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COMBINING ABILITY AND HETEROSIS FOR SOME QUANTITATIVE TRAITS IN EXPERIMENTAL MAIZE HYBRIDS

ABSTRACT

In *rabi* season 2012, six diversed maize inbred lines were crossed in all possible combinations without reciprocals by using a half diallel mating design to obtain 15 single cross. Inbred parents and their F_1 single crosses with a check were evaluated in *rabi* season 2013 to evaluate the role of general and specific combining ability and heterosis for some quantitative traits. Significant general combining ability variances was observed only for cob height and specific combining ability variances were observed for plant height, cob height, cob length, cob girth, number of kernels per cob, cob weight and hundred grain weight. The GCA/ SCA ratio was less than unity for all studied traits except shelling percentage; this means that these traits are pre-dominantly controlled by non-additive gene action. Based on GCA estimates, it could be concluded that the best combiners were ML01, ML05 and ML29 inbred lines for most of the studied traits. This result indicated that these inbred lines could be considered as good combiners for improving these traits. Significant positive SCA effects were found for all studied traits except number of kernels per row and shelling percentage. Based on SCA effects, it could be concluded that the crosses ML01×ML02, ML02×ML05, ML02×ML29 and ML05×ML15 could be exploited by the maize breeders to increase maize yield. Three F_1 hybrids such as ML02×ML15, ML02×ML29 and ML05×ML15 proved to be the outstanding hybrids to immediate further steps for commercial cultivation. In a conclusive decision the F_1 hybrid, ML02×ML29 was the best combination as evaluated through combining ability and standard heterosis.

Key words: half diallel crosses; heterosis; general combining ability; specific combining ability; *Zea mays*

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INTRODUCTION

Maize is one of the most important cereal crops. For many years, it is used as food for human and different animals. Therefore, corn breeders give great and continuous efforts to improve and increase the yielding ability of this crop. In the year 1763, Koelreituer and Sprangel (Allard, 1960) were the first research workers who observed that hybrids were often possessed the most striking and unusual vigor. Since that time, many research workers generally and corn breeders specially started a new era of plant breeding to harness the benefit from this phenomenon, which is now known as heterosis. Hybridization in corn started as early as the year 1908 by the work of East (1908) and Shull (1909), who clearly indicated that hybridization is the opposite of inbreeding. Amiruzzaman *et al.* (2013) reported that variance due to GCA and SCA were highly significant for the characters studied, indicating both additive and non-additive type of gene action were important for controlling the traits. Predominance of non-additive gene action was observed for all the traits. Parent Q7 was the best general combiner for higher grain yield coupled with dwarfness, and Q1 was also good general combiner for grain yield and lateness in maturity. For other traits, parent Q2, Q3 and Q4 were found suitable both for days to tasseling and silking and Q4, Q5 and Q7 for both plant and ear height showing desirable significant negative GCA effects and simultaneously possessed desirable high mean values, indicating that per se performance of the parents could prove as an useful index for combining ability. Additive × additive, additive × dominance and dominance × dominance gene interactions were involved in deriving good specific cross for yield. The cross combinations Q1 × Q7, Q2 × Q3, Q4 × Q6 and Q6 × Q7 possessing significant desirable SCA effects and high heterotic values might be used for obtaining high yielding hybrids. Haddadi *et al.* (2012) showed significant mean squares of general combining ability (GCA) and specific combing ability (SCA) for days to ear silking (DS), plant height (PH), 1000-kernel weight (KW), number of kernels in ear row (KR), number of rows in ear (NR), kernel length (KL), cob to ear weight ratio (CR) and kernel yield (KY) indicating the importance of both additive and non additive genetic effects for these traits. However, high narrow-sense heritability estimates, low degree of dominance and the ratio of estimates of GCA to SCA effects for DS, KW, NR and CR indicated that additive genetic effect were more important for these traits. Most of the crosses with significant SCA effects for DS and KY had at least one parent with significant GCA effects for the same traits. Significant positive correlations were detected between KY and other yield components which included; KW, KR and KL. Therefore, these traits can be used as indirect selection criteria for seed yield improvement. The crosses MO17 × L8, MO17 × L12 and MO17 × L24 had high KY and were thus, considered as good combinations for improving the trait. Bidhendi *et al.* (2012) reported that GCA and SCA effects were significant for grain yield (GY). Based on significant positive GCA effects, the lines derived from LSC could be used as parent in crosses to increase GY. The maximum best- parent heterosis values and highest SCA effects resulted from crosses B73 × MO17 and A679 × MO17 for GY. Yousif and Sadeeq (2011) showed that the value of specific combining ability variance was more than the general combining ability variance for the two traits, indicating the importance of non – additive gene action. Narrow sense heritability ranged from 47.13% – 19.05% for plant and ear height respectively. Average degree of dominance was more than one for the two characters. Heterosis, measured as departure of F_1 from the mean of the parents value were observed for the two characters. Woyengo *et al.* (2010) reported that GCA to SCA ratios was greater than one for all the traits indicating a preponderance of additive over non additive gene action. Six inbred lines had significant ($P < 0.05$) positive GCA effect for grain yield but negative GCA effects for the three diseases. Khalil *et al.* (2010) observed that general combining ability (GCA) and specific combining ability (SCA) effects were significant for the studied trait. Genotype hyb-4 was identified to be the best general combiner for grain yield, while high SCA effects were observed for crosses hyb-4 × HYB-3, hyb-4 × HYB-1 and hyb-5 × HYB-2. The graphical demonstration proposed by the biplot analysis provided an effective overview of GCA and SCA effects, mean performance in crosses, as well as grouping of similar genotypes on the basis of heterosis. Singh and Shahi (2010) showed presence of additive and non-additive gene effects with preponderance of latter. The mean degree of dominance indicated over dominance for all the traits. The distribution of genes with positive and negative effects was symmetrical and one to six dominant genes governed the inheritance of grain yield. The narrow sense heritability was low for all traits except for ear diameter and day to maturity. The predominance of non-additive genetic variation (over-dominance) and low narrow sense of heritability for majority of character may prove useful in hybrid breeding program. Bello and Olaoye (2009) reported that general combining ability (gca) and year (y) effects were significant for all the parameters except plant height, while specific combining ability (sca) and gca x year effects were significant only for grain yield. However, Tze Comp4 Dmr Srbc2, Tze Comp4 C2 and Acr 94 Tze Comp5 which are good general combiners for maize grain yield, also showed positive significant gca x year effects for flowering traits. Significant sca x year interaction effects were recorded for maize grain yield and days to flowering, with Hei 97 Tze Comp3 C4 combining very well with 3 parents (Acr 90 Pool 16-Dt, Tze Comp4-Dmr Srbc2 and Tze Comp4 C2).

