Ann. Bangladesh Agric. (2016) 20(1 & 2) : 1-14
ISSN 1025-482X (Print)
2521-5477 (Online)

LINE × TESTER ANALYSIS FOR YIELD AND RELATED TRAITS IN MAIZE

M. Z. A. Talukder*, A. N. M. S. Karim, S. Ahmed, M. Amiruzzaman and M. Q. I. Matin

Abstract

Early generation evaluation of inbred lines through line × tester method was conducted at Bangladesh Agricultural Research Institute, Gazipur during Rabi 2014-15 involving 26 S_4 lines of maize (*Zea mays* L.) variety Pinacle and three testers for grain yield, yield components and other characters to estimate the general combining ability of the lines and specific combining ability effects of the crosses and to evaluate the test cross performance of the hybrids for grain yield and yield related traits. Performance of the test crosses was evaluated with their parents in alpha lattice design with three replications. Highly significant genotypic differences were observed indicating wide range of variability present among them. Eight lines viz., Pinacle S_4-1, Pinacle S_4-2, Pinacle S_4-5, Pinacle S_4-6, Pinacle S4-15, Pinacle S_4-19, Pinacle S_4-28, and Pinacle S_4-30 were good general combiners for grain yield and possessed high means also. The crosses with significant specific combining ability effect for grain yield were Pinacle S_4-2 × BIL79, Pinacle S_4-5 × BIL79, Pinacle S_4-8 × BIL79, Pinacle S_4-10× BIL79, Pinacle S_4-15× BIL79, Pinacle S_4-19× BIL79, Pinacle S_4-28× BIL79, Pinacle S_4-2× BIL106, Pinacle S_4-6× BIL106, Pinacle S_4-15× BIL106, Pinacle S_4-19× BIL106, Pinacle S_4-22× BIL106, Pinacle S_4-2× BIL28, Pinacle S_4-5× BIL28, Pinacle S_4-6× BIL28, Pinacle S_4-13× BIL28, Pinacle S_4-15× BIL28, and Pinacle S_4-24× BIL28 evolved mostly from low × low general combiner parents that revealed dominance × dominance type of gene action. These 17 combinations might be used for obtaining high yielding hybrids. The information on the nature of gene action with respective variety and character might be used depending on the breeding objectives. Heterosis estimation was carried out using two commercial varieties BHM 9 and NK40. When standard commercial check NK40 was used, the percent heterosis for grain yield varied from 33.20 to 12.30 %. Among the 78 crosses, 11 crosses exhibited significant positive and heterosis for grain yield. Higher heterosis was exhibited by the crosses Pinacle S_4-15 x BIL 79 (12.30%), Pinacle S_4-5 x BIL 79 (11.07%), and Pinacle S_4-2 x BIL 106 (7.46%). The crosses showing significant positive specific combining ability (SCA) values could be used for variety development after verifying them across the agro-ecological zones of Bangladesh.

Keywords: Maize, inbred lines, yield, combining ability, hybrid.

Introduction

Based on genetic structure, several types of hybrids are possible in maize (*Zea mays* L.); 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 have been used broadly in breeding of several economic

---

Plant Breeding Division, Bangladesh Agricultural Research Institute (BARI), Gazipur 1701, Bangladesh.
*Corresponding author: zahirbari@yahoo.com

species of crop. For maize yield, they found that the significance of general combining ability was more than specific combining ability for unselected inbred lines, while specific combining ability was more significant than general combining ability for previously selected lines. They also stated that the general combining ability is largely due to the additive effect of genes, while in specific combining ability, dominance or epistatic effects of genes are commonly involved. They also declared that the additive effect of genes affected the general combining ability, while in specific combining ability dominance or epistatic effects of genes are usually involved. 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, which 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 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 to evaluate the combining ability patterns of selected maize S_4 lines obtained from commercial maize hybrid variety Pinacle for grain yield and yield related traits and to identify and select superior hybrid combinations based on crosses of selected lines with testers and determines percent of heterosis using standard commercial check.

Materials and Methods

Twenty six S_4 generation inbred lines (as female parents) and three testers (as male parents) of maize were selected and crossed in a line × tester fashion to generate 78 cross combinations in Rabi 2013-14 at Bangladesh Agricultural Research Institute, Gazipur. In the following Rabi 2014-15, seeds of 26 parental lines, 78 test crosses, three testers (BIL79, BIL106, and BIL28) and two check varieties (BARI Hybrid Maize-9 and commercial hybrid NK40) were sown following Alpha Lattice Design with two replications. Each entry was planted in two rows of 4 m long plot. The spacing between rows was 60 cm and plant to plant distance was 20 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 per 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 genotypes for all the studied characters indicating wide range of genetic variability among the genotypes. The analysis of variance for combining ability revealed significant differences in the variance due to the parents, parents vs. crosses, crosses, lines, testers, and lines × testers for several characters under study (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. Analysis of variance for parents was 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 the traits indicating wide range of variability present among them. Mean squares due to crosses were highly significant for grain yield, 1000- kernel weight, days to tasseling, and silking, plant and ear height, and ear length. This indicates that the crosses were sufficiently different from each other for these traits and hence, selection is possible to identify the most desirable crosses. The variance among the lines was highly significant for all the traits except seeds per row whereas, variance among testers were significant for days to tasseling, days to silking, plant height, ear height, and 1000-grain weight. The interaction of line × tester also showed highly significant difference for all the traits except seeds per row, which was consistent with that of 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 six characters (Table 1) was observed probably due to predominance of non-additive gene action which suggests the scope of improvement of these characters through heterosis breeding. Similar non-additive gene action was also reported by Suneetha *et al.* (2000) for days to 50% tasselling and days to 50% silking. Singh and Singh (1998) reported

