.5	55	81.5	186	89	20.7	4.145	13	33.9	33.195	81.9	8240	3.451
	Het (%)	1.9	1.85	-8.43*	4.49	10.56	-6.12	-7.89	-6.47	-14.82*	26.48	-1.38	4.76	38.37
TWC-67 (BML-14 × BML-7) × BML-32	Mean	56.5	57	89.5	187.5	83	21.7	4.4	13.2	34.55	32.885	81.3	8222	3.465
	Het (%)	7.62*	5.56	0.56	5.34	3.11	-1.59	-2.22	-5.04	-13.19*	25.3	-2.11	4.53	38.95*
DC-17 (BML-51 × BML-14) × (BML-13 × BML-6)	Mean	48.5	52	81	175.5	91	19.6	4.475	14.4	33.8	31.865	80.55	8157	3.124
	Het (%)	-7.62*	-3.7	-8.99*	-1.4	13.04	-11.11*	-0.56	3.6	-15.08**	21.41*	-3.01	3.71	25.26*
DC-22 (BML-51 × BML-13) × (BML-32 × BML-10)	Mean	52.5	53.5	88.5	191.5	92	19.6	4.18	13.6	35.25	29.94	81.35	8046	3.195
	Het (%)	0	-0.93	-0.56	7.58	14.29	-11.11*	-7.11	-2.16	-11.43*	14.08	-2.05	2.29	28.12*
DC-7 (BML-51 × BML-32) × (BML-13 × BML-6)	Mean	51.5	53.5	82	182.5	92.5	19.75	4.215	13.6	36.2	30.875	81.05	8040	3.458
	Het (%)	-1.9	-0.93	-7.87*	2.53	14.91	-10.43*	-6.33	-2.16	-9.05	17.64	-2.41	2.21	38.65**
TWC-51 (BML-32 × BML-6) × BML-51	Mean	52.5	55	84	207	105	20.9	4.315	13	34.9	31.04	80	8028	3.612
	Het (%)	0	1.85	-5.62	16.29**	30.43*	-5.22	-4.11	-6.47	-12.31*	18.27	-3.67	2.06	44.82*
Ekka 2288	Mean	52.5	54	89	178	80.5	22.05	4.5	13.9	39.8	26.245	83.05	7866	2.494
S.E±		1.2	1.1	2.3	7.1	7	0.8	0.1	0.4	1.6	2.5	1.3	494.6	0.3

Table 2: Continued.....