Amiruzzaman *et al.* (2013) studied heterosis for grain yield, days to tasseling, days to silking, plant height and ear height in a diallel cross involving seven elite maize inbred lines. Standard heterosis for grain yield ranged from -17.60 to 9.71%. For other traits, desirable heterosis varied from -0.10 to -4.42%; -0.03 to -4.20%; -2.44 to -42.11% and -1.33 to -21.87% for days to tasseling, days to silking, plant height and ear height, respectively. Pearson correlation coefficients between heterosis, SCA, D2 and yield of husked ears were obtained. The cross P30F44 x Sprint displayed a high mean and a high heterosis for yield of husked ears, but a moderate estimate of genetic divergence. Estimates of genetic divergence were not effective at predicting the most heterotic crossings, as Pearson correlation coefficients between D2 and heterosis and D2 and CEC were not significant. Positive significant correlations were observed between yield means and CEC and heterosis (Oliboni *et al.*, 2012). Kustanton *et al.* (2012) carried out with objectives of this research to find out the heterosis value and genetic distance on several inbred lines and to find out the relationship between the genetic distance and heterosis in maize. Results showed that there were any interaction of Line x Tester in all characters except for leaf length and kernel water content. The estimate values of specific combining ability (SCA) and the heterosis value were varied among F_1 hybrid and among of the observed characters. The value of genotypic correlation among the characters were ranged 0.20 – 1. The genetic distance between parents of the F_1 hybrid was ranged from 0.25 to 0.65. Correlation coefficient of Spearman's Rank between the genetic distance and SCA ranged -0.009 – 0.143, correlation coefficient of Spearman's Rank between the genetic distance and heterosis ranged -0.120 – 0.181. Abdel-Monaem *et al.* (2009) showed positive significant heterosis values as average percentage from mid-parents were 153.96, 182.66 and 479.29% for ear diameter, ear length and grain yield/plant, respectively. On the other hand highest values of heterotic effects over higher parent were 136.61, 144.66 and 325.57% for ear diameter, ear length and grain yield/plant, respectively. Kumari *et al.* (2008) reported that the inbred lines differed significantly for their flowering parameters, green ear weight, yield, total soluble solids and biochemical traits. Parents DMB 325, DMB 326 and SCI 308 were good general combiners for early maturity, whereas DMB 322 combined well for yield and sugar content. Testers SCI 308 and SCI 302 were good combiners for early maturity and total sugar, respectively. Among the crosses, 13MB321 x SCI 303, DMB 326 x SCI 303 and DMB 327 x SCI 303 were best specific combiners for early maturity, field emergence and fresh ear weight while hybrid DMB 327 x SCI 303 had better specific combining ability for grain yield and sugar content, the latter being heterotic over the standard controls. Gurung *et al.* (2008) studied heterosis and combining ability in yellow maize through line (10) x tester (4) method and reported higher heterosis for grain yield and identified some superior crosses. They also reported that parents of the superior crosses were potential and ideal for developing conventional as well as non-conventional hybrids. Alam *et al.* (2008) showed significant negative heterosis for days to maturity. Significant general and specific combining ability variances were observed for all the characters except ear height. Almost equal role of additive and non-additive gene actions was observed for days to maturity. Additive genetic variance was preponderant for grains per ear and 1000-grain weight and non-additive gene action was involved in plant height, ear height, days to silking, and days to maturity. The inbred lines P_2 and P_5 were found to be best general combiner for 100-grain weight. Shalimuddin *et al.* (2006) showed the range of heterobeltiosis expressed by different crosses was from 8.23 to 25.78 per cent and -0.22 to -8.31 per cent, respectively, for grain yield and days to silking. The better performing four crosses (P1 × P7, P6 × P7, P1 × P4 and P4 × P5) can be utilized for developing high yielding hybrid varieties as well as for exploiting hybrid vigor. Kumari *et al.* (2007) reported significance of both GCA and SCA variance for most of the characters implied that both additives as well as non-additive components are important. The estimates of GCA effect indicated inbred P5 as the most promising parent since it was observed as a good general combiner for plant height, kernel rows, 100-grain weight, yield per plant, whereas P1 and P3 reflected significant GCA effect for early maturity and plant height, respectively. The SCA effect revealed P2 × P6 as the best specific combiner for grain yield per plant, followed by P2 × P5 and P3 × P4.