Table 1. Mean squares and estimates of variance for grain yield, yield components and other characters in maize during rabi 2014-15

Source	df	Days to tasseling	Days to silking	Plant height (cm)	Ear height (cm)	Ear length (cm)	Seeds/row	1000- grain wt (g)	Yield (t/ha)
Genotypes	106	33.18**	33.29**	1623.41**	811.83**	15.97**	77.42**	3213.73**	17.77**
Parents	28	64.39**	64.19**	452.78**	161.34**	7.72**	81.92**	1068.23**	0.94**
Parents vs Crosses	1	301.21**	346.98**	122048.2**	59107.94**	873.69**	4097.42**	256554.8**	1673.3**
Crosses	77	18.35**	17.98**	485.14**	291.28**	7.83**	23.58	703.77**	2.38**
Lines	25	28.12**	28.34**	599.71**	549.75**	6.06**	31.54	511.68**	1.12**
Testers	2	17.90**	21.46**	458.90**	40.68*	0.24	3.19	52.41**	0.19
Lines x Testers	50	13.48**	12.65**	428.90**	172.07**	9.03**	20.41	825.88**	3.11**
Error	106	2.78	3.51	93.66	16.15	1.06	18.50	114.66	0.07
Estimates of variance component									
σ^2g (line)		2.44	2.61	28.47	62.95	-0.49	1.86	-52.37	-0.33
σ^2g (tester)		0.09	0.17	0.58	-2.53	-0.17	-0.33	-14.87	-0.06
σ^2gca		0.05	0.06	0.63	1.34	-0.01	0.04	-1.37	-0.01
σ^2sca		5.35	4.57	167.62	77.96	3.98	0.96	355.61	1.52
σ^2gca/σ^2sca		0.01	0.01	0.004	0.02	-0.002	0.04	-0.003	-0.01

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

non-additive gene action for plant height, ear length, kernel rows, 1000- grain weight, and Mahto and Ganguly (2001) reported non-additive gene action for grain yield.

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. This suggested that 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 the lowest to total variance, which was in conformity with that of Rissi *et al.* (1991); Amiruzzaman and Amin (2011) and Talukder and Banik (2012).

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 testers) are presented in Table 3. The GCA effects of parents indicated that line Pinacle S_4-5, Pinacle S_4-18, Pinacle S_4-23, Pinacle S4-28, and Pinacle S_4-30 exhibited significant negative GCA effects for both days to tasseling and silking. These lines could be utilized for earliness. Roy *et al.* (1998); Hussain *et al.* (2003) and Uddin *et al.* (2006) also observed similar phenomenon in their studies. For both of plant and ear height, line Pinacle S_4-5, Pinacle S_4-6, Pinacle S_4-14, Pinacle S_4-15, and Pinacle S_4-30 contributed highly significant negative effects for evolving shorter plant and ear height indicating to develop dwarf hybrids. The lines Pinacle S_4-2 and Pinacle S_4-30 exhibited significant positive GCA effect both for ear length and seeds per row which ultimately could contribute for evolving longer ears and more seeds per row. The lines Pinacle S_4-1, Pinacle S_4-2, Pinacle S_4-5, Pinacle S_4-19, and Pinacle S_4-30 showed positive GCA effect for bold grains. The lines Pinacle S_4-1, Pinacle S_4-2, Pinacle S_4-5, Pinacle S_4-6, Pinacle S4-15, Pinacle S_4-28, and Pinacle S_4-30 expressed highly significant positive GCA effects for yield that indicated good general combiner for exploiting more positive alleles for yield. These seven lines had high mean values for grain yield also (Table 3) and could be extensively utilized for high yields. 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

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 wt (g)	Yield (t/ha)
Due to line	49.76	51.19	40.13	61.278	52.12	53.44	53.61	52.20
Due to tester	2.53	3.10	2.46	0.363	0.08	0.35	0.19	0.21
Due to line × tester	47.70	45.71	57.41	38.359	49.81	46.21	46.20	47.59

hybridization program to improve a particular trait through transgressive segregation.

