Ethiop. J. Agric. Sci. 20:82-93 (2010)

Combining Ability and Heterotic Relationships between CIMMYT and Ethiopian Maize Inbred Lines

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Abstract

Knowledge of combining ability and heterotic relation of exotic inbred lines with the locally available ones would be helpful for efficient breeding program. The objectives of the current study were to estimate: (i) combining ability effects between Ethiopian and CIMMYT (International Centre for Maize and Wheat Improvement) maize inbred lines and (ii) possible heterotic relationships between the two sources of inbred lines. Forty-two crosses were produced using North Carolina Design II mating scheme by crossing six Ethiopian with seven CIMMYT inbred lines. Combined analyses over three locations showed significant differences among the hybrids for all the studied traits. Both general (GCA) and specific (SCA) effects were significant for most traits, indicating the importance of both additive and non-additive effects for these traits. Female parents E2 and E4 showed significant and positive GCA effects for grain yield. Other female lines that showed desirable GCA effects were E1 for ear height, E2 for days to anthesis, ear and plant heights and E5 for days to anthesis and silkng. Among male parents, C1 was the best general combiner for all agronomic traits, but not for grain yield. Inbred lines C2 and C6 were good general combiners for plant height and days to silking, respectively. Hybrids E4 x C2 and E5 x C3 showed superior SCA effects for grain yield while few other combinations showed desirable SCA effects for days to anthesis, ear and plant heights. The results of this study indicated potential heterotic relationships between CIMMYT and Ethiopian inbred lines for use in hybrid and synthetic development and introgression of germplasm.

Introduction

Maize is one of the most important cereal crops grown in Ethiopia. Millions of smallholder farmers of the country depend on maize for their daily food especially in major producing regions. Even though the total production and productivity exceeds all other cereal crops grown in the country, the national average yield (2.2 t ha^{-1}) (CSA, 2008) is still very low as compared to the global average of 4.8 t ha^{-1} (FAOSTAT, 2008). This low productivity is mainly attributed to lack of appropriate varieties for different maize growing agro-ecologies. Although there exists some locally adapted genotypes, the availability of germplasm with regard to genetic diversity is very limited and insufficient to establish suitable source populations for comprehensive breeding program.

Since its establishment in 1952, the maize research program of Ethiopia has been using a strategy to introduce germplasm from exotic sources. During early stages, materials introduced from east Africa were found to be better adapted to the Ethiopian conditions (Benti *et al.*, 1997). The program has been an active co-operator in CIMMYT's international maize testing network since the network was started in 1975 (Srinivasan and Pandey, 2002). As a result, the national maize research team has identified and released several promising varieties to the farmers. The increase in maize production, area harvested and productivity in Ethiopia can, in part, be attributed to the collaboration of the Ethiopia's maize breeding program with CIMMYT (Srinivasan and Pandy, 2002). Mosisa et al. (2002) emphasized that the availability of improved varieties and crop management practices has helped producers to increase their production substantially since early 1990s.

Despite considerable yield gains realized in Ethiopian maize breeding programs, the heterotic patterns exploited are limited and need to be diversified (Dagne et al., 2006). It is necessary to explore opportunities for identifying new heterotic groups from exotic sources in addition to exploiting the existing ones. The combining ability effects between locally developed inbred lines and adapted CIMMYT inbred lines for grain yield and yield components have to be worked out. Most complete information for hybrid performance is obtained in a single cross diallel or North Carolina Design II mating. According to Hallauer and Miranda (1988), however, the Design II mating scheme is advantageous in that it can handle more parents and produce fewer crosses than the diallel, which are easy to manage in trials. Better performing inbred lines could serve as useful sources of new alleles to broaden the germplasm base and to further increase both yield and stability of production (Beck et al, 1991). These authors also suggested that CIMMYT materials have potential for introducing useful genes for stress tolerance, high yield and stability. Therefore, inbred lines demonstrating good combining ability would be considered for use in cross combination with the national program materials. The objectives of this study were to estimate: (i) combining ability effects of Ethiopian and CIMMYT maize inbred lines for grain yield and some agronomic traits; and (ii) possible heterotic relationships between the two sources of inbred lines.