The objective of this study was to evaluate of combining ability and estimate the heterosis for some quantitative traits in diallel crosses of maize.

MATERIALS AND METHODS

Six yellow maize inbred lines were used from a diversed (Azad *et al.* 2012) stock of maize inbred lines. These inbred lines were: ML01, ML02, ML05, ML15, ML25 and ML29. The inbred lines were developed from ten single cross maize hybrids used as base population and continuous selfing upto six generation in the experimental field of the Department of Genetics and Plant Breeding, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh. In *rabi* season 2012, the seeds of all parental inbred lines were planted in the experimental field. All parental inbred lines were crossed according to a half diallel crosses mating design to obtain 15 single crosses. In *rabi* season 2013, all 21 genotypes, which included 6 parental inbred lines and 15 F_1 hybrids were cultivated. The soil was ploughed three times then ridged. Calcium super phosphate (15.5% P_2O_5) was incorporated in the soil during tillage operation at a rate of 150 kg × ha^{-1} Nitrogen fertilizer in the form of Urea (46% N) was added at the rate of 120 kg × ha^{-1} in two equal doses, the first was after thinning and before the first irrigation and the second before the second irrigation. The first irrigation was applied after 21 days from planting and then at 15 days intervals during the growing seasons. Weeds were controlled by using manual method before irrigation. Plants were thinned later to one plant per hill before the first irrigation. The plot size was 10.5 m^2 and each plot consisted of 5 ridges, 3 m long and 70 cm wide. Samples of ten guarded plants were taken at random from middle two rows of each plot to determine the quantitative characters.

Studied traits

The following measurements were recorded: plant height (cm), cob height (cm), cob length (cm), cob girth (cm), number of kernel rows/cob, number of kernels per row, number of kernels/cob, cob weight (g), shelling percentage, 100 grain weight (g) and grain yield per plant (g).

Diallel analysis for general and specific combining ability: Fifteen single crosses comprise a half diallel between 6 inbred parents. Data of all 21 genotypes were analyzed as randomized complete blocks. The sum of squares of genotypes was partitioned to general and specific combining ability following method 2 model 1 (fixed effect) of Griffing (1956). General combining ability effects for the inbred parents, specific combining ability effects for cross combinations and their respective standard errors were computed using formulae given by Griffing (1956).

Estimation of heterosis: Heterosis expressed as percent of increase of F_1 hybrid over mid parent (average or relative heterosis), better parent (heterobeltiosis) and commercial check (standard heterosis) were computed for each character using the formulae given by Turner (1953) and Hayes *et al.* (1955).