Location: Palem

Hybrid No. & Parentage		DT	DS	DM	PLHT (cm)	EHT (cm)	EL (cm)	ED (mm)	NKRE	NKRR	TW (g)	Sh (%)	GY (kg ha^{-1})	FY (kgplot^{-1})
TWC-51(BML	Mean	56.5	58	97	219.5	121.5	21.55	4.525	13.4	40	39.5	84.85	10463	4.535
-32 × BML-6)	Het (%)	-1.74	-1.69	1.04	-0.68	10.45	11.37	-5.14	-0.74	17.47*	-2.35	6.60**	10.11	43.97**
× BML-51														
TWC-71 (BMLMean	54.5	56.5	95	213.5	113.5	20.6	4.575	13.3	35.75	40.9	84.3	10172	5.09	
-14 × BML-6)	Het (%)	-5.22	-4.24	-1.04	-3.39	3.18	6.46	-4.09	-1.48	4.99	1.11	5.90**	7.05	61.59**
× BML-51														
TWC-82 (BMLMean	60	64	97.5	207	104.5	22.1	4.7	13.9	40.25	33	85.7	10125	3.125	
-13 × BML-7)	Het (%)	4.35	8.47	1.56	-6.33	-5	14.21*	-1.47	2.96	18.21*	-18.42*	7.66**	6.55	-0.78
× BML-32														
DC-18 (BML	Mean	55	57.5	95.5	204.5	108	19.85	4.54	13.2	35.3	41.7	79	10054	3.845
-51 × BML-14)	Het (%)	-4.35	-2.54	-0.52	-7.47	-1.82	2.58	-4.82	-2.22	3.67	3.09	-0.75	5.8	22.06
× (BML-10 ×														
BML-7)														
TWC-6 (BML Mean	57.5	60.5	97.5	217	105	20.25	4.445	13.2	40	37.05	84.25	9938	3.78	
-51 × BML-14)	Het (%)	0	2.54	1.56	-1.81	-4.55	4.65	-6.81	-2.22	17.47*	-8.41	5.84**	4.59	20
× BML-32														
DC-23 (BML	Mean	57	59	97.5	223.5	120.5	21.55	4.57	14.4	38.2	38.9	83.85	9938	3.505
-51 × BML-13)	Het (%)	-0.87	0	1.56	1.13	9.55	11.37**	-4.19	6.67	12.19	-3.83	5.34*	4.59	11.27
× (BML-32														
× BML-7)														
SC-6 (BML	Mean	54	57.5	95.5	211.5	118.5	20.95	4.665	13.3	40.65	36.7	84.3	9641	2.92
-51 × BML-6)	Het (%)	-6.09	-2.54	-0.52	-4.3	7.73	8.27	-2.2	-1.48	19.38	-9.27	5.90**	1.46	-7.3
DC-16 (BML	Mean	55.5	57	96.5	183.5	95	20.35	4.595	13.3	36.45	41.15	82.8	9627	2.795
-51 × BML-14)	Het (%)	-3.48	-3.39	0.52	-16.97**	-13.64	5.17	-3.67	-1.48	7.05	1.73	4.02	1.31	-11.27
× (BML-13 ×														
BML-7)														
TWC-9 (BML	Mean	57	59	96	215.5	110.5	18.95	4.56	13.1	32.4	39	80.4	9541	2.85
-51 × BML-14)	Het (%)	-0.87	0	0	-2.49	0.45	-2.07	-4.4	-2.96	-4.85	-3.58	1.01	0.41	-9.52
× BML-7														
TWC-10 (BML	Mean	57	58.5	94	205.5	109.5	18.85	4.6	13.9	34.4	36.35	83.25	9428	3.45
-51 × BML-14)	Het (%)	-0.87	-0.85	-2.08	-7.01	-0.45	-2.58	-3.56	2.96	1.03	-10.14	4.59*	-0.78	9.52
× BML-6														
KNMH(-4010131)	Mean	57.5	59	96	221	110	19.35	4.77	13.5	34.05	40.45	79.6	9502	3.15
S.EE±		2.1	2.1	1	7.1	5.4	0.8	0.1	0.4	2.2	2.5	1.1	499.3	0.4

Note: *, **: Significant at 5% and 1% level, respectively

SC: Single cross, TWC: Three-way cross, DC: Double cross, DT: Days to 50 per cent tasseling, DS: Days to 50 per cent silking, DM: Days to maturity, PLHT: Plant height, EHT: Ear height, EL: Ear length, ED: Ear diameter, NKRE: Number of kernel rows ear^{-1}, NKRR: Number of kernels row^{-1}, TW: Test weight, Sh (%): Shelling percentage, GY: Grain yield, FY: Fodder yield.

Table 3: Range of mean and heterosis in single, three-way and double crosses for yield and yield contributing characters at locations