Materials and Methods

Seven elite CIMMYT-Zimbabwean maize inbred lines at S_5 to S_7 stages of inbreeding were crossed to six advanced and commercial Ethiopian inbred lines (Table 1). North Carolina Design II (Hallauer and Miranda, 1988) mating system was employed whereby the Ethiopian and CIMMYT lines were used as female and male parents, respectively. The 42 crosses resulted by factorial crossing of these groups of lines and two standard checks (BH540 and BH541) were evaluated at three locations (Bako, Jimma and Pawe research centers) in Ethiopia. The standard checks were included to compare the adaptation of the new crosses to local environments.

Table 1. Ethiopian and CIMMYT maize inbred lines used for North Carolina Design-II mating.

Ethiopian inbred lines		CIMMYT inbred lines	
Code	Pedigree	Code	Pedigree
E1	SC-22	C1	SC(PHAM)-3/[CML-205/SC// CML-202]-X-1-1-B-B
E2	124-b(113)	C2	ZM-605-C2F2-428-3-B-B -B-B-B-B
E3	F-7215	C3	DRB-F2-60-1-2-B-1-B-B-B
E4	A-7033	C4	DRA-F2-141-2-1-1-10-B-B
E5	FH-625-251-1	C5	(LZ-966077/LZ-966205)-B-3-2-2-B-B
E6	KULENI-50-1-2	C6	(LZ-956343/LZ-956003)-B-1-1-2-B-B
		C7	DRB- F2-180-1-2-B-1-1-B-B

Bako is located at 9°06′ N latitude, 37°09' E longitude and an elevation of 1650 m.a.s.l (meters above sea level) with long term annual precipitation of 1244 mm. Jimma is located at 7°46′ N latitude, 36°00' E longitude, and an elevation of 1750 m.a.s.l with long-term annual precipitation of 1500 mm. Pawe is located at 11°12′ N latitude, 36°25′ E longitude, and an elevation of 1100 m.a.s.l with long-term annual precipitation of 1200mm. Nitosol is the dominant soil type at all locations. The experiment at each location was laid out in randomised complete block design with three replications. A plot consisted of two rows of 5.1 m long that spaced 0.75m apart. Two seeds per hill were sown and then thinned to 0.30 m intra-row distance to give a final density of 44,444 plants per hectare. P_2O_5 was applied at the rates of 100 kg ha^{-1} at planting while 100 kg ha^{-1} nitrogen was applied by splitting into two, at planting and six-leaf stage. Other agronomic management practices were applied based on the research recommendations for the areas.

Data were recorded for days to anthesis (DA) as the number of days from emergence to when 50% of the plants in the plot shed pollen. Days to silking (DS) was recorded as the number of days from emergence to when 50% of the plants in the plot had 5 cm silk emerged from the husk. Two weeks after mid-silking, plant height (PH) and ear height (EH) were measured in centimetres as the distance from soil surface to the lower tassel branch and the node bearing the upper most ear, respectively. All ears harvested from each plot were weighed and random samples of ears were shelled to determine percentage moisture. Grain yield (GY) adjusted to 12.5% moisture was computed from the weight of all harvested ears per plot assuming a shelling percentage of 80%. Severity of grey leaf spot (GLS) disease was rated at around 21 days after mid-silking at Bako and Jimma, as GLS is the most important foliar disease of maize in these areas where the relative humidity is very high. The disease was rated using 1 – 5 scale, where 1= no infection and 5= very heavy infection.