Specific combining ability effects

The SCA effect and mean performances of the crosses are presented in Table 4. Among the 78 cross combinations, highly significant and negative SCA effects were exhibited by 11 crosses both for days to tasseling and days to silking. These crosses mainly involved high × average, average × average, and low × average general combining parents. For plant height and ear height, each of eight crosses showed significant negative SCA effects for these

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

Parents	Days to tasseling		Days to silking		Plant height (cm)		Ear height (cm)	
	GCA	mean	GCA	mean	GCA	mean	GCA	mean
Testers								
BIL79	0.58	99	0.58	102	3.10	132.00	0.94	56
BIL106	0.02	104	0.12	108	-0.27	135.00	-0.13	53
BIL28	-0.60	101	-0.69	104	-2.83	130.00	-0.81	49
SE(gi)	0.23		0.26		1.34		0.56	
SE(gi-gj)	0.33		0.37		1.90		0.79	
Lines								
Pinacle S_4-1	1.47*	87	2.03**	90	0.47	114.00	-6.2**	46
Pinacle S_4-2	1.63**	97	1.53*	100	5.13	151.00	1.1	62
Pinacle S_4-3	1.13	97	1.36**	100	13.97**	154.00	3.4*	69
Pinacle S_4-4	-0.37	97	0.03	100	-4.37	160.00	9.6**	71
Pinacle S_4-5	-1.53**	89	-1.97**	92	-7.70*	147.00	-14.6**	62
Pinacle S_4-6	0.63	97	1.53**	100	-17.37**	138.00	-15.1**	58
Pinacle S_4-7	-1.20*	94	-1.14	97	-4.87	157.00	-11.6**	62
Pinacle S_4-8	1.63**	97	2.19**	100	1.97	145.00	-7.9**	59
Pinacle S_4-9	2.97**	90	2.53**	93	0.97	137.50	-3.4*	51
Pinacle S_4-10	2.47**	100	2.69**	103	-2.20	142.50	-3.1*	55
Pinacle S_4-11	0.80	84	0.36	88	14.13**	160.00	13.3**	72
Pinacle S_4-12	2.63**	90	2.53**	93	17.30**	138.00	20.8**	52
Pinacle S_4-13	1.13	97	0.36	100	-8.87*	152.00	6.6**	46
Pinacle S_4-14	-1.37*	90	-1.14	93	-17.70**	106.50	-9.1**	37
Pinacle S_4-15	-0.70	88	-0.81	92	-13.20**	143.00	-3.9*	50
Pinacle S_4-16	-0.37	95	-0.31	98	17.80**	125.00	16.3**	43
Pinacle S_4-18	-3.03**	100	-3.47**	103	3.47	160.00	11.1**	62
Pinacle S_4-19	0.97	86	0.86	89	-6.70	149.00	-0.9	58
Pinacle S_4-20	2.63**	96	2.53**	99	1.13	164.00	-0.2	69

Table 3. Cont'd.

Pinacle S_4-21	2.47**	91	2.03**	94	5.97	158.00	7.4**	67
Pinacle S_4-22	0.47	84	0.53	87	8.30*	161.00	7.1**	68
Pinacle S_4-23	-2.53**	84	-2.14**	87	-0.87	136.50	-4.2**	57
Pinacle S_4-24	-2.37	95	-2.47**	98	8.47*	164.50	0.3	67
Pinacle S_4-26	-0.87	90	-0.81	94	0.47	162.50	-2.6	67
Pinacle S_4-28	-3.03**	100	-3.47**	103	-0.03	155.00	0.9	61
Pinacle S_4-30	-5.70**	86	-5.31**	89	-15.70**	160.00	-14.9**	64
SE(gi)	0.68		0.76		3.95		1.64	
SE(gi-gj)	0.96		1.08		5.59		2.32	

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

Table 3. Cont'd.

Parents	Ear length (cm)		Seeds/row		1000- grain wt (g)		Yield (t/ha)	
Tester	GCA	mean	GCA	mean	GCA	mean	GCA	mean
BIL79	0.06	11	0.28	20	-0.33	235	-0.07	4.05
BIL106	-0.07	9	-0.09	15	-0.79	245	0.05	3.43
BIL28	0.01	10	-0.19	18	1.13	230	0.02	3.76
SE(gi)	0.14		0.60		1.48		0.04	
SE(gi-gj)	0.20		0.84		2.10		0.05	
Lines								
Pinacle S_4-1	0.48	12	1.33	18	12.22**	290	0.50**	4.20
Pinacle S_4-2	1.91**	15	3.00*	27	24.55**	305	0.86**	5.79
Pinacle S_4-3	-0.69	11	2.73	27	-7.78*	275	-0.70**	4.12
Pinacle S_4-4	-0.55	14	0.37	29	-2.78	300	-0.25**	5.40
Pinacle S_4-5	1.98**	16	2.90	24	17.22**	315	0.65**	5.90
Pinacle S_4-6	1.81**	13	0.83	17	2.22	310	0.40**	5.35
Pinacle S_4-7	0.05	11	0.50	24	-4.45	285	-0.17	4.15
Pinacle S_4-8	0.61	13	2.87	45	-1.12	315	-0.02	5.45
Pinacle S_4-9	0.78*	10	0.93	21	0.55	280	-0.09	3.80
Pinacle S_4-10	-0.69	14	-0.93	30	-6.12	300	-0.14	4.20
Pinacle S_4-11	-0.92*	14	-3.10*	26	-2.78	295	0.09	5.15
Pinacle S_4-12	-1.72**	11	-2.33	22	-16.12**	275	-0.37**	4.09
Pinacle S_4-13	-0.72*	13	-2.42	23	-1.12	310	0.04	5.25
Pinacle S_4-14	-0.25	12	1.65	18	3.88	285	-0.08	4.26

Table 3. Cont'd.