Character	Range	Single crosses			Three-way crosses			Double crosses		
		Hyderabad	Karimnagar	Palem	Hyderabad	Karimnagar	Palem	Hyderabad	Karimnagar	Palem
Days to 50% tasseling	Mean	53.5 to 61.0	46.0 to 58.0	51.0 to 63.0	53.0 to 60.5	48.0 to 57.5	50.0 to 63.5	54.0 to 60.5	48.5 to 57.0	50.5 to 64.0
	Het (%)	-6.96 to 6.09	-12.38 to 10.48	-11.30 to 9.57	-7.83 to 5.22	-8.57 to 9.52	-13.04 to 10.43	-6.09 to 5.22	-7.62 to 8.57	-12.17 to 11.30
Days to 50% silking	Mean	56.5 to 63.5	48.5 to 59.5	53.0 to 65.0	55.0 to 62.5	50.0 to 60.0	54.0 to 67.0	56.0 to 62.5	50.5 to 59.0	54.5 to 67.0
	Het (%)	-5.83 to 5.83	-10.19 to 10.19	-10.17 to 10.17	-8.33 to 4.17	-7.41 to 11.11	-8.47 to 13.56	-6.67 to 4.17	-6.48 to 9.26	-7.63 to 13.56
Days to maturity	Mean	92.0 to 102.0	79.0 to 92.0	91.0 to 98.0	90.0 to 101.0	78.5 to 90.5	93.0 to 98.5	90.0 to 100.5	80.5 to 92.0	92.0 to 98.5
	Het (%)	-4.17 to 6.25	-11.24 to 3.37	-5.21 to 2.08	-6.25 to 5.21	-11.80 to 1.69	-3.13 to 2.60	-6.25 to 4.69	-9.55 to 3.37	-4.17 to 2.60
Plant height (cm)	Mean	170.5 to 227.0	128.0 to 195.0	141.5 to 214.0	165.5 to 232.0	131.0 to 207.0	152.5 to 230.5	164.5 to 226.0	144.5 to 219.0	160.0 to 223.5
	Het (%)	-3.94 to 27.89	-28.09 to 9.55	-35.97 to -3.17	-6.76 to 30.70	-26.40 to 16.29	-31.00 to 4.30	-7.32 to 27.32	-18.82 to 23.03	-27.60 to 1.13
Ear height (cm)	Mean	89.5 to 124.0	59.0 to 99.0	73.0 to 118.5	83.5 to 129.5	55.5 to 109.0	76.0 to 122.0	81.5 to 125.5	58.5 to 123.5	84.0 to 120.5
	Het (%)	-5.79 to 30.53	-26.71 to 22.98	-33.64 to 7.73	-12.11 to 36.32	-31.06 to 35.40	-30.91 to 10.91	-14.21 to 32.11	-27.33 to 53.42	-23.64 to 9.55
Ear length (cm)	Mean	14.1 to 20.5	17.5 to 23.0	16.2 to 21.9	15.5 to 21.9	16.1 to 23.1	15.7 to 22.1	15.7 to 20.6	15.7 to 21.3	16.8 to 21.6
	Het (%)	-16.57 to 21.60	-20.63 to 4.08	-16.54 to 13.18	-8.58 to 29.59	-26.98 to 4.76	-19.12 to 14.21	-7.40 to 21.89	-28.80 to -3.40	-13.18 to 11.63
Ear diameter (cm)	Mean	4.3 to 5.0	3.6 to 4.6	4.0 to 4.8	4.0 to 4.8	3.8 to 4.9	3.8 to 4.9	4.0 to 4.8	3.3 to 4.6	4.0 to 4.8
	Het (%)	-7.99 to 7.78	-20.56 to 2.67	-15.62 to 1.15	-12.74 to 4.00	-16.11 to 8.00	-20.23 to 3.04	-13.82 to 4.43	-26.11 to 1.56	-15.20 to 1.68
No.of kernel rows ear^{-1}	Mean	13.0 to 16.2	11.8 to 15.1	12.0 to 14.6	12.4 to 16.0	12.3 to 15.9	12.1 to 15.5	13.1 to 16.4	12.6 to 15.3	11.9 to 14.9
	Het (%)	-12.16 to 9.46	-15.11 to 8.63	-11.11 to 8.15	-16.22 to 8.11	-11.51 to 14.39	-10.37 to 14.81	-11.49 to 10.81	-9.35 to 10.07	-11.85 to 10.37
No.of kernels row^{-1}	Mean	28.3 to 39.0	29.8 to 39.6	27.7 to 40.7	21.5 to 39.6	27.4 to 40.1	26.9 to 41.5	26.9 to 38.5	28.7 to 38.3	28.0 to 40.7
	Het (%)	-2.24 to 34.66	-25.25 to -0.5	-18.8 to 19.38	-25.69 to 36.55	-31.28 to 0.88	-21.00 to 21.88	-7.24 to 32.93	-27.89 to -3.89	-17.77 to 19.53
Test weight (g)	Mean	29.0 to 47.6	20.2 to 37.0	27.2 to 42.4	24.9 to 46.7	18.0 to 38.0	24.6 to 42.5	27.6 to 44.6	17.7 to 37.1	27.4 to 46.0
	Het (%)	-25.83 to 21.74	-22.94 to 40.92	-32.88 to 4.82	-36.32 to 19.44	-31.42 to 44.88	-39.18 to 4.94	-29.41 to 14.07	-32.60 to 41.46	-32.14 to 13.60
Shelling percentage (%)	Mean	79.3 to 87.8	75.4 to 84.2	77.1 to 85.5	76.7 to 87.0	73.8 to 85.3	74.9 to 87.0	79.5 to 86.7	76.0 to 83.3	78.5 to 86.4
	Het (%)	-4.05 to 6.17	-9.21 to 1.32	-3.2 to 7.41	-7.26 to 5.20	-11.20 to 2.65	-5.97 to 9.23	-3.81 to 4.90	-8.55 to 0.30	-1.44 to 8.61
Grain yield (kg ha^{-1})	Mean	5525 to 8746	4561 to 8553	6156 to 9641	3560 to 9090	4243 to 8313	5559 to 10463	3445 to 8891	4455 to 8549	5502 to 10054
	Het (%)	-27.27 to 15.12	-42.01 to 8.74	-35.21 to 1.46	-53.14 to 19.65	-46.06 to 5.68	-41.50 to 10.11	-54.65 to 17.03	-43.37 to 8.69	-42.10 to 5.80
Fodder yield (kg plot^{-1})	Mean	2.8 to 4.9	2.0 to 3.3	1.6 to 4.2	2.5 to 5.3	1.9 to 3.9	1.1 to 5.1	2.7 to 4.8	1.9 to 4.2	1.7 to 4.2
	Het (%)	-26.66 to 28.74	-20.45 to 30.68	-49.37 to 32.06	-35.24 to 37.58	-25.11 to 54.89	-65.40 to 61.59	-28.61 to 25.49	-23.01 to 69.47	-45.56 to 34.13