Individual location analysis of variance was conducted for each tested traits (data not shown) and after testing homogeneity of error variances, combined analysis was done using Agrobase Software (Agronomix Software Inc., 2000). In the analysis, genotype was considered as fixed effect while location and replication within location were considered as random effects. Combining ability analyses were performed in SAS computer program (SAS, 2003) for each trait with significant F-values for genotypes and crosses as described by Hallauer and Miranda (1988) for across environments. The check entries were excluded for the combining ability analysis. The hybrid component of variation was dissected into variation due to female (GCA of female), male (GCA of male) and female x male (SCA) interaction. Significances of GCA effects and SCA effects of the lines and hybrids, respectively, were determined by t-test, using standard errors of GCA and SCA effects.

A biplot was constructed for the crosses using mean grain yield across locations to visualize relationships among parental lines in hybrid combinations and identify possible heterotic associations using a window application GGEbiplot software (Yan, 2001). Although biplot have been primarily used for analysing multi-environment cultivar trials and studying genotype x environment (GxE) interaction, it can also be utilized for studying pattern of response of entries when crossed with testers, that is, line × tester interaction (Narro et al., 2003). In the context of a two-way table from Design II experiment, the females are considered as the rows (cultivars) and the males as the columns (environments). In this study, Ethiopian and CIMMYT lines were considered as rows and columns, respectively. The first two principal component scores (PC1 and PC2) of entries and testers were used to construct the biplot. A polygon was drawn, connecting entries located furthest from the biplot origin so that all other genotypes are contained within the polygon. Subsequently, the polygon was divided into sectors by perpendicular lines drown from the origin to each side of the polygon. All testers and entries included in the same sector represent good hybrid combinations and potential heterotic groups for grain yield. The cosine of the angle between two testers (or entries) vectors approximates the correlation of the two testers (or entries). An angle of zero indicates a correlation of +1; an angle of 90^{o} (or –90^{o}), correlation of 0; and an angle of 180^{o}, a correlation of –1.

Results and Discussion

Combined analysis of variance showed highly significant differences among the three locations for all the studied traits (Table 2) indicating the presence of considerable variation among locations for entry performance. The effects of entries and hybrids were also significant for all tested traits, which could be explained by the inherent genetic variation among the germplasm studied. Desirable genes from this germplasm can effectively be utilized to develop high performing and adapted hybrids to the local conditions. Female GCA mean square was significant for DA, DS, EH and PH whereas male GCA mean square was significant for all traits except for GLS. In addition, individual location analysis showed significant female GCA mean squares for GY at Jimma and Pawe, indicating the importance of GCA for most traits and the presence of genetic variations among the lines studied that could be used as a potential source for introducing useful genes.

Table 2. Combined analysis of variance for the tested traits in a North Carolina Design II mating between Ethiopian and CIMMYT maize inbred lines evaluated at three locations in Ethiopia in 2004.

Source	DF	Mean Squares					DF	Mean Squares
		GY	DA	DS	EH	PH		GLS
Location (L)	2	52.0**	5706.3**	6094.1**	44647.5**	74001.2**	1	25.4**
Replication/L	6	4.3**	16.5**	18.7**	2872.1**	3578.0**	4	0.3**
Entry (E)	43	4.7**	15.1**	19.7**	901.0**	1454.0**	43	0.5**
Hybrids (H)	41	4.7**	15.6**	20.4**	940.6**	1518.7**	41	0.5*
GCA_{Female}	5	3.5	57.8**	75.4**	3084.3**	2715.3*	5	0.5
GCA_{Male}	6	12.8*	27.9*	45.9**	1202.5*	4141.1**	6	2.0
$SCA_{FemalexMale}$	30	3.3**	6.2**	6.1	531.0**	794.7**	30	0.2
Control (C)	1	3.2	0.5	0.0	43.6	256.9	1	0.3
H vs C	1	5.6	5.2	10.6	135.0	1.2	1	1.2
E x L	86	2.3**	3.7**	3.9**	189.6	394.5**	43	0.2**
H x L	82	2.3**	3.9**	4.0**	197.6	405.1**	41	0.2**
GCA_{Female} x L	10	5.2**	5.2*	4.1	243.9	699.5**	5	0.1
GCA_{Male} x L	12	4.2**	7.9**	5.1*	351.1*	373.5	6	0.8**
$SCA_{FemalexMale}$ x L	60	1.4	2.9	3.8	159.2	362.3	30	0.1*
C x L	2	0.6	0.7	0.2	14.4	197.7	1	0.0
H vs C x L	2	1.2	0.9	0.8	36.5	156.3	1	0.1
Error	258	1.4	2.5	2.9	193.4	297.8	172	0.1

