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ASSESSMENT OF INBRED LINES OF FIELD CORN FOR YIELD AND YIELD ATTRIBUTES THROUGH LINE × TESTER METHOD

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Abstract

A line × tester analysis comprising forty eight test-crosses generated by crossing 24 S_3 inbred lines derived from commercial maize hybrid 981 with two testers. Heterosis study of these crosses against two standard checks was evaluated at Bangladesh Agricultural Research Institute, Gazipur during *rabi* 2015-16. The objectives of the study were to estimate general and specific combining ability effects of the inbred lines and to assess the test cross performance and estimate the amount of standard-heterosis of the hybrids for grain yield and yield related characters. Highly significant genotypic differences were observed indicated wide range of variability present among them. Five lines viz. Line 11, Line 14, Line 17, Line 24 and Line 30 were good general combiner for grain yield and possessed high means. Nine crosses showed (Line 18 × BIL22, Line 23 × BIL22, Line 27 × BIL22, Line 7 × BIL28, Line11 × BIL28, Line14 × BIL28, Line 24 × BIL28, Line 25 × BIL28 and Line 30 × BIL28) significant and positive specific combining ability effect for grain yield. The information on the nature of gene action with respective variety and characters might be used depending on the breeding objectives. These crosses, Line 24× BIL28 (11.40 t/ha), Line 18 × BIL22 (11.30 t/ha) and Line 25 × BIL28 (11.20 t/ha) showed higher yield, could be utilized in maize breeding activities. Estimation of heterosis was carried out using two commercial hybrids BARI Hybrid Maize-9 (BHM-9) and NK-40. The percent heterosis for grain yield varied from -23.39 to 4.6% against BHM-9. Among the 48 crosses, 13 crosses exhibited significant positive heterosis for grain yield.

Keywords: Assessment, line×tester, GCA, SCA, maize inbreds, heterosis.

Introduction

Maize (*Zea mays* L.) is the world's leading crop and is widely cultivated as cereal grain. It is one of the most versatile emerging crops having wider adaptability. Globally, maize is known as queen of cereals because of its highest genetic yield potential. Based on genetic structure, several types of hybrids are possible in maize; however those derived from inbred lines are usually used for commercial production. During inbreeding selection based on the performance of test cross progeny is highly useful in improving the general combining ability (GCA) of inbred lines. The general combining ability (GCA) of inbred lines can be effectively tested at an early stage during the inbreeding program. Sprague and Tatum (1942) established the theory of specific combining ability (SCA) and general combining ability (GCA) which has

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been used broadly in breeding of several economic species of crop. For maize yield, they found that the significance of general combining ability was comparatively more than specific combining ability for unselected inbred lines, while specific combining ability was more significant than general combining ability for previously selected lines. Assefa *et al.* 2017 and Narayanamma *et al.* 2013 were supported this statement. Based on the test cross test, about 50% of the inbred lines can be eliminated (Singh and Chaudhary, 1979). The number of inbred lines is reduced through this process is necessary for the next step. For crop improvement combining ability has been used as an important breeding approach to exploit of hybrid vigor and parents selection. Breeder's objectives are to select hybrids on the basis of expected level of heterosis as well as specific combining ability. Combining ability is a prerequisite for developing a good hybrid maize variety. In maize breeding programs, early testing is considered an efficient approach by maize breeders to identify good performing lines by early testing which are then evaluated for grain yield and yield related traits. The present study involving a line × tester analysis aimed at to estimate the GCA and SCA effects of S_3 inbred lines of maize obtained from commercial maize hybrid 981 for grain yield and yield related traits and to evaluate the test cross performance and estimate the amount of heterosis of the hybrids for grain yield and yield related traits.

Materials and Methods

Twenty four S_3 inbred lines (as female parents) and 2 testers (as male parents) were crossed to create 48 cross combinations in rabi 2014-15 at Bangladesh Agricultural Research Institute, Gazipur. Seeds of twenty four parental lines, 48 test crosses, 2 testers (BIL22 and BIL28) and two check hybrids (BARI Hybrid Maize-9 and commercial hybrid NK-40) were sown following alpha lattice design with 2 replications in rabi 2015-16. Each hybrid planted in one row of 4 m long plot. The spacing between rows was 60 cm and plant to plant distance was 25 cm. One healthy seedling per hill was kept after proper thinning. Fertilizers were applied @ 250, 55, 110, 40, 5 and 1.5 kg/ha of N, P, K, S, Zn, B, respectively. Standard agronomic practices were followed and plant protection measures were taken as required. Ten randomly selected plants were used for recording observations on plant height, ear height, and ear length, seeds/row and 1000-grain weight. Days to tasseling, days to silking and grain yield were recorded on whole plot basis. Analysis for general combining ability and specific combining ability was carried out following the method of Kempthorne (1957).

Results and Discussion

The analysis of variance showed significant variations among the hybrids for all the characters studied indicating wide range of genetic variability among the genotypes. The analysis of variance for combining ability revealed significant differences in the variance of parents, parents vs. crosses, crosses, lines, testers and lines × testers for several characters under studied (Table 1). Sofi and Rather (2006) and Narro *et al.* (2003) found similar genotypic difference for ear length, grain weight, grain yield and other characters in their studies.