Table 4: Number of significant heterotic crosses in desirable direction in single, three-way and double crosses for yield and yield contributing traits at individual locations

Trait	Single crosses			Three-way crosses			Double crosses		
	Hyd	Knr	Plm	Hyd	Knr	Plm	Hyd	Knr	Plm
Days to 50% tasseling	2	3	-	20	11	6	9	1	4
Days to 50% silking	-	3	-	16	3	-	20	1	4
Days to maturity	1	11	2	9	39	-	8	24	10
Plant height (cm)	5	-	-	31	10	-	34	6	-
Ear height (cm)	2	3	-	25	15	-	33	8	-
Ear length (cm)	8	-	1	15	-	1	63	-	6
Ear diameter (cm)	1	-	-	-	-	-	-	-	-
Number of kernel rows ear^{-1}	1	-	2	3	10	9	2	1	3
Number of kernels row^{-1}	14	-	-	33	-	6	35	-	2
Test weight (g)	2	3	-	1	7	-	-	42	-
Shelling percentage (%)	1	-	13	7	-	48	8	-	49
Grain yield (kg ha^{-1})	-	-	-	-	-	-	4	-	-
Fodder yield (kg plot^{-1})	2	2	-	1	10	5	14	50	1

Note: Hyd-Hyderabad, Knr-Karimnagar, Plm-Palem

Table 5: Estimation of genetic components and genetic ratios of maize in 7 × 7 diallel at individual locations