RESULTS

Table 1

Mean squares from analysis of variance for Genotypes, General Combining Ability (GCA) and Specific Combining Ability (SCA) of all studies traits of maize

SOV	df	PH	CH	CL	CG	NKR/C	NK/R
Genotypes	20	892.77**	964.57**	6.36**	9.83**	6.86**	57.88**
GCA	5	276.97	579.19*	1.86	0.42	0.75	9.71
SCA	15	1153.69**	1157.94*	2.93*	13.45**	4.44	18.88
Error	40	170.24	20.60	1.48	0.87	1.58	22.29
GCA/SCA	-	0.24	0.50	0.635	0.031	0.169	0.514
σ^2A		-219.18	-144.68	-0.26	-3.26	-0.92	-2.30
σ^2D		983.34	1137.34	1.44	12.58	2.86	-3.41
σ^2g		-109.59	-72.34	-0.13	-1.63	-0.46	-1.15
σ^2s		983.34	1137.34	1.44	12.58	2.86	-3.41
σ^2g / σ^2s		-0.11	-0.06	-0.09	-0.13	-0.16	0.33

SOV	df	NK/C	CW	S%	HGW	GY/P
Genotypes	20	33102.88**	37.80**	10093.41**	34.26*	9033.38**
GCA	5	10451.25	896.10	30.69	5.21	1236.86
SCA	15	41841.12**	3321.59*	13.68	42.58**	1760.08
Error	40	3765.02	1261.51	18.28	16.38	1030.02
GCA/SCA	-	0.25	0.269	2.243	0.122	0.703
σ^2A		-1439.46	-606.38	4.26	-9.34	-130.80
σ^2D		3266.97	2060.08	-4.60	26.2	730.06
σ^2g		-719.73	-303.19	2.13	-4.67	-65.40
σ^2s		3266.97	2060.08	-4.60	26.2	730.06
σ^2g / σ^2s		0.22	-0.15	-0.46	-0.18	-0.09

* and ** means significant at 5% and 1% level of probability, respectively; σ^2A = Additive genetic variance, σ^2D = Dominant component, σ^2g = General combining ability variance, σ^2s = Specific combining ability variance; PH= Plant height (cm), CH= Cob height (cm), CL= Cob length (cm), CG= Cob girth (cm), NKR/C= Number of kernel rows per cob, NK/R= Number of kernels per row, NK/C= Number of kernels per cob, CW= Cob weight (g), S%= Shelling percentage, HGW= 100 grain weight (g) and GY/P= Grain yield per plant (g)

Results indicated that mean squares of genotypes were highly significant for all studied traits i.e., plant height, cob height, cob length, cob girth, number of kernel rows per cob, number of kernels per row, number of kernels per cob, cob weight, shelling percentage, 100 grain weight and grain yield per plant (Table 1). General combining ability mean squares (GCA) were significant for the trait of cob height. Also, mean squares of Specific Combining Ability (SCA) were highly significant for plant height, cob height, cob length, cob girth, number of kernel rows per cob, number of kernels per cob, cob weight and 100 grain weight. The GCA/SCA ratio was less than unity for all studied traits except shelling percentage. This means that these traits are predominantly controlled by non-additive gene action except pith weight and shelling percentage. Similar results were reported by Hassaballa *et al.* (2002), El-Morshidy *et al.* (2003), El-Moselhy (2005), El-Diasty (2007) and Abdel-Moneam *et al.* (2009).

General combining ability effects (g_i): Significant GCA effects were found for all studied traits. Based on GCA estimates, it could be concluded that the best combiners for plant height were ML01, ML02, ML15, ML25 and ML29; for cob height ML01, ML02, ML05, ML15 and ML29; for cob length ML01, ML02, ML05, ML25 and ML29; for cob girth ML01, ML05, ML15, ML25 and ML29; for number of kernel rows per cob ML01, ML05, ML15, ML25 and ML29; number of kernels per row ML01, ML15, ML25 and ML29; number of kernels per cob ML01, ML05, ML15 and ML29; cob weight ML01, ML05, ML15, ML25 and ML29; for shelling percentage only ML01; for hundred grain weight ML01 and ML25 and for grain yield per plant inbred lines were ML01, ML05 and ML29. These results indicated that these inbred could be considered as good combiners for improving these traits (Table 2).

Table 2

Estimates of general combining ability effects (g_i) for inbred parents for all studied traits of maize

Parents	PH	CH	CL	CG	NKR/C	NK/R	NK/C	CW	S%	HGW	GY/P
ML01	7.55**	7.39**	2.65**	0.33*	2.19**	0.84**	83.18**	86.73**	4.22**	3.76**	79.26**
ML02	4.36*	6.87**	0.56*	-2.88**	-3.19**	-5.19**	-182.18**	-85.49**	-3.28*	-3.56**	-92.35**
ML05	2.00	5.19**	1.99**	2.37**	0.67**	-4.55**	130.57**	54.18**	-0.90	-1.04	58.65**
ML15	6.65**	5.33**	-2.24**	0.82**	0.94**	1.95*	157.64**	103.83**	-1.32	-8.70**	-98.93**
ML25	6.37**	-5.16**	1.28**	3.05**	1.81**	7.05**	-170.87**	92.27**	-2.72	3.76**	-84.66**
ML29	5.46**	3.92**	0.55**	0.77**	0.87**	0.89*	118.43**	71.03**	-2.10	-2.12	70.12**
SE (±)	4.21	1.47	0.24	0.30	0.28	1.33	20.41	12.38	1.36	1.23	11.04