Table 1. Mean squares and estimates of variance for grain yield, yield components and other characters in maize evaluated at Gazipur during rabi 2015-16

Source	df	Days to tasseling	Days to silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Seeds/ row	1000 grains weight (g)	Yield (t/ha)
Genotypes	73	11.6**	13.1**	1001.8**	485.16**	7.5**	53.0**	2641.0**	15.0**
Parents	25	19.5**	20.4**	364.2**	177.48***	2.4**	16.9**	1160.7**	1.25**
Parents vs Crosse	1	93.7**	122.9**	49860**	25921.5**	232.2**	2442**	135876**	1002**
Crosses	47	5.7**	7.0**	301.4**	107.62**	5.4**	21.4**	593.6**	1.25**
Lines	23	5.8**	7.2**	278.2**	160.77**	6.5**	24.4**	458.1**	1.26**
Testers	1	1.5	0.2	799.3**	283.59**	4.6**	0.3	376.0**	1.14**
Lines x Testers	23	5.7**	7.1**	302.9**	46.81*	4.5**	19.2**	738.5**	1.25**
Error	73	2.1	2.8	39.43	23.13	0.7	1.8	6.1	0.17
Estimate of component of variance									
σ^2g (line)		0.03	0.02	-6.19	28.49	0.50	1.296	-70.11	0.01
σ^2g (tester)		-0.09	-0.14	10.34	4.93	0.01	-0.395	-7.55	-0.02
σ^2gca		0.01	0.01	-0.02	0.85	0.01	0.030	-2.03	0.01
σ^2sca		1.45	1.96	131.75	11.84	1.88	8.706	366.24	0.54
σ^2gca/σ^2sca		0.01	0.01	-0.01	0.59	0.01	0.02	-1.40	0.01

*P=0.05 and **P=0.01.

Table 2. Proportion contribution of lines, testers and their interactions to total variance in maize

Source	Days to tasseling	Days to silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Seeds/row	1000 grain weight (g)	Yield (t/ha)
Due to line	50.25	50.25	45.17	73.18	58.07	55.93	37.77	49.25
Due to tester	0.56	0.05	5.64	5.27	1.80	0.03	1.35	1.94
Due to line × tester	49.19	49.70	49.19	21.55	40.14	44.05	60.89	48.81

Analysis of variance for parents found highly significant for all the traits indicating sufficient variability among them. Significant differences were also observed between interactions of parent vs crosses for all traits, indicated wide range of variability present among them. Mean sum squares due to crosses (hybrids) were highly significant for grain yield, 1000 grain weight, days to tasseling and silking, plant and ear height and ear length. This indicates that the crosses were significantly different from each other for these traits and hence, selection is possible to identify the most desirable crosses. The variance among the lines were highly significant for all the traits whereas variance among testers were significant for plant height, ear height, ear length, 1000 grains weight and grain yield. For tester GCA, showed non significant differences for days to tasseling and silking and seeds per row. The interaction of line × tester also showed highly significant difference for all traits which was consistent with Venkatesh *et al*. (2001) and Narro *et al*. (2003).

The higher estimation of dominance variance (σ^2sca) as compared to additive variance (σ^2gca) for all the eight characters (Table 1) probably due to predominance of non-additive gene action which suggesting the scope of improvement of these characters through heterosis breeding for hybrid development.

The contribution of lines, testers and their interactions to total variances are presented in Table 2. The proportional contribution of lines and interactions to total variances was much higher than testers in all the traits. However, the contribution of lines was higher than the interactions to total variances for all the characters except plant height and 1000grains weight. This suggests female parent contributed maximum to total variance in maize, which was followed by interaction and the estimate of variances due to general combining ability. Testers contributed lowest to total variance, which is in conformity with Rissi *et al*. (1991).

General combining ability effects

Selection of parents with good general combining ability is a prime requisite for any successful breeding program especially for heterosis breeding. The gca effects and *per se* performance of parents (line and tester) are presented in Table 3. Both negative and positive GCA effects were observed for days to tesseling and silking. The GCA effects of parents Line 5, Line 10, Line 22 and Line 27 exhibited significant and negative GCA effects for both days to tasseling and silking. These lines could be utilized for evolving earliness. Roy *et al*. (1998), Hussain *et al*. (2003) and Uddin *et al*. (2006) also observed similar phenomenon in their study. For plant height and ear height Line1, Line7, Line12, Line13, Line14 and Line22 were found to be good general combiners while Line8, Line9 and Line19 were poor general combiners. In maize, shorter plant and ear height is desirable for lodging resistance. This result is in conformity with the findings of Habtamu and Hadji (2010), Mosa (2010) and Rahman *et al.* (2010). The lines Line 11, Line 14, Line 17, Line 19, Line24 and Line30 exhibited significant and positive GCA effect both for ear length and seeds/row which ultimately can contribute for evolving longer ears and more seeds per row. The lines Line11, Line16, Line18, Line22, Line24 and Line29 showing positive gca effect for bold grains. Estimates of GCA effects for grain yield showed that out of the 24 inbred lines studied in line × tester cross eight exhibited positive and highly significant GCA effects while five lines exhibited negative and significant GCA effects. The lines Line2, Line11, Line14, Line17, Line18, Line19, Line24 and Line30 expressed highly significant and positive GCA effects for yield, indicated good general combiner for exploiting more positive alleles for yield. These eight lines had high mean values for grain yield (Table 3) and could be extensively utilized for evolving high yielding hybrids. In case of grain yield of maize inbred line several studies (Ahmad and Saleem, 2003; Legesse *et al*. 2009; Mosa, 2010) also found both positive and negative GCA effects. However Bayisa *et al.* (2008) did not find significant GCA effects in line×tester analysis for grain yield. Significant GCA effect for yield in maize was reported by Paul and Duara (1991) and Ivy and Hawlader (2000). As GCA is generally associated with additive gene action in inheritance of characters, the lines and testers with high GCA may be utilized in hybridization program to improve a particular trait through transgressive segregation.