*,** Significant at 0.05 and 0.01 level of probability, respectively.
DF= Degrees of freedom, DA = Days to anthesis, DS = Days to silking, EH = Ear height (cm), GLS= Grey leaf spot disease (1-5 scale), PH = Plant height (cm) and GY= Grain yield (t ha^{-1}).

The SCA mean squares were significant for GY, DA, EH and PH depicting that some hybrid combinations performed lower or higher than what had been expected based on GCA effects of the parents for these traits. This suggests the need for exploitation of heterosis in single cross maize hybrids for increasing performances. Previously, Mandefro and Habtamu (2001), reported the importance of both GCA and SCA effects in controlling grain yield and other agronomic traits in maize inbred lines. The effect of female was strong on DA, DS and EH while male had a strong effect on GY and PH. No significant difference was observed between the controls and between hybrids and controls. The interactions of entry, hybrid, female and male GCA with location were significant for most traits indicating that some genotypes performed differently in different environments. Significant GCA x location interaction mean square showed that the GCA of inbred lines was affected by the environmental conditions under which the hybrids were grown. Thus selection of good combining inbred line would be effective if based on hybrid performance across a range of environments. SCA x location interaction mean square was not significant for the studied traits except GLS.

GY ranged from 5.3 for cross E6 x C1 to 7.9 t ha^{-1} for E4 x C2 (Table 3). DA ranged from 67.7 to 74.3 days while DS ranged from 69.6 to 77.1 days. Hybrids E2 x C4, E5 x C1, E5 x C4 and E5 x C6 were earlier to flower and silk. EH and PH ranged from 92.9 to 135.7 cm and 186.2 to 247.1 cm, respectively. Shorter EH and PH were exhibited by E1 x C1, E1 x C2, E2 x C5 and E5 x C1. GLS scores ranged from 1.4 to 2.5 based on 1 – 5 scale. GLS resistant hybrids were E1 x C6, E4 x C5, and E6 x C5. The higher yielding hybrids E2 x C6 and E4 x C2 also had acceptable GLS reactions of 1.6 and 2.0, respectively. The frequency distribution of GLS scores (Fig. 1) revealed that about 57% of the hybrids had a GLS score of less than 2.0 while the resistant check (BH-540) had a GLS score of 2.1.

Table 3. Minimum, maximum, mean, standard error of the mean (SE(m)) and coefficient of variation (CV(%)) for the tested traits of 42 crosses and two standard checks evaluated at three locations in Ethiopia in 2004.

Traits	Hybrids		Standard Checks		Mean	SE(m)	CV (%)
	Minimum	Maximum	BH-540	BH-541			
Grain yield (t ha^{-1})	5.31	7.87	6.69	7.52	6.56	0.39	17.76
Days to anthesis	67.67	74.33	71.00	70.67	71.36	0.52	2.20
Days to silking	69.56	77.11	73.11	73.11	73.86	0.57	2.31
Ear height (cm)	92.89	135.67	117.44	120.56	116.32	4.64	11.96
Plant height (cm)	186.22	247.11	219.89	227.44	223.92	5.75	7.71
Grey leaf spot (1-5)	1.42	2.50	2.08	2.42	1.94	0.13	15.79