Specific combining ability effects (Sij): Significant SCA effects were found in all studied traits for some crosses except number of kernels per row and shelling percentage (Table 3). Based on SCA effects, it could be concluded that the crosses i.e., No. ML01×ML25, ML05×ML15, ML15×ML25 and ML25×ML29 showed significant and positive SCA effects for plant height; crosses no. ML01×ML02, ML01×ML05, ML01×ML25, ML01×ML29, ML02×ML15, ML05×ML15, ML15×ML25, ML15×ML29 and ML25×ML29 for cob height; crosses no. ML01×ML05, ML01×ML15, ML01×ML29, ML05×ML15 and ML05×ML29 for cob length; crosses no. ML01×ML02, ML01×ML25, ML02×ML15, ML05×ML15, ML15×ML25 and ML25×ML29 for cob girth; crosses no. ML01×ML02, ML01×ML15, ML01×ML29, ML02×ML05, ML02×ML29, ML05×ML15 and ML25×ML29 for number of kernel rows per cob; crosses no. ML01×ML02, ML02×ML25 and ML05×ML15 for number of kernels per cob; crosses no. ML01×ML02, ML02×ML15 and ML05×ML15 for cob weight; crosses no. ML02×ML15 and ML05×ML15 for hundred grains weight and crosses no. ML01×ML02, ML02×ML15, ML02×ML29 and ML05×ML15 showed significant and positive SCA effects for grain yield per plant.

Table 3

Estimates of SCA effect of the crosses for all studied traits of maize

Crosses	PH	CH	CL	CG	NKR/C	NK/R	NK/C	CW	S%	HGW	GY/P
ML01 × ML02	5.95	17.99**	0.75	2.01**	2.06**	3.47	101.94*	52.53*	2.54	1.16	48.64*
ML01 × ML05	4.08	12.36**	0.85*	1.10	0.06	2.19	28.46	23.85	1.90	1.74	22.71
ML01 × ML15	4.01	-6.01*	1.82**	0.81	1.24*	1.15	66.24	18.42	2.03	-0.54	19.54
ML01 × ML25	28.41**	19.28**	0.74	1.48*	-0.15	4.64	55.76	39.86	3.23	2.23	33.48
ML01 × ML29	5.44	11.22**	1.14*	0.11	1.19*	1.75	53.95	38.80	-1.26	2.94	34.14
ML02 × ML05	-3.03	-10.04**	0.53	0.67	1.44**	0.89	54.45	-5.01	0.43	-2.86	2.21
ML02 × ML15	14.13	24.63**	0.09	1.58**	0.66	1.71	37.33	49.73*	-2.14	4.64*	42.49*
ML02 × ML25	-3.04	5.22	-0.53	0.78	0.73	3.23	100.72*	39.73	1.37	3.11	37.32
ML02 × ML29	12.93	4.22	0.28	0.75	1.51**	1.08	70.11	33.99	4.36	1.06	54.03*
ML05 × ML15	19.49*	20.01**	0.95*	1.67**	1.12*	2.83	115.85**	64.79**	1.30	6.34**	71.13**
ML05 × ML25	-26.74**	-7.78**	0.72	0.73	0.76	4.61	42.08	24.78	-1.08	-0.41	28.92
ML05 × ML29	2.20	-1.06	0.92*	0.50	0.07	-1.43	20.31	0.01	-0.76	-2.72	-7.67
ML15 × ML25	23.32**	18.69**	0.73	1.98**	1.11	-1.47	73.26	42.84	0.76	3.29	37.29
ML15 × ML29	-4.31	5.93*	0.88	0.88	0.40	1.50	22.60	31.92	0.70	3.66	27.41
ML25 × ML29	21.09*	11.59**	0.90	1.15*	1.16*	3.09	69.90	37.33	1.16	-0.71	32.32
SE (±)	7.80	2.71	0.45	0.56	0.37	2.46	37.79	22.92	2.51	2.27	20.44

Heterosis over mid-parent: Results showed positive significant heterosis values for all studied traits except shelling percentage for all crosses (Table 4). For the trait plant height crosses no. ML01×ML02, ML01×ML15, ML01×ML25, ML01×ML29, ML02×ML15, ML02×ML29, ML05×ML15, ML15×ML25 and ML25×ML29; for cob height all crosses except ML02×ML05; for cob length all crosses except ML02×ML25, ML15×ML29 and ML25×ML29; all crosses for cob girth; all crosses for number of kernel rows per cob except cross no. ML01×ML25; all crosses for number of kernels per row except crosses no. ML01×ML29, ML02×ML05, ML02×ML29, ML05×ML29 and ML15×ML29;

all crosses for number of kernels per cob; all crosses for cob weight except crosses no. ML02×ML05 and ML05×ML29; for hundred grain weight crosses no. ML02×ML15, ML05×ML15, ML15×ML25 and ML15×ML29 and all crosses for grain yield per plat except cross no. ML05×ML29 showed positive significant heterosis over mid-parent.