Table 3. General combining ability (gca) effects and mean of parents for grain yield and yield components and other characters in maize

Parents	DT		DS		PH		EH	
Tester parents	gca	mean	gca	mean	gca	mean	gca	mean
BIL22	0.13	91	0.04	94	2.89	130	1.72	43
BIL28	-0.13	89	-0.04	92	-2.89	128	-1.72	40
SE(gi)	0.20		0.22		0.91		0.69	
SE(gi-gj)	0.30		0.32		1.28		0.98	
Line parents								
Line1	0.57	86	0.81	89	-17.95**	129	-5.01**	44
Line2	0.92	86	-0.14	89	-3.70	171	-2.26	65
Line5	-1.58*	85	-2.09*	88	-7.65*	141	-3.01	56
Line7	-1.08	89	-1.69*	93	-7.95**	142	-7.01**	48
Line8	-0.83	89	-1.19	91	13.05**	151	11.24**	50
Line9	1.17	85	0.81	88	8.05**	163	8.74**	60
Line10	-2.33**	86	-2.19**	88	7.30*	162	3.49	48
Line11	-0.33	93	-0.30	96	6.80*	163	8.99**	78
Line12	-0.58	86	-0.54	88	-6.20*	136	-7.76**	46
Line13	1.17	89	1.16	92	-11.55**	150	-6.51**	50

Parents	DT		DS		PH		EH	
Tester parents	gca	mean	gca	mean	gca	mean	gca	mean
Line14	0.17	87	-0.44	90	-6.55*	133	-4.76*	55
Line15	-1.08	86	-1.04	89	-1.45	132	-0.76	51
Line16	0.87	88	0.91	90	8.05**	165	11.74**	58
Line17	1.17	86	1.10	90	9.30**	154	5.24**	64
Line18	1.42	87	1.06	89	-4.45	158	-1.26	70
Line19	1.67*	86	1.81*	88	10.55**	166	2.24	69
Line21	1.17	82	0.91	85	8.55**	151	5.74**	62
Line22	-2.02**	78	-2.26**	81	-10.95**	148	-4.26*	46
Line23	-1.23	86	-1.19	88	-4.45	156	-1.01	62
Line24	-0.18	84	0.81	87	0.80	158	-0.26	52
Line25	-0.83	86	-0.90	89	8.80**	145	3.99	53
Line27	-1.83*	86	-1.44*	87	3.55	153	-1.76	54
Line29	0.97	80	0.91	83	1.30	159	-3.76	60
Line30	0.97	85	1.56*	88	-3.20	149	-3.01	66
SE(gi)	0.74		0.79		3.14		2.40	
SE(gi-gj)	1.10		1.16		4.44		3.40	

DT= Days to tasseling, DS=Days to silking, PH= Plant height (cm), EH= Ear height (cm)

Table 3. cont'd

Parents	Ear length (cm)		Seeds/row		1000 grains weight (g)		Yield (t/ha)	
Tester parents	gca	mean	gca	mean	gca	mean	gca	mean
BIL22	0.22	12	-0.05	19	-1.98	295	-0.11	3.70
BIL28	-0.22	12	0.05	21	1.98	320	0.11	4.00
SE(gi)	0.12		0.19		0.36		0.06	
SE(gi-gj)	0.17		0.27		0.50		0.08	
Line parents								
Line1	-0.33	13	-1.49**	18	-8.85**	260	-0.23	4.15
Line 2	0.12	13	0.51	17	-6.35**	310	0.75**	5.15
Line 5	-1.66**	13	-2.49**	25	-1.35	280	-0.74*	4.75
Line 7	-1.91**	13	-2.99**	21	-21.35**	315	-0.08	5.50
Line 8	0.12	12	1.51*	16	1.15	275	-0.68*	4.03
Line 9	0.42	12	0.76	18	-7.60	305	-0.36	5.00
Line 10	-0.13	11	-2.24	16	1.15	290	0.17	3.60
Line 11	1.37**	13	3.01**	21	3.40**	315	0.47*	5.30

Parents	Ear length (cm)		Seeds/row		1000 grains weight (g)		Yield (t/ha)	
Tester parents	gca	mean	gca	mean	gca	mean	gca	mean
Line 12	-1.08**	13	-3.49**	19	-3.85	300	-1.31**	5.10
Line 13	0.32	11	2.26**	17	-11.35	275	0.46	3.50
Line 14	0.92**	13	1.51**	22	-1.35	315	0.54**	5.45
Line 15	-0.28	12	-0.99	16	-6.35	280	-0.48	3.70
Line 16	-1.78**	13	-2.49**	19	13.65**	315	0.02	5.00
Line 17	2.29**	12	4.26**	18	1.65	305	0.72**	5.40
Line 18	-2.41**	11	-2.49**	17	3.65**	315	1.01**	5.28
Line 19	1.02**	11	3.51**	17	0.65	275	0.59**	5.50
Line 21	-0.48	11	-3.24	15	-11.35**	280	-0.58*	3.70
Line 22	0.47	13	1.26*	21	6.15**	310	-0.01	4.70
Line 23	0.37	11	1.01	16	1.15	275	0.15	3.40
Line 24	2.02**	13	3.76**	23	11.15**	315	0.82**	5.45
Line 25	-1.43**	11	-2.24	15	-6.35**	270	-1.30**	3.60
Line 27	0.27	12	0.51	22	-6.35**	310	0.24	5.40
Line 29	-0.28	12	-0.49	19	3.65**	300	0.14	4.80
Line 30	1.38**	14	2.24**	25	1.15	305	0.79**	5.65
SE(gi)	0.32		0.67		1.23		0.20	
SE(gi-gj)	0.49		0.95		1.74		0.29	

*P=0.05 and **P=0.01

Specific combining ability effects

The sca effect and mean performances of the crosses are presented in Table 4. Among the 48 cross combinations, highly significant and negative sca effect were exhibited by six crosses both for days to tasseling and days to silking. in case of plant height and ear height each of five crosses showed significant and negative SCA effects for these two traits which are desirable. In maize, negative values of days to tasseling, days to silking, plant height and ear height are expected for earliness and dwarf plant type, respectively. Among the 48 cross combinations, 9 crosses showed positive sca effect for ear length, 11 crosses for seeds/row and 14 crosses for 1000 grain weight. In case of grain yield, nine crosses (Line 18 × BIL22, Line 23 × BIL22, Line 27 × BIL22, Line 7 × BIL28, Line11 × BIL28, Line14 × BIL28, Line 24× BIL28, Line 25 × BIL28 and Line 30 × BIL28) exhibited significant and positive SCA effects. These crosses also had high mean values for grain yield. Crosses involving both good general combiner as well as one good and other poor combiner showed high SCA effects which are due to additive × additive and additive × dominant gene action, respectively. These results were in agreement with the earlier findings of Das and Islam (1994) in maize.