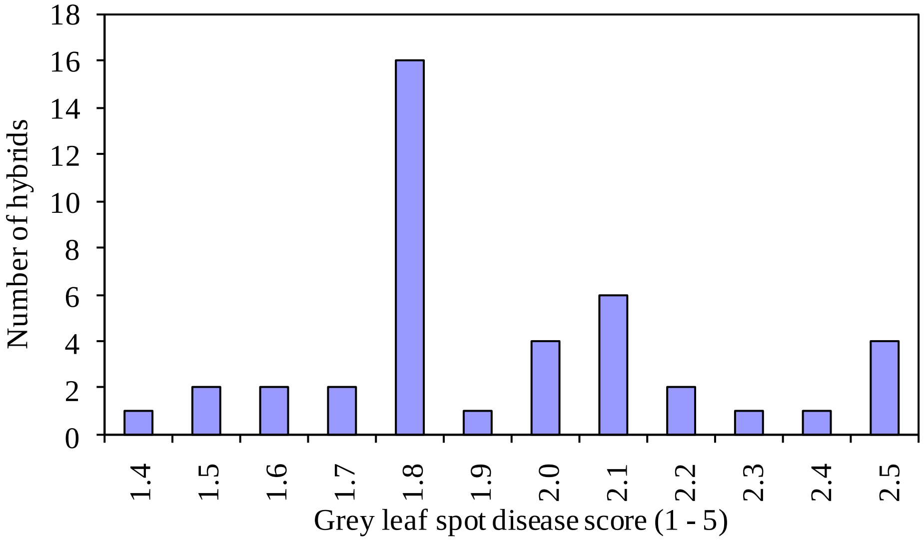

Figure 1. Frequency distribution of GLS score (1 – 5) of the 42 crosses evaluated at three locations in Ethiopia in 2004.

Even though few hybrids yielded higher than the best check (BH-541), most hybrids showed better resistance to GLS. This is because CIMMYT inbred lines were selected for GLS disease resistance during the course of line development. Hybrids that had high GY and lower GLS disease score could be recommended for release or further breeding work. Similarly, hybrids that had early anthesis and silking, shorter ear and plant heights would be used as sources of genes for the development of early maturing and short statured varieties.

Estimates of GCA effects of females (Table 4) and males (Table 5) showed significant variation within inbred lines for GY and agronomic traits. For GY, female GCA effects were estimated for Jimma and Pawe as these locations showed significant GCA mean squares individually, but not when combined. As a result, E2 and E4 were identified as the best general combiners for GY at Jimma and Pawe, respectively. Inbred line E1 had highly significant positive GCA effects for DA and DS, but significant negative GCA effect for EH, This indicates that the line had a tendency to mature late but was shorter in EH. Inbred lines E2 and E5 were good general combiners for DA and DS, EH and PH while E3 and E6 were poor general combiners for these traits. Among the male parents, C1 showed highly significant negative GCA effects for all the studied traits, indicating that C1 was poor combiner for GY but the best combiner for early anthesis and silking, and shorter PH. This indicated that the line had gene combinations that enhance early maturity and reduced PH, which are desirable for lodging resistance and late season drought escape. Though statistically not significant for GY, C5 and C6 showed relatively higher GCA effects of 0.48 and 0.47 t ha^{-1}, respectively.

Table 4. Estimates of GCA effects for GY and other agronomic traits of female parents evaluated in North Carolina Design II cross at three locations in Ethiopia in 2004.

Inbred line	Grain Yield (t ha^{-1})		Days to anthesis	Days to silking	Ear height (cm)	Plant height (cm)
	Jimma	Pawe				
E1	0.09	-0.09	0.83**	0.77**	-4.18*	-3.30
E2	0.80*	-0.47	-0.37	-0.69**	-10.67**	-6.54*
E3	0.24	0.26	0.76**	1.10**	5.22**	7.02*
E4	-0.88*	0.61*	-0.17	-0.11	3.68*	-0.84
E5	0.31	0.23	-1.67**	-1.78**	-2.26	-5.43
E6	-0.56	-0.54*	0.62*	0.71**	8.22**	9.08**
SE	0.35	0.25	0.26	0.23	1.80	3.04

*,** Significant at 0.05 and 0.01 level of probability, respectively. SE= Standard error.