Character	Location	σ^2 gca	σ^2 sca	σ^2 D	σ^2 H	h^2 narrow sense	h^2broad sense	σ^2 gca/ σ^2 sca	Degree of Dominance	Genetic Ratio
Days to 50 per cent tasseling	Hyderabad	2.18	4.11	4.35	4.11	0.45	0.87	0.53	0.97	0.51
	Karimnagar	3.24	10.36	6.47	10.36	0.36	0.94	0.31	1.26	0.38
	Palem	3.18	2.85	6.36	2.85	0.42	0.6	1.11	0.67	0.69
Days to 50 per cent silking	Hyderabad	1.83	3.91	3.66	3.91	0.4	0.83	0.47	1.03	0.48
	Karimnagar	2.79	8.47	5.57	8.47	0.38	0.95	0.33	1.23	0.4
	Palem	2.04	3.47	4.08	3.47	0.31	0.58	0.59	0.92	0.54
Days to maturity	Hyderabad	1.86	3.94	3.72	3.94	0.42	0.86	0.47	1.03	0.49
	Karimnagar	2.73	12.13	5.45	12.13	0.24	0.77	0.22	1.49	0.31
	Palem	0.54	0.59	1.08	0.59	0.36	0.55	0.92	0.74	0.65
Plant height (cm)	Hyderabad	184.21	863.24	368.42	863.24	0.28	0.94	0.21	1.53	0.3
	Karimnagar	196.54	380.72	393.08	380.72	0.47	0.92	0.52	0.98	0.51
	Palem	280.86	389.95	561.71	389.95	0.56	0.95	0.72	0.83	0.59
Ear height (cm)	Hyderabad	52.12	225.23	104.24	225.23	0.28	0.88	0.23	1.47	0.32
	Karimnagar	44.79	202.41	89.58	202.41	0.27	0.89	0.22	1.5	0.31
	Palem	100.08	129.63	200.15	129.63	0.57	0.94	0.77	0.8	0.61
Ear length (cm)	Hyderabad	0.22	10.49	0.44	10.49	0.04	0.95	0.02	4.89	0.04
	Karimnagar	0.29	7.03	0.59	7.03	0.07	0.94	0.04	3.46	0.08
	Palem	0.69	6.35	1.38	6.35	0.16	0.92	0.11	2.15	0.18
Ear diameter (cm)	Hyderabad	0	0.3	0.01	0.3	0.02	0.96	0.01	6.64	0.02
	Karimnagar	0	0.16	0	0.16	0	0.76	0	29.41	0
	Palem	0.02	0.17	0.04	0.17	0.17	0.92	0.11	2.11	0.18
Number of kernel rows ear^{-1}	Hyderabad	0.21	0.62	0.43	0.62	0.36	0.88	0.34	1.21	0.41
	Karimnagar	0.3	0.86	0.6	0.86	0.35	0.85	0.35	1.19	0.41
	Palem	0.22	0.26	0.44	0.26	0.53	0.85	0.84	0.77	0.63
Number of kernels row^{-1}	Hyderabad	1.72	52.51	3.43	52.51	0.06	0.98	0.03	3.91	0.06
	Karimnagar	1.94	50.61	3.88	50.61	0.07	0.96	0.04	3.61	0.07
	Palem	4.27	33.46	8.54	33.46	0.18	0.86	0.13	1.98	0.2
Test weight (g)	Hyderabad	5.31	39.52	10.63	39.52	0.2	0.94	0.13	1.93	0.21
	Karimnagar	6.77	9.06	13.53	9.06	0.48	0.8	0.75	0.82	0.6
	Palem	9.93	20.99	19.85	20.99	0.43	0.89	0.47	1.03	0.49
Shelling percentage (%)	Hyderabad	2.58	4.24	5.16	4.24	0.47	0.85	0.61	0.91	0.55
	Karimnagar	3.47	7.9	6.95	7.9	0.39	0.84	0.44	1.07	0.47
	Palem	2.9	5.67	5.81	5.67	0.46	0.91	0.51	0.99	0.51
Grain yield (kg ha^{-1})	Hyderabad	21914.82	6259359	43829.65	6259359	0.01	0.96	0	11.95	0.01
	Karimnagar	33582.92	3917137	67165.84	3917137	0.02	0.92	0.01	7.64	0.02
	Palem	35250.94	2409396	70501.88	2409396	0.02	0.84	0.01	5.85	0.03
Fodder yield plot^{-1} (kg)	Hyderabad	0.07	0.96	0.14	0.96	0.11	0.91	0.07	2.66	0.12
	Karimnagar	0.01	0.3	0.02	0.3	0.04	0.85	0.03	4.28	0.05
	Palem	0.03	0.32	0.05	0.32	0.09	0.65	0.08	2.52	0.14

variable for all the characters (data not shown). All the single, three-way and double crosses showed significant differences at three locations except double crosses for kernels row^{-1} at Karimnagar and Palem locations, while parents showed significant differences for days to 50% tasseling, plant height, ear height, number of kernel rows ear^{-1}, test weight and shelling percentage at all three locations. Non significant differences were noticed incase of parents for grain (Table 1) and fodder yield at all the locations. Although, variation is non significant in parents, crosses had shown significant variation for grain and fodder yield. This could be due to complimentary gene action of alleles at individual loci resulting in over dominance either in positive or negative or both the directions. The mean sum of squares of double vs. three-way crosses were significant for days to maturity, test weight, shelling percentage, grain yield and fodder yield at Hyderabad location and for ear height, ear diameter, number of kernel rows ear^{-1}, test weight, grain and fodder yield at Karimnagar location. The mean sum of squares of double vs. single crosses were significant for days to maturity and grain yield (kg ha^{-1}) at Hyderabad and Karimnagar, plant height at Karimnagar and Palem and ear height at all three locations while significant variation was observed for test weight and fodder yield plot^{-1} (kg) at Karimnagar location alone and for ear length, number of kernel rows ear^{-1} and number of kernels row^{-1} at Palem location alone. The mean sum of squares of three-way vs. single crosses were significant for days to maturity, plant height and number of kernels row^{-1} at Karimnagar and Palem locations, but ear height and fodder yield plot^{-1} (kg) differed significantly at all the three locations while ear length, ear diameter and grain yield (kg ha^{-1}) at Palem, Karimnagar and Hyderabad locations, respectively.