Table 4. Specific combining ability (sca) and mean of crosses for grain yield, its components and other characters in maize

Crosses	Days to tasseling		Days to silking		Plant height (cm)		Ear height (cm)	
	sca	mean	sca	mean	sca	mean	sca	mean
Line 1 × BIL22	-0.63	84	-0.29	88	-13.14**	160	-8.47**	76
Line 2 × BIL22	0.13	85	-0.29	88	0.61	180	1.28	86
Line 5 × BIL22	1.13	85	1.21	87	12.36**	188	-0.97	76
Line 7 × BIL22	-1.88*	85	-1.79*	87	6.86	181	-6.53*	70
Line 8 × BIL22	-0.13	84	0.21	86	2.86	196	-0.72	83
Line 9 × BIL22	0.38	82	0.71	84	-0.64	165	2.28	81
Line 10 × BIL22	2.38*	85	2.21*	88	-7.39*	176	-6.47*	75
Line 11 × BIL22	-1.93*	85	-1.04	87	0.11	170	1.53	71
Line 12 × BIL22	1.13	84	1.71	86	13.61**	207	2.28	97
Line 13 × BIL22	-0.63	84	-0.54	86	-13.64**	180	-8.47**	78
Line 14 × BIL22	0.88	86	0.96	88	-1.64	198	0.28	98
Line 15 × BIL22	-0.38	85	-0.29	87	-10.64*	194	-2.72	90
Line 16 × BIL22	-0.13	85	0.21	87	-8.14*	191	-2.72	84
Line 17 × BIL22	-0.63	80	-1.04	83	12.61**	200	7.28*	93
Line 18 × BIL22	0.63	83	0.96	86	-9.64*	198	-1.72	97
Line 19 × BIL22	-1.63	85	-2.29*	88	-3.14	192	-1.22	91
Line 21 × BIL22	-0.13	85	-0.29	88	10.86**	198	2.78	81

Crosses	Days to tasseling		Days to silking		Plant height (cm)		Ear height (cm)	
	sca	mean	sca	mean	sca	mean	sca	mean
Line 22 × BIL22	1.93*	83	1.86*	85	-2.14	165	-6.78*	73
Line 23 × BIL22	1.88*	85	2.21	88	-10.64*	176	-7.47*	80
Line 24 × BIL22	-0.88	86	-1.29	89	-0.39	177	-1.22	77
Line 25 × BIL22	0.88	86	0.96	88	17.11**	183	2.53	82
Line 27 × BIL22	-2.63**	82	-2.79**	84	3.86	180	0.78	78
Line 29 ×BIL22	-0.13	83	-0.29	86	1.11	179	2.78	83
Line 30 × BIL22	-0.13	84	-0.54	86	-10.89**	194	-2.97	85
Line 1 × BIL28	0.63	85	0.29	88	13.14**	191	8.47**	96
Line 2 × BIL28	-0.13	85	0.29	88	-0.61	201	-1.28	98
Line 5 × BIL28	-1.13	85	-1.21	87	-12.36**	213	0.97	99
Line 7 × BIL28	1.88	86	1.79	89	-6.86	182	6.53*	81
Line 8 × BIL28	0.13	87	-0.21	89	-2.86	176	0.72	84
Line 9 × BIL28	-0.38	85	-0.71	87	0.64	189	-2.28	84
Line 10 × BIL28	-2.38*	81	-2.21*	84	7.39*	198	6.47*	88
Line 11 × BIL28	1.93*	88	1.04	91	-0.11	199	-1.53	87
Line 12 × BIL28	-1.13	85	-1.71	88	-13.61**	210	-2.28	95
Line 13 × BIL28	0.63	85	0.54	88	13.64**	183	8.47**	86
Line 14 × BIL28	-0.88	89	-0.96	92	1.64	178	-0.28	85

Crosses	Days to tasseling		Days to silking		Plant height (cm)		Ear height (cm)	
	sca	mean	sca	mean	sca	mean	sca	mean
Line 15 × BIL28	0.38	85	0.29	89	10.64**	177	2.72	76
Line 16 × BIL28	0.13	85	-0.21	88	8.14	186	2.72	85
Line 17 × BIL28	0.63	81	1.04	84	-12.61**	191	-7.28*	90
Line 18 × BIL28	-0.63	84	-0.96	86	9.64*	191	1.72	85
Line 19 × BIL28	1.63	85	2.29*	89	3.14	186	1.22	84
Line 21 × BIL28	0.13	85	0.29	87	-10.86**	217	-2.78	93
Line 22 × BIL28	-1.93*	81	-1.86*	83	2.14	177	-6.78*	85
Line 23 × BIL28	-1.88*	80	-2.21*	83	10.64**	198	7.47*	86
Line 24 × BIL28	0.88	85	1.29	89	0.39	185	1.22	81
Line 25 × BIL28	-0.88	85	-0.96	88	-17.11**	193	-2.53	86
Line 27 × BIL28	2.63**	85	2.79**	88	-3.86	185	-0.78	77
Line 29 × BIL28	0.13	85	0.29	88	-1.11	177	-2.78	76
Line 30 × BIL28	0.13	85	0.54	89	10.89**	193	2.97	80
SE(Sij)	1.03		1.12		4.44		3.40	
SE(Sij-Skl)	1.54		1.66		6.28		4.81	

