

Full Length Research Paper

Combining ability of maize inbred lines (*Zea mays* L.) for yields in mid altitude sub-humid Agroecology of Ethiopia

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Maize is an important staple food for most Ethiopians, but the national average productivity of maize is below that of the world. Development and cultivation of high yielding maize hybrids can improve maize productivity and production. Having information on combining ability and heterosis of maize inbred lines is important for the development of high yielding maize hybrids. The objectives of this study were to identify good hybrids based on grain yield and yield related traits, to estimate the general combining ability (GCA) and specific combining ability (SCA). Thirteen inbred lines were crossed in 2017 with two line testers using a line by tester mating design. The resulting 26 crosses were evaluated in a randomized incomplete block design (RCBD) with three replications during the main rainy seasons between June and November, 2018 at Bako, Ethiopia. In addition, the 13 parental lines including the two tester lines were evaluated using RCBD with three replications in a separate trial. Analysis of variance (ANOVA) showed that mean squares due to crosses were highly significant ($P \leq 0.01$) for most of the traits studied, except ear aspect. Also mean square due to line was significantly different ($P < 0.01$ or $P < 0.05$) in all studied traits except days to anthesis (AD) and ear aspect (EA). The overall mean grain yields (GY) of the hybrids were 6.32 t/ha ranging from 5.21 to 8.19 t/ha. L7 had the lowest negative GCA for grain yield whereas L6 had the highest positive GCA. Among the crosses with high positive SCA, estimates showed high mean grain yield, which implied good correspondence between SCA effects and mean GY. The result obtained in this study could be useful to design for developing high yielding hybrids and synthetics adapted to the mid altitude sub humid agro ecologies of Ethiopia.

Key words: Grain yield, maize inbred lines, line by tester, general combining ability, specific combining ability.

INTRODUCTION

Maize (*Zea mays* L) is a diverse species, with rich morphological and biological variability. It is a monoecious plant, bearing distinct male and female flowers. It is predominantly cross pollinated through wind.

Maize is grown in many countries of the world, across a wide range of climates and ecological zones (Dowswell, 1996).

This crop is one of the most important staples crops in

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the world. Maize, wheat, and rice are among the stable crops supporting over 75% of the world's population (Ji and Wang, 2013). Maize is first among cereal crops of 41.56% followed by wheat with 29.39% and rice with 29.05% in terms of production (FAOSTAT, 2018).

Maize is one of the most crucial field crops in Ethiopia, with respect to production, yield, area under cultivation and economic importance. Its production has increased five folds over the past two decades (from 1.45 in 1993 to 7.84 million tons in 2017), while the area coverage increased two folds over the same period (FAOSTAT, 2018). In the main cropping season of 2017, maize production accounted for the highest share in food security and economy of Ethiopia (CSA, 2017). Among the cereal crops, maize was first in terms of production (26.8%) and productivity (3.38 t/ha). However, the national average maize productivity of the country is very low in comparison to the average yield per hectare of the world (5.2 t/ha) and that of the developed countries (7.2 t/ha).

Hybrid development involves the evaluation and selection of new locally developed maize inbred lines based on their hybrid performance through combining ability studies (Hallauer et al., 2010; Amiruzzaman et al., 2011). Combining ability studies provide vital information on the genetic mechanisms that control the pattern of inheritance of quantitative traits. This illuminating information enables the breeder to select suitable parents for further improvement or use in hybrid breeding for commercial release (Abuali et al., 2012). Combining ability indicates the potential breeding values of parental lines to produce hybrids through determining the general combining ability (GCA) and specific combining ability (SCA) of the inbred lines. GCA is the mean performance of a line in a hybrid combination. On the other hand, SCA refers to cases in which some hybrid combinations perform comparatively better or less than expected based on the average performance of the parental lines involved. GCA and SCA effects are important indicators of the level of usefulness of the inbred lines in hybrid combinations and in categorizing materials into heterotic groups (Tolera et al., 2017). Combining ability analysis and collection of correct genetic information in breeding materials is necessary at the beginning of the development of the inbred line. It provides reliable estimates of genetic components and gene action governing complex traits.