Pinacle S_4-15	-0.65	16	-2.48	28	-1.12	325	0.90**	6.15
Pinacle S_4-16	-1.29**	12	-1.02	22	-9.45*	305	-0.50**	4.20
Pinacle S_4-18	-1.25**	13	-6.38**	18	-1.12	300	-0.14	5.15
Pinacle S_4-19	-0.12	15	0.93	16	8.88*	310	0.17**	5.76
Pinacle S_4-20	0.11	11	-1.27	28	-1.12	285	-0.16	3.90
Pinacle S_4-21	0.68	13	-0.03	30	-2.78	300	0.14*	5.20
Pinacle S_4-22	-0.82*	14	-0.03	36	-17.78**	310	-1.11	5.55
Pinacle S_4-23	0.71	11	-1.03	27	-4.45	295	-0.39**	4.77
Pinacle S_4-24	0.08	14	-1.67	24	2.22	315	0.10	4.20
Pinacle S_4-26	-0.39	15	2.37	29	-6.12	280	-0.30**	4.40
Pinacle S_4-28	-0.49	14	-0.80	30	5.55	285	0.32**	5.35
Pinacle S_4-30	1.35**	14	3.10*	28	8.88*	295	0.42**	5.60
SE(gi)	0.42		1.76		4.37		0.11	
SE(gi-gj)	0.59		2.48		6.18		0.15	

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

two traits. These crosses mainly involved high × average, average × average, and low × average general combining parents. In maize, negative values days to tasseling, days to silking, plant height, and ear height are expected for earliness and dwarf plant type, respectively. For ear length, seeds per row, and 1000-grain weight, significant positive SCA effects were observed in 16, one, and 15 crosses, respectively. Positive SCA effect is expected for these yield components. In case of grain yield, 17 crosses (Line 2 × BIL79, Line 5 × BIL79, Line 8 × BIL79, Line 10 × BIL79, Line 15 × BIL79, Line 19 × BIL79, Line 28 × BIL79, Line 2 × BIL106, Line 6 × BIL106, Line 15 × BIL106, Line 19 × BIL106, Line 22 × BIL106, Line 2 × BIL28, Line5 × BIL28, Line 6 × BIL28, Line 13 × BIL28, Line 15 × BIL28, and Line 24 × BIL28) exhibited significant positive SCA effects. These crosses also had high mean values for grain yield also. These crosses mainly involved high × average, average × average, low × average, high × low, average × low, and low × low general combining parents. In general, 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. These results are in agreement with the earlier findings of Das and Islam (1994) and Lata *et al.* (2006) in maize.

Table 4. Specific combining ability (SCA) and mean of crosses for grain yield and its components 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 × BIL79	-0.41	92	-0.41	96	-11.43*	192.00	-8.28**	82
Line 2 × BIL79	0.65	93	0.55	96	14.94*	215.00	12.80**	102
Line 3 × BIL79	-0.24	91	-0.14	95	-3.51	194.00	-4.52	84
Line 4 × BIL79	-0.58	92	-0.91	95	-6.10	202.00	-1.61	96
Line 5 × BIL79	-1.02	91	-0.95	94	8.77	213.50	1.97	99
Line 6 × BIL79	1.60	93	1.86	96	-2.67	199.50	-0.36	96
Line 7 × BIL79	-1.08	91	-1.74	94	-1.93	215.00	-0.44	100
Line 8 × BIL79	0.98	93	1.22	96	10.94	224.50	9.63**	109
Line 9 × BIL79	0.10	91	0.53	95	-9.01	202.00	-9.19**	89
Line 10 × BIL79	1.92	93	1.59	96	17.40**	216.00	3.89	110
Line 11 × BIL79	-2.02*	88	-1.95	92	15.27*	210.50	-2.53	103
Line 12 × BIL79	0.10	90	0.36	93	-32.67**	160.00	-1.36	103
Line 13 × BIL79	-0.91	89	-0.91	91	3.24	198.50	7.06**	89
Line 14 × BIL79	-0.85	88	-0.45	91	-2.90	189.00	-2.87	78
Line 15 × BIL79	1.76	90	1.36	92	-0.34	189.00	-4.19	76
Line 16 × BIL79	1.42	93	1.59	97	-12.60*	173.00	-9.44**	72
Line 18 × BIL79	-0.02	91	-0.45	95	-23.73**	158.50	-0.37	80
Line 19 × BIL79	-1.40	89	-1.14	93	36.33**	216.00	9.81**	90
Line 20 × BIL79	2.26*	92	2.76*	96	-9.10	189.00	-9.44**	76
Line 21 × BIL79	-2.19*	87	-2.28*	90	2.27	197.00	3.63	88
Line 22 × BIL79	-0.07	89	-0.47	91	6.83	199.00	5.81*	89
Line 23 × BIL79	-0.08	93	-0.08	96	9.07	214.00	5.89*	95
Line 24 × BIL79	-0.02	92	-0.12	96	-9.56	192.00	-0.53	87
Line 26 × BIL79	0.10	92	0.19	95	0.49	199.50	-5.36*	82
Line 28 × BIL79	-1.91	92	-1.41	95	2.57	206.50	0.46	94
Line 30 × BIL79	0.65	94	0.55	97	-2.56	198.00	-2.07	90
Line 1 ×BIL106	1.26	94	0.86	96	-0.01	198.00	1.61	93
Line 2 × BIL106	1.09	95	1.42	98	2.24	203.00	-2.94	91
Line 3 × BIL106	-2.35	91	-2.62	94	-9.40	188.00	-12.37**	80
Line 4 × BIL106	1.26	94	1.19	97	7.16	202.00	15.31**	107
Line 5 × BIL106	-0.24	92	0.26	95	2.40	219.50	0.72	111
Line 6 × BIL106	2.81**	94	2.72*	97	2.27	216.00	3.80	113
Line 7 × BIL106	-2.57*	88	-2.97*	90	-4.67	206.50	-4.52	104

Table 4. Cont’d.