*P=0.05 and **P=0.01

Table 4. cont'd

Crosses	Ear length (cm)		Seeds/row		1000 grains wt (g)		Yield (t/ha)	
	sca	mean	sca	mean	sca	mean	sca	mean
Line 1 × BIL22	0.58	15	1.05	27	-30.52**	325	-0.27	9.50
Line 2 × BIL22	-0.67	14	-2.95**	25	-3.02*	375	-0.39	10.25
Line 5 × BIL22	0.46	15	0.55	25	1.98	345	0.14	10.10
Line 7 × BIL22	-0.89	15	0.05	31	1.98	370	-0.72**	10.20
Line 8 × BIL22	-0.37	14	-1.95*	26	-3.02*	365	-0.42	9.60
Line 9 × BIL22	0.53	13	1.80*	25	15.73**	365	0.26	9.53
Line 10 × BIL22	-0.02	12	0.80	25	3.98*	345	0.33	9.90
Line 11 × BIL22	-1.68**	14	-3.55**	25	-15.73**	350	-0.83**	10.15
Line 12 × BIL22	0.77	14	-0.45	26	-5.52**	350	0.21	9.10
Line 13 × BIL22	1.07*	16	3.70**	32	1.98	360	-0.41	10.16
Line 14 × BIL22	-0.97*	16	-2.95**	31	1.98	360	-0.84**	10.30
Line 15 × BIL22	-0.27	15	-1.35	26	-3.02*	345	-0.32	9.00
Line 16 × BIL22	0.23	15	-0.45	26	-13.02**	370	-0.37	10.50
Line 17 × BIL22	1.66**	15	1.80**	28	-8.02**	340	-0.07	10.05
Line 18 × BIL22	1.39**	18	2.55**	34	-13.02**	370	0.94**	11.30
Line 19 × BIL22	-2.07	14	-1.45	27	1.98	355	-0.25	9.85
Line 21 × BIL22	-0.17	15	-0.70	24	0.98	345	-0.26	9.20

Crosses	Ear length (cm)		Seeds/row		1000 grains wt (g)		Yield (t/ha)	
	sca	mean	sca	mean	sca	mean	sca	mean
Line 22 × BIL22	0.48	13	1.80*	25	0.48	355	0.11	9.00
Line 23 × BIL22	1.48**	15	2.55**	26	14.48**	360	0.95**	10.45
Line 24 × BIL22	0.03	17	-2.20**	30	-5.52**	355	-0.83**	10.39
Line 25 × BIL22	-0.98	15	0.80	26	-6.98**	345	-0.80**	10.00
Line 27 × BIL22	1.22**	17	1.95*	32	13.02**	360	0.94**	11.00
Line 29 ×BIL22	0.13	14	1.55	25	2.98	345	0.26	9.20
Line 30 × BIL22	-0.17	16	-2.30**	29	-15.52	365	-0.74**	10.45
Line 1 × BIL28	-0.58	14	-1.05	25	30.52**	365	0.27	9.65
Line 2 × BIL28	0.67	13	2.95**	27	3.02*	385	0.39	10.60
Line 5 × BIL28	-0.46	19	-0.55	34	-1.98	370	-0.14	10.65
Line 7 × BIL28	0.89	15	-0.05	30	-1.98	390	0.72**	11.10
Line 8 × BIL28	0.37	12	1.95*	26	3.02*	345	0.42	8.35
Line 9 × BIL28	-0.53	13	-1.80*	25	-15.73**	390	-0.26	9.85
Line 10 × BIL28	0.02	14	-0.80	30	-3.98*	365	-0.33	10.34
Line 11 × BIL28	1.68**	18	3.55**	33	15.73**	375	0.83**	11.06
Line 12 × BIL28	-0.77	14	0.45	24	5.52**	355	-0.21	9.36
Line 13 × BIL28	-1.07*	14	-3.70**	25	-1.98	345	0.41	10.10
Line 14 × BIL28	0.97*	18	2.95**	34	-1.98	365	0.84**	11.10

Crosses	Ear length (cm)		Seeds/row		1000 grains wt (g)		Yield (t/ha)	
	sca	mean	sca	mean	sca	mean	sca	mean
Line 15 × BIL28	0.27	14	1.35	24	3.02*	350	0.32	9.10
Line 16 × BIL28	-0.23	18	0.45	33	13.02**	375	0.37	11.19
Line 17 × BIL28	-1.66**	15	-1.80*	28	8.02**	350	0.07	9.52
Line 18 × BIL28	-1.39**	17	-2.55**	31	13.02**	360	-0.94**	10.00
Line 19 × BIL28	2.07**	17	1.45	32	-1.98	365	0.25	10.70
Line 21 × BIL28	0.17	15	0.70	26	-0.98	350	0.26	9.30
Line 22 × BIL28	-0.48	12	-1.80*	25	-0.48	345	-0.11	8.72
Line 23 × BIL28	-1.48**	14	-2.55**	26	-14.48**	350	-0.95**	9.31
Line 24 × BIL28	-0.03	16	2.20**	30	5.52**	380	0.83**	11.40
Line 25 × BIL28	0.98**	15	-0.80	29	6.98**	400	0.80**	11.20
Line 27 × BIL28	-1.22**	14	-1.95*	26	-13.02**	350	-0.94**	10.50
Line 29 × BIL28	-0.13	15	-1.55	25	-2.98	355	-0.26	9.35
Line 30 × BIL28	0.17	14	2.30**	30	15.52**	390	0.74**	11.05
SE (Sij)	0.49		0.95		1.74		0.29	
SE (Sij-Skl)	0.74		1.34		2.46		0.41	