Table 5. Estimates of GCA effects for GY and other agronomic traits of male parents evaluated in North Carolina Design II cross at three locations in Ethiopia in 2004.

Inbred lines	Grain Yield (t ha^{-1})	Days to anthesis	Days to silking	Ear height (cm)	Plant height (cm)
C1	-0.83**	-1.14**	-1.15**	-8.94**	-15.90**
C2	0.40	-0.14	-0.17	0.27	-5.86*
C3	-0.12	0.03	0.55	4.08	8.64**
C4	-0.27	-0.10	-0.47	1.65	3.08
C5	0.48	1.19**	1.12**	-1.73	0.42
C6	0.47	-0.33	-0.92**	-0.85	0.20
C7	-0.13	0.49	1.05**	5.53*	9.42**
SE	0.28	0.35	0.29	2.36	2.43

*,** Significant at 0.05 and 0.01 level of probability, respectively. SE= Standard error.

Inbred lines C2 and C6 were good combiners for PH and DS, respectively. Inbred lines with high GCA effects for GY were desirable as they had a tendency to produce high yielding hybrid progenies. On the other hand, inbred lines that showed negative GCA effects for DA, DS, PH and EH were desirable as they had favourable genes for early maturity and shorter plant stature. Based on these criteria, Ethiopian inbred lines E2 and E5 and CIMMYT inbred lines C2 and C6 could be regarded as desirable inbred lines to use in hybrid development for midaltitude agro ecologies of Ethiopia.

The mean GY and SCA effects of hybrids for GY, DS, PH and EH are presented in Table 6. Among the 42 hybrids, 26% of them had GY more than 7.0 t ha^{-1}, which were on par with grain yield of the best check. Hybrids E2 x C6, E3 x C1, E4 x C2, E5 x C3 and E6 x C7 showed significant and positive SCA effects for grain yield. This indicates that inbred lines involved in these hybrids are genetically divergent and hence could be regarded as distinct heterotic groups. The two parental lines of each cross may have different genes controlling GY and the crosses have taken the advantage of additive gene effect. In line with this finding, Hallauer and Miranda (1988), and Mandefro and Habtamu (2001) reported that SCA is more important in determining grain yield in single cross while GCA is more important in populations. Hybrids E5 x C6 and E6 x C7 had highly significant and negative SCA effects for DA. Hybrids E2 x C5, E4 x C4 and E6 x C6 showed highly significant negative SCA effects for EH while E2 x C7 and E5 x C1 had highly significant negative SCA effects for PH. The hybrids with low SCA for DA, PH and EH are desirable as they had earlier anthesis and shorter stature than what have been expected based on GCA of their parents.

The first two principal component axes in the biplot for mean grain yield of inbred lines in entry x tester hybrids explained 42.6 and 28.4% of the total variation, respectively (Fig. 2). Entries E2, E3, E4, E5 and E6 defined a polygon that was divided into five sectors by perpendicular lines. Four clear entry sectors are observed in this polygon; these are sectors E2, E4, E5 and E6. In sector E2, E2 × C5 and E3 × C1 were good hybrid combinations. Even though no tester fell in sector E4, this entry combined well with C2 since the angle between them is small and both have reasonable vector length. In sector E5, the vertex entry E5 combined well with testers C3 and C7. The cross E6 × C4 was good hybrid combination in sector E6, it had also non-significant positive SCA effect. Among all hybrid combinations, E5 × C3 showed the highest SCA effect as they had long vectors projecting in the same direction.