Line 8 × BIL106	-0.58	93	-0.91	96	-3.26	217.00	-4.78	113
Line 9 × BIL106	-0.52	93	-0.45	96	-0.40	216.50	-1.20	115
Line 10 × BIL106	1.10	94	1.36	97	3.66	218.00	5.98*	122
Line 11 × BIL106	-3.58**	89	-3.24**	91	29.40**	223.50	6.86**	110
Line 12 × BIL106	0.48	92	0.22	94	-25.73**	165.00	1.53	104
Line 13 × BIL106	3.10**	94	3.03**	96	-3.67	184.50	-8.39*	93
Line 14 × BIL106	-4.08**	86	-3.24**	90	-2.76	182.50	-3.44	84
Line 15 × BIL106	3.48**	93	3.22**	96	14.10*	196.00	-1.87	85
Line 16 × BIL106	0.60	89	0.03	92	-11.34	168.00	5.31	91
Line 18 × BIL106	-0.74	90	-1.08	92	-9.76	180.00	4.39	97
Line 19 × BIL106	-3.19**	87	-3.12*	90	-8.90	177.50	-10.53**	81
Line 20 × BIL106	3.93**	93	4.19**	96	18.66**	202.50	6.14*	97
Line 21 × BIL106	-1.08	90	-1.08	93	1.74	222.50	3.72	117
Line 22 × BIL106	3.98**	94	3.88**	97	-11.40*	206.00	-12.70**	99
Line 23 × BIL106	-2.90**	87	-2.81*	90	9.66	224.50	8.98**	120
Line 24 × BIL106	0.09	88	0.09	91	13.57*	220.00	13.39**	121
Line 26 × BIL106	-0.35	87	-0.45	90	-11.56*	191.50	-14.53**	92
Line 28 × BIL106	0.26	87	0.36	90	-2.01	198.50	1.14	107
Line 30 × BIL106	5.09**	97	4.76**	100	-5.76	190.50	1.39	97
Line 1 × BIL28	-4.35**	87	-4.28**	90	1.10	194.00	-0.53	94
Line 2 × BIL28	-0.74	90	-0.47	93	4.66	195.00	-0.86	93
Line 3 × BIL28	0.42	94	0.59	97	-13.10*	191.00	-11.78**	85
Line 4 × BIL28	-0.02	93	-0.45	96	13.27*	214.00	15.30**	111
Line 5 × BIL28	-0.40	92	-0.14	95	-0.17	198.00	-3.52	91
Line 6 × BIL28	1.59	95	1.09	97	-3.93	205.00	-3.44	101
Line 7 × BIL28	-3.35**	90	-2.95*	93	-5.06	200.50	9.63	113
Line 8 × BIL28	1.76	94	1.86	97	8.99	212.00	-6.19*	96
Line 9 × BIL28	1.59	93	1.59	96	-27.26**	184.00	-20.61**	83
Line 10 × BIL28	4.65**	96	4.55**	99	16.10	224.00	11.97**	115
Line 11 × BIL28	-6.24**	84	-6.14**	87	11.16	216.50	8.64**	111
Line 12 × BIL28	1.59	90	1.26	93	-0.10	202.00	5.72*	98
Line 13 × BIL28	1.15	89	1.72	93	12.77*	211.50	0.80	92
Line 14 × BIL28	-2.74*	85	-2.97**	88	-12.67*	183.50	-6.52**	84
Line 15 × BIL28	-3.08**	86	-2.41**	89	1.57	213.00	4.72	102
Line 16 × BIL28	1.98*	90	2.05	93	-5.56	202.50	-4.70	91

Table 4. Cont’d.

Line 18 × BIL28	1.10	89	0.36	91	3.99	209.50	-0.02	95
Line 19 × BIL28	2.92**	93	1.92	95	3.57	207.00	-5.94*	88
Line 20 × BIL28	-1.52	88	-1.12	92	-6.06	194.00	0.13	93
Line 21 × BIL28	-1.40	88	-0.81	91	2.49	200.00	5.81*	98
Line 22 × BIL28	-0.41	88	-0.41	90	13.57*	216.50	15.56**	113
Line 23 × BIL28	1.15	89	1.55	92	1.44	201.00	-5.87*	91
Line 24 × BIL28	-0.74	86	-1.14	88	-15.01*	182.00	-9.69**	86
Line 26 × BIL28	-1.24	84	-1.08	88	6.74	194.00	8.39**	90
Line 28 × BIL28	-0.19	85	-0.62	88	9.60	193.50	1.47	82
Line 30 × BIL28	1.43	86	1.69	89	-16.34**	165.00	-9.86**	70
SE(Sij)	1.18		1.32		6.84		2.84	
SE(Sij-Skl)	1.67		1.87		9.68		4.02	

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

Table 4. Cont’d.