*P=0.05 and **P=0.01

Table 5. Heterosis of the crosses over NK-40 for different characters in maize

Crosses	DT	DS	PH	EH	Ear Length	Seeds/row	1000 grains wt (g)	Yield (t/ha)
Line 1 × BIL22	3.7**	4.8**	-12.1**	-3.8**	0.0	-6.9**	-16.7**	-10.8**
Line 2 × BIL22	4.9**	4.8**	-1.1	8.9**	-6.7**	-13.8**	-3.8**	-3.8**
Line 5 × BIL22	4.9**	3.6**	3.3**	-3.8**	0.0	-13.8**	-11.5**	-5.2**
Line 7 × BIL22	4.9**	3.6**	-0.5	-11.4**	0.0	6.9**	-5.1**	-4.2**
Line 8 × BIL22	3.7**	2.4**	7.7**	5.1**	-6.7**	-10.3**	-6.4**	-9.9**
Line 9 × BIL22	1.2**	0.0	-9.3**	2.5	-13.3**	-13.8**	-6.4**	-10.5**
Line 10 × BIL22	4.9**	4.8**	-3.3**	-5.1**	-20.0**	-13.8**	-11.5**	-7.0**
Line 11 × BIL22	4.9**	3.6**	-6.6**	-10.1**	-6.7**	-13.8**	-10.3**	-4.7**
Line 12 × BIL22	3.7**	2.4**	13.7**	22.8**	-6.7**	-10.3**	-10.3**	-14.6**
Line 13 × BIL22	3.7**	2.4**	-1.1	-1.3	6.7**	10.3**	-7.7**	-4.6**
Line 14 × BIL22	6.2**	4.8**	8.8**	24.1**	6.7**	6.9**	-7.7**	-3.3**
Line 15 × BIL22	4.9**	3.6**	6.6**	13.9**	0.0	-10.3**	-11.5**	-15.5**
Line 16 × BIL22	4.9**	3.6**	4.9**	6.3**	0.0	-10.3**	-5.1**	-1.4
Line 17 × BIL22	-1.2**	-1.2**	9.9**	17.7**	0.0	-3.4*	-12.8**	-5.6**
Line 18 × BIL22	2.5**	2.4**	8.8**	22.8**	20.0**	17.2**	-5.1**	6.1**
Line 19 × BIL22	4.9**	4.8**	5.5**	15.2**	-6.7**	-6.9**	-9.0**	-7.5**
Line 21 × BIL22	4.9**	4.8**	8.8**	2.5	0.0	-17.2**	-11.5**	-13.6**
Line 22 × BIL22	2.5**	1.2**	-9.3**	-7.6**	-13.3**	-13.8**	-9.0**	-15.5**
Line 23 × BIL22	4.9**	4.8**	-3.3**	1.3	0.0	-10.3**	-7.7**	-1.9

Crosses	DT	DS	PH	EH	Ear Length	Seeds/row	1000 grains wt (g)	Yield (t/ha)
Line 24 × BIL22	6.2**	6.0**	-2.7**	-2.5	13.3**	3.4*	-9.0**	-2.4*
Line 25 × BIL22	6.2**	4.8**	0.5	3.8**	0.0	-10.3**	-11.5**	-6.1**
Line 27 × BIL22	1.2**	0.0	-1.1	-1.3	13.3**	10.3**	-7.7**	3.3**
Line 29 ×BIL22	2.5**	2.4**	-1.6	5.1**	-6.7**	-13.8**	-11.5**	-13.6**
Line 30 × BIL22	3.7**	2.4**	6.6**	7.6**	6.7**	0.0	-6.4**	-1.9
Line 1 × BIL28	4.9**	4.8**	4.9**	21.5**	-6.7**	-13.8**	-6.4**	-9.4**
Line 2 × BIL28	4.9**	4.8**	10.4**	24.1**	-13.3**	-6.9**	-1.3*	-0.5
Line 5 × BIL28	4.9**	3.6**	17.0**	25.3**	26.7**	17.2**	-5.1**	0.0
Line 7 × BIL28	6.2**	6.0**	0.0	2.5	0.0	3.4*	0.0	4.2**
Line 8 × BIL28	7.4**	6.0**	-3.3**	6.3**	-20.0**	-10.3**	-11.5**	-21.6**
Line 9 × BIL28	4.9**	3.6**	3.8**	6.3**	-13.3**	-13.8**	0.0	-7.5**
Line 10 × BIL28	0.0	0.0	8.8**	11.4**	-6.7**	3.4*	-6.4**	-2.9**
Line 11 × BIL28	8.6**	8.3**	9.3**	10.1**	20.0**	13.8**	-3.8**	3.8**
Line 12 × BIL28	4.9**	4.8**	15.4**	20.3**	-6.7**	-17.2**	-9.0**	-12.1**
Line 13 × BIL28	4.9**	4.8**	0.5	8.9**	-6.7**	-13.8**	-11.5**	-5.2**
Line 14 × BIL28	9.88**	9.5**	-2.2*	7.6**	20.0**	17.2**	-6.4**	4.2**
Line 15 × BIL28	4.9**	6.0**	-2.7**	-3.8**	-6.7**	-17.2**	-10.3**	-14.6
Line 16 × BIL28	4.9**	4.8**	2.2*	7.6**	20.0**	13.8**	-3.8**	5.1**
Line 17 × BIL28	0.0	0.0	4.9**	13.9**	0.0	-3.4*	-10.3**	-10.6**