The polygon view of a biplot provided the best way for visualizing the interaction patterns between entries and testers, and effectively interprets the biplot. Since biplot graphically presents the data, it greatly enhances our ability to understand the patterns of data, which is more reliable than the individual observations. Narro et al. (2003) used biplot models to study line x tester interaction and successfully separated the lines into different subgroups corresponding to the populations from which they were derived. In the current study, two potential heterotic patterns are suggested: Ethiopian lines E2 and E3 as opposite heterotic pattern to CIMMYT lines C1, C5 and C6; and an Ethiopian line E5 as different hetetotic pattern to C3 and C7. Therefore, crosses [E2, E3] × [C1, C5, C6] and [E5] × [C3, C7] are expected to show high performance and heterosis. Tester C6 is located almost on the perpendicular line that separates sectors E2 and E5, indicating that E2 and E5 were almost equally good as partners for C6. This is also evident from the fact that E2 × C6 and E5 × C6 had positive SCA effects and closer observed GY of 7.84 and 7.51 t ha^{-1}, respectively. Moreover, SCA effect for the cross E5 × C6 was significant (Table 6). E6 is located in the opposite direction of most testers, indicating that it did not combine well with most of the testers, except with C4 and C7. Entry E1 and tester C4 were located near the origin, and did not combine well with any of the mating partners. This observation was in consistent with mean values and SCA effects of the crosses. However, some discrepancies are expected because the biplot explained only 71% rather than 100% of the total variation.

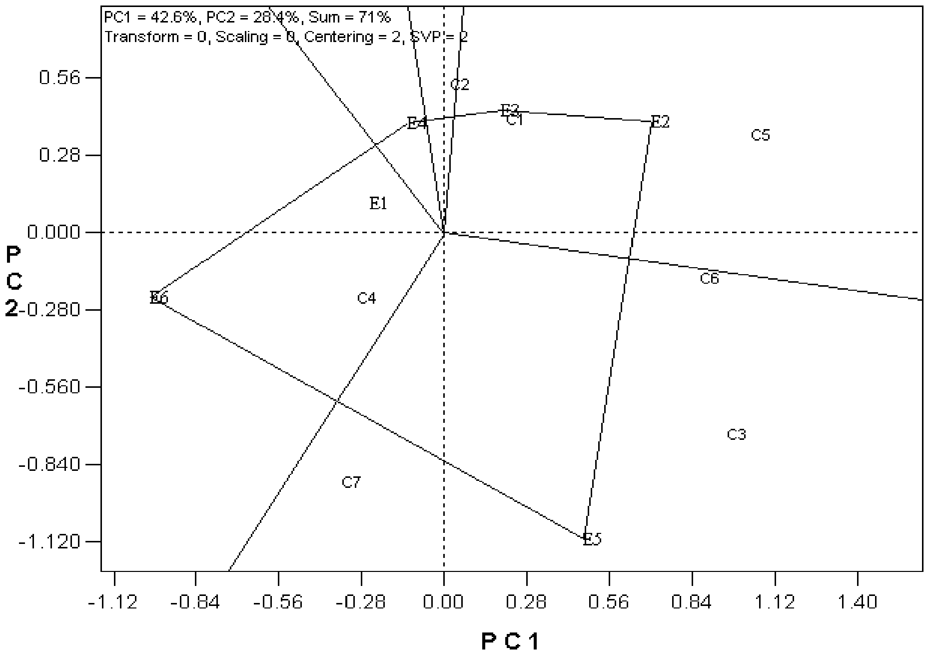

Figure 2. Biplot for GY and putative heterotic relationships between Ethiopian and CIMMYT inbred lines cross combinations evaluated at three locations in Ethiopia.

Table 6. Mean grain yield and estimates of SCA effects for GY and other agronomic traits of the 42 crosses evaluated at three locations in Ethiopia in 2004.