Crosses	Ear length		Seeds/row		1000-grain wt		Yield (t/ha)	
	SCA	mean	SCA	mean	SCA	mean	SCA	mean
Line 1 × BIL79	-1.73**	16	-7.35**	29	-6.33	375	-0.17	11.58
Line 2 × BIL79	3.91**	22	5.02	41	24.13**	405	1.45**	13.31
Line 3 × BIL79	-2.18**	16	2.32	38	-17.79*	365	-1.28**	10.55
Line 4 × BIL79	-1.66*	18	1.09	39	-11.67	382	-0.47**	11.64
Line 5 × BIL79	1.47*	21	-0.45	37	21.79	415	1.33**	13.55
Line 6 × BIL79	0.19	19	-0.64	37	-10.13	385	-0.86**	11.34
Line 7 × BIL79	-0.56	16	-1.15	36	-6.33	355	-0.25	10.30
Line 8 × BIL79	3.57**	20	1.32	39	29.13**	390	1.49**	12.15
Line 9 × BIL79	-3.01**	14	-0.18	37	-22.79**	340	-1.24**	9.39
Line 10 × BIL79	2.10**	19	3.02	38	33.67**	400	1.45**	12.45
Line 11 × BIL79	0.04	17	-4.11	31	-10.87	355	-0.22	10.90
Line 12 × BIL79	-2.14**	15	1.09	36	-22.79**	345	-1.23**	9.85
Line 13 × BIL79	0.77	20	0.29	38	-1.33	385	0.25	12.15
Line 14 × BIL79	-3.59**	16	-1.25	36	-30.87**	355	-1.97**	10.05
Line 15 × BIL79	2.82**	22	0.96	38	32.21**	420	1.71**	13.70
Line 16 × BIL79	-1.56*	18	-3.85	32	13.67*	385	0.30	11.96
Line 18 × BIL79	-3.43**	16	2.52	38	-20.87**	350	-1.52**	10.25
Line 19 × BIL79	4.99**	24	1.32	37	7.21	380	1.21**	12.95
Line 20 × BIL79	-2.80**	15	3.49	39	-29.67**	335	-1.17**	9.91
Line 21 × BIL79	1.54*	19	-2.45	33	5.79	370	0.21	11.40

Table 4. Cont'd.

Line 22 × BIL79	1.26*	19	-1.04	34	23.87**	390	0.15	11.36
Line 23 × BIL79	-1.36*	17	0.22	38	-8.00	360	-0.86**	10.36
Line 24 × BIL79	1.27*	19	0.29	38	7.46	375	0.10	11.20
Line 26 × BIL79	0.09	18	-0.51	37	0.54	370	0.20	11.51
Line 28 × BIL79	1.57*	20	3.55	39	5.33	375	0.75**	11.33
Line 30 × BIL79	-0.39	18	0.32	36	-14.21**	355	-0.66**	10.79
Line 1 × BIL106	-1.18	17	-3.88	31	8.87	380	0.27	11.20
Line 2 × BIL106	2.94**	20	4.62	39	32.00**	395	2.01**	13.11
Line 3 × BIL106	-2.93**	14	-5.11*	28	-27.54**	335	-1.76**	9.46
Line 4 × BIL106	-0.01	17	0.49	34	-4.46	360	-0.24	10.95
Line 5 × BIL106	1.17	18	1.89	34	8.67	375	0.21	12.14
Line 6 × BIL106	1.51*	18	2.65	34	19.13**	385	1.16**	12.61
Line 7 × BIL106	-2.68**	14	-4.54	27	-27.79**	340	-1.97**	9.45
Line 8 × BIL106	0.57	16	-1.28	31	2.00	355	0.25	11.21
Line 9 × BIL106	-1.39*	14	0.89	33	-12.54	340	-0.95**	10.05
Line 10 × BIL106	0.82	16	0.39	32	10.54	365	0.20	11.10
Line 11 × BIL106	0.77	17	-0.60	32	7.00	375	0.15	11.00
Line 12 × BIL106	-1.89**	15	-4.88	27	-17.54*	350	-0.79**	10.62
Line 13 × BIL106	1.12	18	5.47*	37	10.54	380	0.15	11.10
Line 14 × BIL106	-1.50*	16	2.54	39	-13.00*	360	-1.02**	10.70
Line 15 × BIL106	1.64*	19	3.65	40	12.46	385	1.12**	12.95
Line 16 × BIL106	-0.14	17	-6.19*	30	0.54	375	-0.10	11.70
Line 18 × BIL106	-0.20	16	3.17	36	-3.00	365	-0.20	11.05
Line 19 × BIL106	1.54*	18	-4.71	27	17.46*	385	0.83**	12.20
Line 20 × BIL106	-1.34*	15	1.54	33	-14.46*	355	-0.64**	10.70
Line 21 × BIL106	0.74	17	-0.35	33	0.33	360	0.06	10.81
Line 22 × BIL106	1.67*	18	1.77	35	15.79*	375	1.21**	12.08
Line 23 × BIL106	-2.41**	14	-1.43	32	-16.13*	345	-1.28**	9.56
Line 24 × BIL106	-0.20	16	-2.13	26	-3.00	365	0.19	11.30
Line 26 × BIL106	-0.26	16	0.49	29	7.46	375	0.12	11.35
Line 28 × BIL106	0.46	16	1.64	30	-4.46	365	-0.32*	10.88
Line 30 × BIL106	-1.23*	16	-2.75	33	-18.00*	360	-0.87**	10.55
Line 1 × BIL28	-0.39	17	1.52	37	2.46	380	-0.58**	10.95
Line 2 × BIL28	1.62*	19	1.22	37	15.54*	395	1.45**	12.95
Line 3 × BIL28	0.34	18	0.15	34	12.00	380	0.20	11.08
Line 4 × BIL28	-0.53	17	-0.48	33	-27.54	340	-0.98**	10.22

Table 4. Cont'd.