Details of combining ability of maize germplasm are necessary for maximizing the benefits of hybrid development. Many researchers have reported on the combining ability and heterosis for maize grain yield (Dagne, 2008; Berhanu et al., 2009; Amiruzzaman et al., 2011; Abuali et al., 2012; Mohammad et al., 2016; Dar et al., 2017; Tolera et al., 2017; Tulu et al., 2018). Combining ability analysis can be very useful if properly conducted and the results are correctly interpreted. If such studies reveal the required genetic information,

inbred lines with poor combining abilities are jettisoned and only promising inbred lines are advanced in subsequent cycles of selection (Sadat and Khalil, 2011). Therefore, evaluation of inbred lines for combining ability and heterosis is an important component of maize hybrid breeding program.

Justification of the study

This research was informed by the need to determine the combining ability of inbred lines and hybrids for yield and yield components so as to ascertain their possible value in current and future maize improvement programmes in Ethiopia, a country where the crop is a foremost staple.

Aim of the study

The purpose of the research was to study and evaluate the combining ability of maize inbred lines and hybrids for yield and yield components.

This study was under-taken with the following objectives:

- (1) To estimate general combining ability for yield and yield components.
- (2) To estimate specific combining ability for early generation white maize inbred lines for yield and yield components.

MATERIALS AND METHODS

Descriptions of experimental site

The experiment was conducted at Bako National Maize Research Center (BNMRC) during 2018 main cropping season. BNMRC is located in East Wollega Zone of the Oromia National Regional State, Western Ethiopia. The center is 250 km from Addis Ababa, the capital city of the country, and lies between 9°6' North latitude and 37°09' East longitude in the sub-humid agro-ecology and average altitude of 1650 m above sea level (Figure 1). The mean annual rainfall of the previous 56 years was 1239.4 mm and the mean annual rain fall during the season, in 2017 was 1316.7 mm according to metrological data from Bako Agricultural Research. The minimum, mean and maximum air temperature is 13.3, 28.0, and 20.6°C, respectively and the relative humidity was 63.55%. The soil is reddish brown in color and clay loam in texture (Wakene, 2001). According to USDA soil classification, the soil is alfisols developed from basalt parent materials, and is deeply weathered and slightly acidic in reaction (Wakene et al., 2001).

Experimental materials

Twenty-eight entries composed of 26 test crosses and two standard checks (BH546 and BH547) were used for this study. The test crosses were made by using line by tester mating design which involved crossing 13 white maize inbred lines with testers (referred to as tester A and tester B) in 2017 main season. F1 hybrids were evaluated in the rainy season of 2018. In addition, the testers and