Table 4

Percentage of heterosis over mid-parents for all studied traits of maize

Crosses	PH	CH	CL	CG	NKR/C	NK/R	NK/C	CW	S%	HGW	GY/P
ML01 × ML02	13.61**	58.64**	8.09*	37.41**	37.36**	36.63**	82.79**	91.85**	7.95	12.43	99.86**
ML01 × ML05	8.36	41.74**	16.09**	27.84**	12.61*	25.06*	46.26**	48.75**	5.74	11.02	50.04*
ML01 × ML15	17.58**	34.34**	21.42**	31.84**	30.75**	33.70*	69.07**	88.91**	4.72	18.43	92.41**
ML01 × ML25	30.05**	65.49**	23.99**	35.09**	10.07	51.07**	66.37**	91.93**	7.36	16.66	93.39**
ML01 × ML29	15.60*	49.81**	19.00**	17.56**	23.86**	24.51	53.01**	69.97**	2.44	13.19	81.31**
ML02 × ML05	1.43	5.35	14.29**	24.73**	31.36**	23.96	52.93**	31.01	5.24	1.18	52.52*
ML02 × ML15	9.72*	36.59**	10.43*	38.13**	17.86**	32.91*	64.55**	98.89**	0.19	29.95**	126.10**
ML02 × ML25	8.08	39.56**	4.66	29.66**	24.94**	35.93**	70.19**	85.79**	6.74	16.08	103.43**
ML02 × ML29	16.10**	33.75**	7.93*	22.49**	33.16**	21.92	64.65**	73.90**	7.55	10.55	88.01**
ML05 × ML15	18.25**	57.53**	13.98**	36.08**	18.39**	32.48**	59.94**	85.34**	2.96	30.93**	104.98**
ML05 × ML25	-9.56	10.81*	21.01**	26.72**	14.90*	36.63**	59.55**	49.72**	0.93	5.32	60.58*
ML05 × ML29	5.89	15.57**	22.65**	18.38**	14.97*	21.00	35.36**	26.27	0.51	-3.86	24.89
ML15 × ML25	28.53**	70.13**	10.98*	43.49**	19.14**	37.44**	68.10**	101.56**	3.43	26.96**	101.64**
ML15 × ML29	11.26	46.64**	-1.14	26.79**	25.76**	22.81	50.28**	79.22**	3.36	24.04**	100.70**
ML25 × ML29	24.36**	49.30**	4.08	26.93**	17.56*	27.16**	57.85**	65.94**	7.08	3.34	52.01*
SE (±)	9.189	3.65	0.634	0.702	0.716	3.17	50.54	31.38	3.51	3.52	28.17

Heterosis over better-parent: Results showed significant heterosis values over better-parents in all studied traits except shelling percentage and hundred grain weights for most crosses. The highest crosses over their better parents for cob girth and number of kernels per cob. The crosses no. ML01×ML15, ML01×ML25, ML01×ML29, ML02×ML15, ML05×ML15, ML15×ML25 and ML25×ML29 showed significant and positive heterosis for plant height; crosses no. ML01×ML02, ML01×ML05, ML01×ML15, ML01×ML25, ML01×ML29, ML02×ML15, ML02×ML25, ML02×ML29, ML05×ML15, ML15×ML25, ML15×ML29 and ML25×ML29 for cob height; all crosses except ML01×ML02, ML02×ML15, ML02×ML25, ML02×ML29, ML15×ML29 and ML25×ML29 for cob length; all crosses except cross no. ML01×ML05 and ML01×ML25 for number of kernel rows per cob; crosses no. ML01×ML02, ML01×ML15, ML01×ML25, ML02×ML15, ML02×ML25 and ML15×ML25 for number of kernels per row; all crosses except ML01×ML05, ML02×ML05, ML05×ML25 and ML05×ML29 and crosses no. ML01×ML02, ML01×ML15, ML01×ML25, ML01×ML29, ML02×ML15, ML02×ML25, ML02×ML29, ML05×ML15, ML15×ML25 and ML15×ML29 were showed significant and positive heterosis over better-parent (Table 5).