The mean sum of squares of double crosses, three-way crosses and single crosses Vs parents were highly significant for all the characters at all the three locations except non significant for days to maturity at Hyderabad and Palem locations (data not shown). Sherawat and Rana (1994) found significant differences for days to heading and maturity in single and double crosses and for 1000-grain weight and yield in multiple crosses of Wheat. Sesay (2016) reported highly significant differences within top cross and three-way cross hybrids for all the traits. In Tomato, Ashakina *et al*. (2016) found significant differences among single, three-way and double crosses for days to 50% flowering, number of fruits plant^{-1} and yield plant^{1}.

Mean values of top ranking ten hybrids over the highest yielding check at each location and heterosis percentage over the highest yielding check are presented in Table 2. The overall mean grain yield of all the hybrids was 7857 kg ha^{-1} at Palem location followed by 6795 kg ha^{-1} at Hyderabad and 6684 kg ha^{-1} at Karimnagar. Among all the crosses, TWC-51 (BML-32 × BML-6) × BML-51 gave the highest grain yield of 10463 kg ha-1 at Palem location while TWC-31 (BML-32 × BML-14) × BML-51 gave highest grain yield of 9090 kg ha-1at Hyderabad. However, at Karimnagar SC-2 (BML-51 × BML-14) gave the highest grain yield of 8553 kg ha-1.Grain yield ranged from 3445 kg ha^{-1} to 9090 kg ha^{-1} at Hyderabad, 4243 kg ha^{-1} to 8553 kg ha^{-1} at Karimnagar and 5502 kg ha-1 to 10463 kg ha^{1} at Palem locations. TWC-31 (BML-32 × BML-14) × BML-51 significantly out yielded (9090 kg ha-1) the highest yielding check NK 6240 (7597 kg ha-1) at Hyderabad and about fifty crosses were found numerically superior to the same check in yield performance. None of the crosses were found significantly superior over highest yielding check Ekka 2288 (7866 kg ha^{-1}) at Karimnagar but, fourteen crosses were found numerically superior to the same check in yield performance. Similarly, none of the crosses were found significantly superior over the highest grain yielding check KNMH-4010131 (9502 kg ha^{-1}) at Palem however, nine crosses were found to be numerically superior to the same check. Among the inbred lines BML-51 gave the highest grain yield of 3572 kg ha^{-1} at Karimnagar and 2885 kg ha^{-1} at Hyderabad whereas, BML-6 gave highest grain yield 5480 kg ha^{-1} at Palem location.

At Karimnagar two double crosses *i.e.*, DC-7 (BML-51 × BML-32) × (BML-13 × BML-6) and DC-17 (BML-51 × BML-14) × (BML-13 × BML-6) and TWC-2 (BML-51 × BML-32) × BML-13 were early in maturity against the high yielding check Ekka 2288, whereas at Hyderabad two double crosses *i.e.*, DC-15 (BML-51 × BML-14) × (BML-13 × BML-10) and DC-91 (BML-14 × BML-13) × (BML-10 × BML-7) were found to be early in days to 50% silking and days to maturity against high yielding check NK 6240. On the contrary, none of the high yielding hybrids were found to be early in flowering and maturity traits against the high yielding check KNMH-4010131 at Palem.

For ear length all the high yielding crosses except SC-2 (BML-51 X BML-14) at Hyderabad and TWC-82 (BML-13 × BML-7) × BML-32 and DC-23 (BML-51 × BML-13) × (BML-32 × BML-7) at Palem were found to be significantly superior over the high yielding checks at respective locations while none of the hybrids were significantly superior over the high yielding check at Karimnagar location. At Hyderabad SC-19 (BML-32 × BML-7) was significantly superior over high yielding check NK 6240 for ear diameter while none of the crosses were found significant over high yielding check at Karimnagar and Palem locations.