Crosses	DT	DS	PH	EH	Ear Length	Seeds/row	1000 grains wt (g)	Yield (t/ha)
Line 18 × BIL28	3.7**	2.4**	4.9**	7.6**	13.3**	6.9**	-7.7**	-6.1**
Line 19 × BIL28	4.9**	6.0**	2.2*	6.3**	13.3**	10.3**	-6.4**	0.5
Line 21 × BIL28	4.9**	3.6**	19.2**	17.7**	0.0	-10.3**	-10.3**	-12.7**
Line 22 × BIL28	0.0	-1.2**	-2.7**	7.6**	-20.0**	-13.8**	-11.5**	-18.1**
Line 23 × BIL28	-1.2**	-1.2**	8.8**	8.9**	-6.7**	-10.3**	-10.3**	-12.6**
Line 24 × BIL28	4.9**	6.0**	1.6	2.5	6.7**	3.4*	-2.6**	7.0**
Line 25 × BIL28	4.9**	4.8**	6.0**	8.9**	0.0	0.0	2.6**	5.2**
Line 27 × BIL28	4.9**	4.8**	1.6**	-2.5	-6.7**	-10.3**	-10.3**	-1.4
Line 29 × BIL28	4.9**	4.8**	-2.7**	-3.8**	0.0	-13.8**	-9.0**	-12.2**
Line 30 × BIL28	4.9**	6.0**	6.0**	1.3	-6.7**	3.4*	0.0	3.8**
Mean	4.24	3.72	3.07	6.86	-0.42	-4.17	-7.64	-5.58
Minimum	-1.23	-1.19	-12.09	-11.39	-20.00	-17.24	-16.67	-21.60
Maximum	9.88	9.52	19.23	25.32	26.67	17.24	2.56	7.04
Std. Error	0.32	0.34	0.97	1.36	1.59	1.54	0.57	1.02
$CD_{(0.05)}$	0.64	0.68	1.96	2.74	3.20	3.10	1.14	2.06
$CD_{(0.01)}$	0.86	0.90	2.62	3.65	4.28	4.14	1.52	2.75

DT= Days to tasseling, DS=Days to silking, PH= Plant height (cm), EH= Ear height (cm)

Table 6. Heterosis of the crosses over BHM-9 for different characters in maize

Crosses	DT	DS	PH	EH	Ear Length	Seed/row	1000 grains wt (g)	Yield (t/ha)
Line 1 × BIL22	-3.4**	-1.1**	-20.0**	-20.0**	-16.7**	-18.2**	-9.7**	-12.8**
Line 2 × BIL22	-2.3**	-1.1**	-10.0**	-9.5**	-22.2**	-24.2**	4.2**	-6.0**
Line 5 × BIL22	-2.3**	-2.2**	-6.0**	-20.0**	-16.7**	-24.2**	-4.2**	-7.3**
Line 7 × BIL22	-2.3**	-2.2**	-9.5**	-26.3**	-16.7**	-6.1**	2.8**	-6.4**
Line 8 × BIL22	-3.4**	-3.4**	-2.0*	-12.6**	-22.2**	-21.2**	1.4*	-11.9**
Line 9 × BIL22	-5.7**	-5.6**	-17.5**	-14.7**	-27.8**	-24.2**	1.4*	-12.6**
Line 10 × BIL22	-2.3**	-1.1**	-12.0**	-21.1**	-33.3**	-24.2**	-4.2**	-9.2**
Line 11 × BIL22	-2.3**	-2.2**	-15.0**	-25.3**	-22.2**	-24.2**	-2.8**	-6.9**
Line 12 × BIL22	-3.4**	-3.4**	3.5**	2.1	-22.2**	-21.2**	-2.8	-16.5**
Line 13 × BIL22	-3.4**	-3.4**	-10.0**	-17.9**	-11.1**	-3.0*	0.0	-6.8**
Line 14 × BIL22	-1.1**	-1.1**	-1.0	3.2**	-11.1**	-6.1**	0.0	-5.5**
Line 15 × BIL22	-2.3**	-2.2**	-3.0**	-5.3**	-16.7**	-21.2**	-4.2**	-17.4**
Line 16 × BIL22	-2.3**	-2.2**	-4.5**	-11.6**	-16.7**	-21.2**	2.8**	-3.7**
Line 17 × BIL22	-8.0**	-6.7**	0.0	-2.1	-16.7**	-15.2**	-5.6**	-7.8
Line 18 × BIL22	-4.6**	-3.4**	-1.0	2.1	0.0	3.0*	2.8**	3.7**
Line 19 × BIL22	-2.3**	-1.1**	-4.0**	-4.2**	-22.2**	-18.2**	-1.4*	-9.6**
Line 21 × BIL22	-2.3**	-1.1**	-1.0	-14.7**	-16.7**	-27.3**	-4.2**	-15.6**
Line 22 × BIL22	-4.6**	-4.5**	-17.5**	-23.2**	-27.8**	-24.2**	-1.4*	-17.4**
Line 23 × BIL22	-2.3**	-1.1**	-12.0**	-15.8**	-16.7**	-21.2	0.0	-4.1**