Table 5

Percentage of heterosis over better-parents for all studied traits of maize

Crosses	PH	CH	CL	CG	NKR/C	NK/R	NK/C	CW	S%	HGW	GY/P
ML01 × ML02	8.43	56.18**	-1.35	36.22**	36.11**	36.09**	81.46**	84.23**	5.18	12.37	97.69**
ML01 × ML05	4.02	41.18**	12.42**	24.97**	6.48	13.59	25.52**	19.93	4.66	6.99	22.85
ML01 × ML15	16.83**	29.88**	17.84**	27.43**	30.08**	31.40*	65.73**	72.15**	0.21	7.06	70.76**
ML01 × ML25	28.27**	59.58**	17.94**	31.88**	8.00	46.19**	66.28**	89.11**	6.46	16.01	92.05**
ML01 × ML29	14.90*	39.34**	15.43**	12.97*	21.10**	21.91	45.82**	57.49**	1.03	10.54	69.12**
ML02 × ML05	0.83	3.33	7.49*	22.99**	23.15**	12.19	30.45**	9.09	3.58	-2.55	23.83
ML02 × ML15	13.31*	64.93**	3.64	31.63**	16.19**	31.15*	62.47**	74.74**	-1.65	17.54	102.62**
ML02 × ML25	1.81	32.56**	0.19	25.51**	21.50**	32.04*	69.05**	75.89**	4.86	15.51	102.63**
ML02 × ML29	10.17	22.62**	1.34	18.71**	29.03**	18.91	55.83**	67.54**	6.23	7.90	73.60**
ML05 × ML15	12.82*	52.89**	13.73**	27.95**	12.50*	18.48	35.00**	39.36**	-0.48	14.53	53.13**
ML05 × ML25	-14.33*	7.26	18.79**	21.01**	10.65*	20.50	36.87**	19.37	0.73	0.96	30.77
ML05 × ML29	1.05	7.90	22.44**	16.32**	11.11*	12.06	21.19**	8.47	0.15	-5.16	8.44
ML15 × ML25	27.58**	69.66**	8.71*	41.19**	17.51**	35.28**	64.88**	86.19**	-0.22	15.35	80.06**
ML15 × ML29	11.23	40.88**	-1.18	17.28**	23.58**	18.23	40.54**	52.49**	0.24	9.79	67.66**
ML25 × ML29	25.33**	43.81**	2.00	19.19**	17.12**	20.56	50.35**	51.67**	6.50	0.38	40.87
SE (±)	9.189	3.65	0.634	0.702	0.716	3.17	50.54	31.38	3.51	3.52	28.17

Heterosis over check variety

Three hybrids showed significant standard heterosis for plant height over NK -40, two (ML01×ML25 and ML15×ML25) were in positive direction and one (ML05×ML25) recordedbin negative direction. All crosses exhibited highly positive significant heterosis for cob height except ML02×ML05, ML05×ML25 and ML05×ML29. All crosses except ML15×ML29, revealed highly positive significant heterosis for cob length. Five crosses such as ML01×ML02, ML01×ML25, ML02×ML15, ML05×ML15 and ML15×ML25 showed positive significant heterosis for cob girth. Five crosses out of 15, such as ML01×ML02, ML01×ML15, ML02×ML05, ML02×ML29 and ML15×ML29 showed positive significant heterosis over check for number of kernel rows per cob. Three crosses ML01×ML25, ML05×ML15 and ML05×ML25 for number of kernels per row, six crosses ML01×ML02, ML01×ML05, ML02×ML05, ML02×ML29, ML05×ML15 and ML05×ML25 for number of kernels per cob, only the cross ML05×ML15 for cob weight, no cross for shelling percentage, only the cross ML05×ML15 for hundred grain weight and four crosses ML02×ML25, ML02×ML29, ML05×ML15 and ML05×ML25 showed positive significant heterosis for grain yield per plant over check variety (Table 6).