At all the three locations none of the high yielding hybrids were found to be significantly superior over the high yielding check for number of kernel rows ear^{-1}. For number of kernels row^{-1} at Hyderabad two single crosses *i.e.*, SC-1 (BML-51 × BML-32) and SC-19 (BML-10 × BML-7), three double crosses *i.e.*, DC-63 (BML-32 × BML-14) × (BML-13 × BML-6), DC-76 (BML-32 × BML-10) × (BML-13 × BML-7) and DC-101 (BML-14 × BML-6) × (BML-13 × BML-7) and single three-way cross TWC-31 (BML-32 × BML-14) × BML-51 were found to be significant over high yielding check NK 6240 and three three-way crosses *viz*., TWC-6 (BML-51 × BML-14) × BML-32, TWC-51 (BML-32 × BML-6) × BML-51 and TWC-82 (BML-13 × BML-7) × BML-32 were found to be significantly superior over high yielding check KNMH-4010131at Palem location. On the contrary, none of the crosses were found to be significant over high yielding check Ekka 2288 at Karimnagar location.

Test weight of SC-2 (BML-51 × BML-14), three way crosses *viz*., TWC-2 (BML-51 × BML-32) × BML-13, TWC-20 (BML-51 × BML-10) × BML-6, TWC-52 (BML-32 × BML-6) × BML-14 and DC-53 (BML-51 × BML-6) × (BML-32 × BML-10) were found to be significantly superior over the highest yielding check Ekka 2288 at Karimnagar location. On the contrary, none of the high yielding entries exhibited significantly superior test weight over the check KNMH-4010131 at Palem whereas SC-2 (BML-51 × BML-14) was found to be significantly superior to the highest yielding check NK 6240 at Hyderabad.

Shelling percentage was highly uniform among the high yielding hybrids, but at Karimnagar and Hyderabad none of the high yielding hybrids were significantly superior against the high yielding check Ekka 2288 (83.05%) and NK 6240

(82.65%), respectively. On the contrary at Palem SC-6 (BML-51 × BML-6), five three-way crosses viz., TWC-6 (BML-51 × BML-14) × BML-32, TWC-51 (BML-32 × BML-6) × BML-51, TWC-71 (BML-14 × BML-6) × BML-51 and TWC-82 (BML-13 × BML-7) × BML-32 and DC-23 (BML-51 × BML-13) × (BML-32 × BML-7) had significant values over the check KNMH-4010131.

High yielding hybrids were on par to the check Ekka 2288 for grain yield ha^{-1} at Karimnagar whereas at Hyderabad, TWC-31 (BML-32 × BML-14) × BML-51 was found to be significantly superior against the high yielding check NK 6240. On the contrary at Palem location, none of the high yielding hybrids were significantly superior over the highest yielding check KNMH-4010131. Five three-way crosses *i.e.*, TWC-2 (BML-51 × BML-32) × BML-13, TWC-20 (BML-51 × BML-10) × BML-6, TWC-51 (BML-32 × BML-6) × BML-51, TWC-52 (BML-32 × BML-6) × BML-14 and TWC-67 (BML-14 × BML-7) × BML-32 and two double crosses *i.e.*, DC-7 (BML-51 × BML-32) × (BML-13 × BML-6) and DC-53 (BML-51 × BML-6) × (BML-32 × BML-10) and were found to be highly significant over the highest yielding check Ekka 2288 at Karimnagar for fodder yield kg plot^{-1} whereas SC-2 (BML-51 × BML-14) at Hyderabad and two three-way crosses *i.e.*, TWC-51 (BML-32 × BML-6) × BML-51 and TWC-71 (BML-14 × BML-6) × BML-51 at Palem were found to be significantly superior to the highest yielding check at respective locations.