Hybrid	Mean grain yield ($t\ ha^{-1}$)	Specific combining ability			
		Grain yield ($t\ ha^{-1}$)	Days to anthesis	Ear height (cm)	Plant height (cm)
E1 x C1	5.53	-0.09	-0.51	-5.19	-6.40
E1 x C2	6.84	-0.02	-0.07	-5.62	-10.55*
E1 x C3	6.01	-0.32	-0.23	-2.43	7.50
E1 x C4	6.62	0.44	0.12	8.55*	1.28
E1 x C5	7.27	0.33	0.27	8.83*	6.17
E1 x C6	6.46	-0.47	0.79	2.39	1.17
E1 x C7	6.46	0.14	-0.36	-6.54	0.84
E2 x C1	5.60	-0.20	0.57	12.19**	19.94**
E2 x C2	7.15	0.11	-0.32	3.99	4.24
E2 x C3	6.79	0.29	-0.38	3.40	-0.26
E2 x C4	5.97	-0.39	-0.80	-8.40*	-9.59
E2 x C5	7.61	0.50	0.90	-10.90**	-9.81
E2 x C6	7.84	0.75*	0.64	7.78*	9.74
E2 x C7	5.43	-1.06**	-0.62	-8.05*	-14.26**
E3 x C1	6.54	0.78*	0.11	-1.59	0.17
E3 x C2	6.68	-0.31	-0.22	-7.90*	-2.54
E3 x C3	5.81	-0.67*	-0.95	-2.72	-8.37
E3 x C4	5.88	-0.44	-0.04	2.82	9.41
E3 x C5	7.49	0.43	-0.78	3.43	-6.37
E3 x C6	7.42	0.35	0.18	3.66	5.41
E3 x C7	6.33	-0.13	1.70**	2.28	2.30
E4 x C1	5.79	0.09	0.16	5.83	5.80
E4 x C2	7.87	0.93**	-0.96	5.52	2.99
E4 x C3	6.62	0.20	0.66	-2.63	-3.85
E4 x C4	6.23	-0.04	-0.10	-11.98**	-11.51*
E4 x C5	6.95	-0.07	-0.29	-4.92	3.26
E4 x C6	6.22	-0.79*	0.45	0.70	-1.40
E4 x C7	6.07	-0.33	0.08	7.48*	4.71
E5 x C1	5.43	-0.59	-0.46	-8.78*	-16.39**
E5 x C2	6.42	-0.83*	0.98*	-3.76	-5.65
E5 x C3	7.73	1.01**	0.81	9.87**	12.41*
E5 x C4	6.37	-0.2	-0.28	-0.04	0.74
E5 x C5	7.14	-0.18	-0.24	4.46	8.74
E5 x C6	7.51	0.20	-1.72**	-0.86	-1.59
E5 x C7	7.31	0.60	0.91	-0.91	1.74
E6 x C1	5.31	0.01	0.14	-2.47	-3.12
E6 x C2	6.65	0.12	0.58	7.77*	11.51*
E6 x C3	5.50	-0.51	0.08	-5.49	-7.43
E6 x C4	6.48	0.63	1.10*	9.04*	9.68
E6 x C5	5.62	-1.00**	0.14	-0.90	-1.99
E6 x C6	6.56	-0.04	-0.34	-13.67**	-13.32*
E6 x C7	6.79	0.79*	-1.71**	5.73	4.68
SE	0.39	0.33	0.48	3.55	5.36

*,** Significant at 0.05 and 0.01 level of probability, respectively. SE= Standard error

According to Yan and Hunt (2002), biplot can help to graphically visualize the SCA of genotypes, the best mating partner for each genotype, groups of similar genotypes, the best crosses and hypotheses to be formulated on the genetic relationship among the parents. Such information can help the researchers to focus on a few parents and crosses in further investigations. In general, Ethiopian inbred lines (E2, E5 and E6) with high response to the change of testers and CIMMYT inbred lines (C3, C5 and C6) with high power to discriminate between the lines could be used for high yielding hybrid development. In general, results of the current study are useful to determine which inbred lines had the most desirable expression of relevant traits and to estimate the heterotic relationship between each pair of inbred lines to facilitate the identification of hybrids that combine desirable agronomic traits and disease resistance.

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