Table 6

Percentage of standard heterosis for all studied traits of maize

Crosses	PH	CH	CL	CG	NKR/C	NK/R	NK/C	CW	S%	HGW	GY/P
ML01 × ML02	4.68	42.35**	17.35**	15.58**	15.93**	16.01	30.29*	22.44	5.31	9.00	25.76
ML01 × ML05	-0.78	24.69**	17.81**	9.09	1.77	18.58	25.80*	19.79	1.50	11.91	22.57
ML01 × ML15	2.51	14.71**	22.95**	5.63	11.95*	12.02	18.00	5.32	4.16	3.85	8.63
ML01 × ML25	12.55**	40.94**	28.31**	9.95*	-4.43	24.62*	19.39	15.70	2.84	12.53	22.17
ML01 × ML29	0.81	23.07**	20.55**	2.16	7.96	8.46	15.56	12.93	-1.33	12.49	24.30
ML02 × ML05	-2.66	-5.82	27.86**	7.36	17.69**	17.12	30.74*	8.96	3.71	1.93	23.54
ML02 × ML15	9.39	50.33**	23.29**	11.69*	0.00	10.91	14.96	16.14	2.22	13.88	26.09
ML02 × ML25	-1.71	20.82**	19.18**	6.49	7.52	11.67	21.24	16.90	4.99	11.91	27.11*
ML02 × ML29	6.36	11.76*	20.55**	7.36	15.04**	5.79	23.49*	20.14	6.36	9.80	27.59*
ML05 × ML15	7.61	33.96**	19.18**	11.69*	7.52	23.68*	35.30**	39.19**	3.44	19.79*	52.78**
ML05 × ML25	-18.28**	-6.03	29.23**	5.63	5.75	25.79*	37.17**	19.22	-2.31	5.60	30.47*
ML05 × ML29	-3.61	-5.47	28.31**	5.19	6.19	16.98	21.47	8.34	-2.19	-0.81	8.19
ML15 × ML25	10.51*	39.90**	18.27**	12.12*	3.98	11.36	18.25	10.56	3.71	10.65	12.95
ML15 × ML29	-3.59	16.17**	3.20	6.06	10.17*	5.18	11.37	9.35	4.19	11.73	23.23
ML25 × ML29	6.95	17.93**	10.96*	7.79	4.42	7.25	19.15	8.76	4.01	2.15	3.53
SE (±)	9.189	3.65	0.634	0.702	0.716	3.17	50.54	31.38	3.51	3.52	28.17

DISCUSSION

Analysis of variance for six parental lines along with their 15 F_1 hybrids and one chek (NK-40) for 11 characters revealed significant mean squares against the genotypes. The coefficient of variation ranged from 0.98 to 22.53% and the highest coefficient of variation was estimated for pith weight. General combining ability (GCA) and specific combining ability (SCA) were explained through analysis of variance, where GCA variances was significant for cob height, whereas, SCA values were significant for all the characters except number of kernels per row, shelling percentage and grain yield per plant. The dominant component (σ^2D) values was negative for shelling percentage (-4.60), therefore, other characters could be shown heterotic effects in hybrid combinations. The negative value of σ^2_g/σ^2_s was ruled out by minimizing sampling errors as reflected by reasonable (< 10%) coefficient of variation of the characters but only the negative ratio of σ^2_g/σ^2_s did not counterbalanced by CV% for the characters, cob weight and grain yield per plant, suggested that these two characters were not subjected to proper sampling during experimentation but the unexpected results had been ruled out by the other yield contributing characters. Among the six inbred lines, ML01, ML05 and ML29 appeared as the best general combiners in hybridization series for gaining heterotic effect in hybrid combinations regarding grain yield per plant. Not only that these three parental line showed significant SCA against grain yield per plant in the cross combinations like, ML01×ML02, ML02×ML05, ML02×ML29 and ML05×ML15. The results suggested that another two inbred lines, ML02 and ML15 appeared as excellent specific combiners in hybridization series. For the development of single cross maize hybrids the combinations like, ML01×ML02, ML02×ML05, ML02×ML29 and ML05×ML15 could be exploited by the maize breeders to increase maize yield.

Heterotic cross combination

Conventional maize breeding leverages the theory of heterosis or hybrid vigor. Heterosis may be defined as the occurrence of the greatest possible number of loci with a dominant alleles. This imparts improved vigor, size, yield, disease resistance or tolerance to environmental effects. In short, the single cross hybrid or progeny of the two inbred lines is superior in performance than either of the parents independently. Whatsoever, Heterosis were estimated for 15 F_1 hybrids over MP, BP and CV. Heterosis over MP and BP are exploited for experimental issues but heterosis over CV (check variety) is considered either a hybrid variety would accepted or rejected for commercial cultivation by the farmers. Generally standard heterosis is measured over a commercially cultivated popular variety and it is noted that OPV is included when a new OPV is recommended for commercial cultivation and hybrid variety is integrated for comparison during release of new hybrid variety. Therefore, the recommended hybrid variety for *rabi* season, NK-40 was included as a check variety for better comparison of different quantitative characters of the 13 experimental hybrids. However, three F_1 hybrids such as ML02×ML15, ML02×ML29 and ML05×ML15 proved to be the outstanding hybrids to immediate further steps for commercial cultivation. In a conclusive decision the F_1 hybrid, ML02×ML29 was the best combination as evaluated through combining ability and standard heterosis. Henceforth, the superior F_1 hybrid, ML02×ML29 is in hand that is ready for further evaluation in different location and environment before release for commercial cultivation of hybrid maize in Bangladesh.

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