Line 5 × BIL28	0.19	18	0.32	33	15.54	385	0.98**	12.15
Line 6 × BIL28	1.07	19	0.62	35	18.67*	385	1.21**	12.60
Line 7 × BIL28	-1.19	17	0.39	35	-10.87	355	-1.35**	10.16
Line 8 × BIL28	0.12	18	-1.01	33	-7.79	360	0.14	11.62
Line 9 × BIL28	0.37	17	0.72	36	-26.33**	325	-1.99**	8.15
Line 10 × BIL28	0.21	17	0.09	35	-0.87	350	0.04	11.10
Line 11 × BIL28	-0.58	16	-0.81	34	27.21**	380	0.15	11.38
Line 12 × BIL28	-0.96	17	-3.88	30	-14.67*	350	-0.96**	9.90
Line 13 × BIL28	2.17**	20	2.89	36	30.79**	395	1.94*	12.91
Line 14 × BIL28	-1.21	17	0.99	34	-16.13*	350	-0.98**	9.97
Line 15 × BIL28	0.67	18	-0.95	32	3.67	375	0.77**	12.12
Line 16 × BIL28	-0.19	17	-3.28	30	4.13	375	0.04	11.51
Line 18 × BIL28	-0.48	17	4.22	37	-7.79	365	-0.82**	10.62
Line 19 × BIL28	0.84	18	-0.18	37	7.00	370	0.20	11.20
Line 20 × BIL28	-2.23**	15	0.49	37	-7.54	355	-1.08**	9.99
Line 21 × BIL28	1.39*	18	-0.31	36	0.54	365	-0.02	11.02
Line 22 × BIL28	0.24	17	-0.11	34	0.33	375	-0.12	11.45
Line 23 × BIL28	-2.13**	15	2.25	36	-19.21**	355	-0.89**	10.80
Line 24 × BIL28	1.89**	19	-2.14	31	18.87**	395	1.01**	12.67
Line 26 × BIL28	-0.40	18	-0.81	37	-3.00	375	-0.77**	10.90
Line 28 × BIL28	0.04	19	0.15	38	2.46	380	0.25	12.13
Line 30 × BIL28	0.36	19	0.66	38	0.54	380	0.22	12.18
SE(Sij)	0.73		3.04		7.57		0.18	
SE(Sij-Skl)	1.03		4.30		10.71		0.26	

**P=0.05 and **P=0.01,* DT= Days to tasseling, DS=Days to silking, PH= Plant height (cm), EH= Ear height (cm)

Heterosis

The standard/economic heterosis expressed by the F_1 hybrids over the standard check variety NK 40 for yield and yield related traits are shown in Table 5. All the traits showed significant heterosis in different crosses. For grain yield (t/ha), 11 crosses showed significant and positive heterosis over the standard check variety NK 40, which was found in the range of 33.20 - 12.30% (Table 5). The highest heterosis was exhibited by the cross Line 15 × BIL 79 (12.30%), Line 4 x BIL 79 (11.07%), and Line 2 × BIL 106 (7.46%), respectively. Amiruzzaman (2010) and Kadir (2010) in their studies found 17.60 to 9.71 % and 15.21 to 27.97% standard heterosis for kernel yield, respectively.

Significant and negative heterosis was exhibited by four crosses for both days to tasseling and days to silking indicating earliness (Table 4). Malik *et al.* (2004) also observed crosses with significant and negative heterosis in their studies. None of the crosses showed significant and positive heterosis for grain yield coupled with significant and negative heterosis for days to silking. Ahmed *et al*. (2008) reported significant and negative heterosis for days to silking in their studies with maize.

Conclusion

From this study, inbred lines with good GCA (Pinacle S_4-1, Pinacle S_4-2, Pinacle S_4-5, Pinacle S_4-6, Pinacle S4-15, Pinacle S_4-19, Pinacle S_4-28, and Pinacle S_4-30), and cross combinations with desirable SCA (Pinacle S_4-2 × BIL79, Pinacle S_4-5 × BIL79, Pinacle S_4-8 × BIL79, Pinacle S_4-10× BIL79, Pinacle S_4-15× BIL79, Pinacle S_4-19× BIL79, Pinacle S_4-28× BIL79, Pinacle S_4-2× BIL106, Pinacle S_4-6× BIL106, Pinacle S_4-15× BIL106, Pinacle S_4-19× BIL106, Pinacle S_4-22× BIL106, Pinacle S_4-2× BIL28, Pinacle S_4-5× BIL28, Pinacle S_4-6× BIL28, Pinacle S_4-13× BIL28, Pinacle S_4-15× BIL28, and Pinacle S_4-24× BIL28) for the traits have been identified. Through crossing and/ or recombination of inbred lines with desirable traits of interest, there is possibility of cross combinations for synthetic varieties. Therefore, cross combinations which was found promising could be utilized for future breeding work. Finally, the information will be helpful for the researchers who want to develop high yielding varieties of maize.