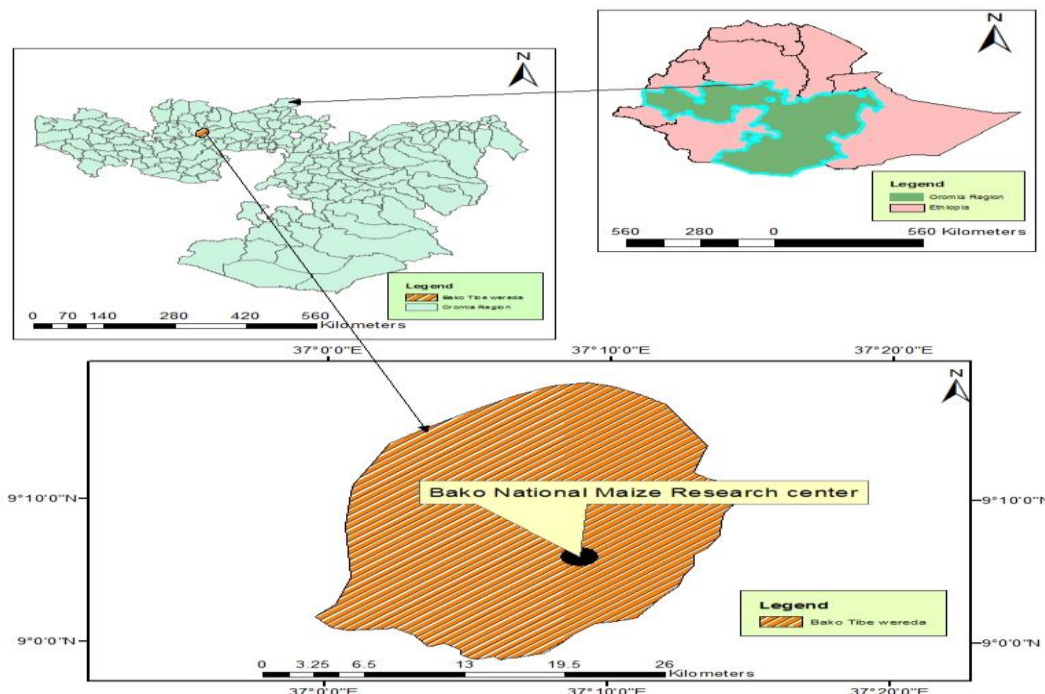


Figure 1. Map of study area Bako National Maize Research Center (ARC).

Table 1. List of maize inbred lines and testers used for test cross formation.

Inbred line code	Pedigree of maize inbred lines	Source
L1	BKINT2012F2-1-1-1-1	BNMRC
L2	BKINT2012F2-1-1-2-1	>>
L3	BKINT2012F2-1-1-2-2	>>
L4	BKINT2012F2-1-1-2-3	>>
L5	BKINT2012F2-7-1-1-1	>>
L6	BKINT2012F2-16-2-1-1	>>
L7	BKINT2012F2-26-2-1-1	>>
L8	BKINT2012F2-26-2-2-1	>>
L9	BKINT2012F2-44-1-1-1	>>
L10	BKINT2012F2-48-1-1-1	>>
L11	BKINT2012F2-69-1-1-1	>>
L12	BKINT2012F2-79-1-1-1	>>
L13	BKINT2012F2-1-2-1-1	>>
TB	PO'00E-3-2-1-2-1	>>
TA	ILO'00E-1-9-1-1-1-1-1	>>

L= Inbred line, TA=Tester B, TB=Tester A.

the inbred line parents evaluated in a separate trial along with the hybrid trial for estimation of the magnitudes of heterosis for each test cross during the same season. The inbred lines and testers were developed at BNMRC through pedigree breeding technique. The list and the pedigrees of the inbred lines and testers used in the line x tester crosses are shown in Table 1. The standard checks BH546 and BH547 are high yielding (8.5 to 11.5 t/ha) medium maturing conventional white commercial maize hybrids released by BNMRC for the mid-altitude sub-humid maize growing agro-ecology

of Ethiopia, the high potential maize production belt.

Experimental design

The experimental design was (0, 1) alpha lattice design (Patterson and Williams, 1976) with 4 plots and 7 incomplete blocks with three replicates for hybrids. For the parental inbred lines, experimental design was randomized complete block design with three replications. Each entry was planted in one row by 5.1 m long plot



Figure 2. Ear length and ear diameter for L6 x TA.

with spacing of 0.75 m between rows and 0.30 m between plants within a row.

Trial management

The experimental materials were hand planted with two seeds per hole, which were later thinned down to one plant to get a planting density equivalent to 44,444 plant population per hectare. Planting was conducted at the onset of the rainy season (June 3, 2018) after ample amount of moisture level had been attained to ensure good germination and seedling development. Pre-emergence herbicide, [®]Primagram-Gold was applied at the rate of 3 L/ha after planting to control weeds. Hand weeding and slashing was used to control weeds throughout the growing season. Di-ammonium phosphate (Nitrogen, phosphorus, Sulfur) and urea fertilizers were applied at the rate of 180 and 200 kg/ha, respectively. NPS fertilizer was applied once at sowing time, while urea was applied in split, half at planting and the remaining half at 10 to 12 leaf or (35 to 40) days after planting. Based on recommendations for the areas, other agronomic practices were carried out.