Crosses	DT	DS	PH	EH	Ear Length	Seed/row	1000 grains wt (g)	Yield (t/ha)
Line 24 × BIL22	-1.1**	0.0	-11.5**	-18.9**	-5.6**	-9.1**	-1.4	-4.7**
Line 25 × BIL22	-1.1**	-1.1**	-8.5**	-13.7**	-16.7**	-21.2**	-4.2**	-8.3**
Line 27 × BIL22	-5.7**	-5.6**	-10.0**	-17.9**	-5.6**	-3.0*	0.0	0.9
Line 29 ×BIL22	-4.6**	-3.4**	-10.5**	-12.6**	-22.2**	-24.2**	-4.2**	-15.6**
Line 30 × BIL22	-3.4**	-3.4**	-3.0**	-10.5**	-11.1**	-12.1**	1.4*	-4.1**
Line 1 × BIL28	-2.3**	-1.1**	-4.5**	1.1	-22.2**	-24.2**	1.4*	-11.5**
Line 2 × BIL28	-2.3**	-1.1**	0.5	3.2**	-27.8**	-18.2**	6.9**	-2.8**
Line 5 × BIL28	-2.3**	-2.2**	6.5**	4.2**	5.6**	3.0*	2.8**	-2.3*
Line 7 × BIL28	-1.1**	0.0	-9.0**	-14.7**	-16.7**	-9.1**	8.3**	1.8
Line 8 × BIL28	0.0	0.0	-12.0**	-11.6**	-33.3**	-21.2**	-4.2**	-23.4**
Line 9 × BIL28	-2.3**	-2.2**	-5.5**	-11.6**	-27.8**	-24.2**	8.3**	-9.6**
Line 10 × BIL28	-6.9**	-5.6**	-1.0	-7.4**	-22.2**	-9.1**	1.4*	-5.1**
Line 11 × BIL28	1.1**	2.2**	-0.5	-8.4**	0.0	0.0	4.2**	1.5
Line 12 × BIL28	-2.3**	-1.1**	5.0**	0.0	-22.2**	-27.3**	-1.4*	-14.1**
Line 13 × BIL28	-2.3**	-1.1**	-8.5**	-9.5**	-22.2**	-24.2**	-4.2**	-7.3**
Line 14 × BIL28	2.3**	3.4**	-11.0**	-10.5**	0.0	3.0*	1.4*	1.8
Line 15 × BIL28	-2.3**	0.0	-11.5**	-20.0**	-22.2**	-27.3**	-2.8**	-16.5**
Line 16 × BIL28	-2.3**	-1.1**	-7.0**	-10.5**	0.0	0.0	4.2**	2.7**
Line 17 × BIL28	-6.9**	-5.6**	-4.5**	-5.3**	-16.7**	-15.2**	-2.8**	-12.7**

Crosses	DT	DS	PH	EH	Ear Length	Seed/row	1000 grains wt (g)	Yield (t/ha)
Line 18 × BIL28	-3.4**	-3.4**	-4.5**	-10.5**	-5.6**	-6.1**	0.0	-8.3**
Line 19 × BIL28	-2.3**	0.0	-7.0**	-11.6**	-5.6**	-3.0**	1.4*	-1.8
Line 21 × BIL28	-2.3**	-2.2**	8.5**	-2.1	-16.7**	-21.2**	-2.8**	-14.7**
Line 22 × BIL28	-6.9**	-6.7**	-11.5**	-10.5**	-33.3**	-24.2**	-4.2**	-20.0**
Line 23 × BIL28	-8.0**	-6.7**	-1.0	-9.5**	-22.2**	-21.2**	-2.8**	-14.6**
Line 24 × BIL28	-2.3**	0.0	-7.5**	-14.7**	-11.1**	-9.1**	5.6**	4.6**
Line 25 × BIL28	-2.3**	-1.1**	-3.5**	-9.5**	-16.7**	-12.1**	11.1**	2.8**
Line 27 × BIL28	-2.3**	-1.1**	-7.5**	-18.9**	-22.2**	-21.2**	-2.8**	-3.7**
Line 29 × BIL28	-2.3**	-1.1**	-11.5**	-20.0**	-16.7**	-24.2**	-1.4*	-14.2**
Line 30 × BIL28	-2.3**	0.0	-3.5**	-15.8**	-22.2**	-9.1**	8.3**	1.4
Mean	-2.95	-2.11	-6.21	-11.14	-17.01	-15.78	0.06	-7.74
Min	-8.05	-6.74	-20.00	-26.32	-33.33	-27.27	-9.72	-23.39
Max	2.30	3.37	8.50	4.21	5.56	3.03	11.11	4.59
SE	0.30	0.32	0.89	1.13	1.33	1.36	0.61	1.00
$CD_{(0.05)}$	0.60	0.64	1.78	2.28	2.67	2.73	1.24	2.01
$CD_{(0.01)}$	0.80	0.85	2.38	3.04	3.56	3.64	1.65	2.68

Heterosis

The standard heterosis expressed by the F_1 hybrids over the two standard checks namely NK-40 and BHM-9 (commercial hybrid)) for different characters are presented in Table 5 and 6. The percent of heterosis in F_1 hybrids varied from character to character and cross to cross.

For grain yield, the percent heterosis for kernel yield varied from -21.60 to 7.0% when compared with standard commercial variety of NK-40 (10.65 t/ha). Among the 48 F_1s, nine crosses exhibited significant positive heterosis for kernel yield (Table 5). The highest heterosis 7.0% was exhibited by the cross Line 24 × BIL28 followed by Line 18 × BIL22 (6.1%) and Line 25 × BIL28 (5.2%). Talukder *et al*. (2016) found -51.39 to 12.53% heterosis when used NK-40 as a check in their study.

When BHM-9 used as check (10.90 t/ha), the percent heterosis for kernel yield varied from -23.39 to 4.6%. Karim *et al*. (2018) found -13.04 to 5.25% heterosis in their study.It showed that among the 48 F_1s, four crosses exhibited significant positive heterosis for kernel yield (Table 6). The highest heterosis 4.6% was exhibited by the cross Line 24 × BIL28 followed by Line 18 × BIL22 (3.7%) and Line 25 × BIL28 (2.8%).

Conclusion

Five lines viz., Line 11, Line 14, Line 14, Line 17 and Line 30 were good general combiner for grain yield. Nine (Line 18 × BIL22, Line 23 × BIL22, Line 27 × BIL22, Line 7 × BIL28, Line 14 × BIL28, Line 24 × Line BIL28, BIL 25 × BIL28 and BIL 30 × BIL28) crosses showed significant and specific combining ability effect for grain yield. Considering SCA and GCA value and heterosis study promising inbred (S_6) lines could be developed which may be utilized for future maize breeding work.

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