References

Ahmed, S., F. Khatun, M. S. Uddin, B. R. Banik and N. A. Ivy. 2008. Combining ability and heterosis in maize (*Zea mays* L.). *Bangladesh J. Pl. Breed. Genet.* 21(2): 27-32.

Amiruzzaman, M. 2010. Exploitation of hybrid vigor from normal and quality protein maize crosses. Ph.D Dissertation, Dept. of Genetics and Plant Breeding, Bangladesh Agricultural University, Mymensingh, Bangladesh. 200 P.

Amiruzzaman. M. and M. N. Amin. 2011. Evaluation of inbred lines of field corn through line × tester method. Annual Research Report, Plant Breeding Division, BARI, Gazipur, Bangladesh. 25-32 P.

Das, U. R. and M. H. Islam. 1994. Combining ability and genetic studies for grain yield and its components in maize (*Zea mays* L.). *Bangladesh J. Pl. Breed. Genet.* 7(2): 41-47.

Hussain, S. A., M. Amiruzzaman and Z. Hossain. 2003. Combining ability estimates in maize. *Bangladesh J. Agril. Res*. 28(3): 435-440.

Ivy, N. A. and M. S. Howlader. 2000. Combining ability in maize. *Bangladesh J. Agril. Res*. 25: 385-392.

Kadir, M. M. 2010. Development of quality protein maize hybrids and their adaptation in Bangladesh. Ph. D Dissertation, Dept. of Genetics & Plant Breeding, Bangladesh Agricultural University, Mymensingh, Bangladesh.

Kempthorne, O. 1957. An Introduction to Genetic Statistics, New York, John Wiley & Sons, Inc. London: Chapman & Hall Ltd. Pp. 458-471.

Lata, S., G. Katna, J. K. Sharma and J. Dev. 2006. Component of variation, combining ability and heterosis studies for yield and its related traits in maize (*Zea mays* L.). *Crop Improv*. 33**:** 151-155.

Malik S. I., H. N. Malik, N. M. Minhas and M. Munir. 2004. General and specific combining ability studies in maize diallel crosses. *Intl. J. Agric. Biol*. 6(5): 856-859.

Mahto, R. N. and D. K. Ganguly. 2001. Heterosis and combining ability studies in maize (*Zea mays* L.). *J. Res. Brirsa Agric. Univ.* 13: 197-199.

Narro, L., S. Pandey, J. Crossa, C. D. Leon and F. Salazar. 2003. Using line × tester interaction for the formation of yellow maize synthetics tolerance to acid soils. *Crop Sci.* 43**:** 1717-1728.

Paul, S. K. and R. K. Duara. 1991. Combining ability studies in maize (*Zea mays* L.). *Intl. J. Tropics. Agric.* 9(4): 250-254.

Rissi, R. D., A. R. Hallauer and R. R. De. 1991. Evaluation of four testers for evaluating maize lines in a hybrid development program. *Revista Brasllelia de Genetica* 14(2): 467-481.

Roy, N. C., S. U. Ahmed, A. S. Hussain and M. M. Hoque. 1998. Heterosis and combining ability analysis in maize (*Zea mays* L.). *Bangladesh J. Pl. Breed. Genet*. 11(1 & 2): 35-41.

Singh, D. N. and I. S. Singh.1998. Line × tester analysis in maize. *J. Res. Birsa Agric. Univ.* 10(2): 177-182.

Singh, R. K. and B. D. Chaudhary. 1979. Biometrical methods in quantitative genetic analysis. New Delhi, Kalyani Publishers. Pp. 127-223.

Sofi, P. and A. G. Rather. 2006. Genetic analysis of yield trails in local and CIMMYT inbred line crosses using Line × tester analysis in maize (*Zea mays* L.). *Asian J. Plant Sci***.** 5(6): 1039-1042.

Sprague, G. F. and L. A. Tatum. 1942. General versus specific combining ability in single crosses of corn*. J. Amer. Soci. Agron,* 37: 923-928.

Suneetha Y., J. R. Patel and T. Srinivas. 2000. Studies on combining ability for forage characters in maize. *Crop Res*. 19(2): 266-270.

Uddin, M. S., F. Khatun, S. Ahmed, M. R. Ali and S. A. Bagum. 2006. Heterosis and combining ability in field corn (*Zea mays* L.). *Bangladesh J. Bot.* 35(2): 109-116.

Venkatesh, S., N. N. Singh and N. P. Gupta. 2001. Early generation identification and utilization of potential inbred lines in modified single cross hybrids of maize (Z*ea mays* L.). *Indian J. Genet.* 61(4): 353-355.

Talukder, M. Z. A. and B. Banik. 2012. Evaluation of inbred lines through line × tester method. Annual Research Report, Plant Breeding Division, BARI, Gazipur, Bangladesh. Pp. 16-24.