Heterosis

Range of mean and heterosis and number of significant heterotic crosses in desirable direction against the high yielding check at each location for the important traits is furnished in table 3 and 4, respectively. Standard heterosis was computed against the high yielding check at all the three locations. Four double crosses namely *viz*., DC-101 (BML-14 × BML-6) × (BML-13 × BML-7), DC-91 (BML-14 × BML-13) × (BML-10 × BML-7), DC-18 (BML-51 × BML-14) × (BML-10 × BML-7) and DC-63 (BML-32 × BML-14) × (BML-13 × BML-6) exhibited significant positive heterosis of 17.03%, 16.52,14.72 and 13.29, respectively against the popular check NK 6240 for grain yield kg ha^{-1} at Hyderabad while none of the crosses had shown significant and positive heterotic effects at Karimnagar and Palem. Kumar *et al*. (2013) and Soni and Khanorkar (2013) reported high heterosis of 189.85% and 99.16%, respectively for grain yield. All the ten high yielding crosses except TWC-2 (BML-51 × BML-32) × (BML-13) had positive and significant heterosis for fodder yield. Shelling percentage at Karimnagar, test weight at Palem and grain yield at Karimnagar and Palem had non significant heterotic values.

Estimates of heterosis revealed that most of the hybrids exhibited lower values for grain yield indicating poor divergence among the parental lines. Negative heterosis observed for days to 50 per cent flowering and days to maturity suggested the synthesis of early hybrids which is a desirable trait. In general, there were no obvious differences in average performance between the different categories of hybrids *i.e.*, single, three-way and double crosses and this could be attributed to the involvement of potential inbreds as parental lines. Four three-way cross hybrids *i.e.*, TWC-46 (BML-32 × BML-7) × BML-51, TWC-56 (BML-14 × BML-13) × BML-51, TWC-86 (BML-13 × BML-6) × BML-51 and TWC-98 (BML-10 × BML-6) × BML-14 with medium maturity and superior performance were also tested in Peninsular Zonal trials (AICRP, IIMR, 2016) under medium and late maturity during kharif 2016 at five locations *viz*., Hyderabad, Karimnagar, Coimbattore, Mandya and Kolhapur and the average grain yield of these hybrids were ranged from 8100 kg ha^{-1} to 9400 kg ha^{-1} but, yields were inferior to single crosses. However, in some of the crosses one cycle of mating systems were imposed in order to break the tight linkages and resulting population was advanced through selfing. As a result excellent recombinants were identified and stabilized.

Variance components and Heritability

Genetic components of variation and genetic ratios for 7 × 7 diallel at individual locations were estimated (Table 5) to determine the gene action governing various traits. In the present study all the characters except days to 50 per cent tasseling at Palem showed non additive gene effects at individual environments indicating preponderance of non additive gene action in the inheritance of all the characters studied. The predominance of SCA variance denotes that non additive genetic effects were largely influencing the expression of the traits, hence potential hybrids were identified through exploitation of heterosis.

Narrow sense heritability was moderate for days to 50 per cent tasseling, days to 50 per cent silking, number of kernel rows ear^{-1} and shelling percentage, low for ear length, ear diameter, number of kernels row^{-1}, grain yield and fodder yield at all individual locations, low to medium for days to maturity, test weight and shelling percentage across the three locations indicated that grain yield and its contributing characters are predominantly governed by dominant gene action. Low to moderate narrow-sense heritability for all characters at all locations indicated that environment played a major role in control of these traits among the single, three-way and double cross hybrids evaluated.

The values of mean degree of dominance was less than unity for days to 50 per cent tasseling, days to 50 per cent silking, days to maturity, plant height, ear height, number of kernel rows ear^{-1}, test weight and shelling percentage indicating the existence of partial dominance and greater than unity for ear length, ear diameter, number of kernels row^{-1}, grain and fodder yield indicating the existence of dominance in controlling these traits.

Baker, 1978 opined that the closer genetic ratio to unity shows the predictability based on GCA alone. Less than unity indicated the importance of both general and specific combining abilities on progeny performance. In addition to this, a GCA/SCA ratio with a value greater than one indicated additive genetic effect and less than one dominant genetic effect.The results of the present investigation however suggested the preponderance of dominant gene action in governing the yield and yield contributing characters.

In conclusion, different classes of hybrids such as SC-2 and DC-53 at Karimnagar, TWC-51, TWC-71, TWC-82 and DC-18 at Palem and TWC-31, DC-91 and DC-101 at Hyderabad had superior performance. These hybrids were found to be early either for days to silking or days to maturity and had the ability to adapt to the location of evaluation.

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