Data collection

Data on grain yield and other important agronomic traits were collected as follows:

- (1) Days to anthesis: The number of days from emergence to when 50% of the plants in a plot started shedding pollens
- (2) Days to silking: The number of days from plant emergence to when 50% of the plants in a plot have grown 2 to 3 cm long silks.
- (3) Anthesis-silking interval (ASI): The number of days between days to silking and days to anthesis (this is calculated data).
- (4) Days to physiological maturity: The number of days from planting to when 50% of the plants in a plot form black layer at the tip of the kernel.
- (5) Stand count at harvest: The number of plants on each plot.

(6) Number of ears per plant: The ratio of total number of ears harvested from a plot to the total number of plants in that particular plot (calculated data).

(7) Grain weight (t/ha): The weight of the ears per plot adjust to 12.5% moisture level and 80% shelling percentage to estimate grain yield in tons (t/ha) for each genotype (Carangal et al., 1970)

(8) Actual moisture content: Moisture content of samples from the bulk of shelled grain in each plot measured using a handheld moisture tester. Recorded at the same time as the measurement of grain weight per plot and 1000 kernels weight.

(9) 1000 kernel weight (g): Randomly selected 1000 kernels from the bulk of shelled grain of each experimental unit were counted and weighed by adjusting to 12.5% moisture content of the grain.

(10) Plant aspects: Recorded on a 1 to 5 scale, where 1 means the best variety (considering general appeal of the plants per row: plant vigor, ear size, good ear placement or position, husk cover, uniformity, disease infestation, and so on), while 5 means the worst plant aspect

(11) Ear aspects: Recorded on a 1 to 5 scale where 1 refers to the best ear aspect (considering general appeal of the ears: ear size, uniformity, bare tipness (whether the grain filled up to the tip of the ear), kernel row arrangement, ear rot infection and other acceptable characters), while 5 refers to the poorest ear aspect with undesirable characteristics (Figure 3).

(12) Ear height (cm): Average height in cm of five randomly selected plants per plot measured from the ground level to the upper most ear bearing node.

(13) Plant height (cm): Average height in centimeter of five randomly selected plants measured from the ground level to the first tassel branch.

(14) Ear cob length (cm): Average length in cm of ten randomly taken ears from each experimental unit measured from the base to tip of the ear at the time of harvest (Figure 2).

(15) Ear cob diameter (cm): Average diameter in cm of ten randomly taken ears of a plot measured using digital caliper at harvest time (Figure 2).

(16) Number of rows per ear: Average number of kernel rows of five randomly taken ears of a plot.

(17) Number of kernels per row: Average number of kernels per row of five randomly sampled ears per plot.



Figure 3. Ear aspect evaluation for inbred lines.

Statistical analysis

Analysis of variance

Analysis of variance (ANOVA) was carried out using the PROC MIXED procedure in SAS (SAS Institute, 2014) to determine the differences among the genotypes. Genotypes were considered as fixed effects while replications and blocks within replications were considered random. Significant differences were further subjected to least significant difference (LSD) to separate treatment means.

Line by tester analysis

Line × tester analysis was done for traits that showed significant differences among crosses to partition the mean square due to crosses into lines (GCA_m), tester (GCA_f) and line × tester interactions (SCA_m) Table 2 (Singh and Chaudhary, 1985).

Contribution of lines (L) = $\frac{SS(L)}{SS(Crosses)} \times 100$, Contribution of testers (T) = $\frac{SS(T)}{SS(Crosses)} \times 100$, Contribution of line by tester (L × T) = $\frac{SS(L \times T)}{SS} \times 100$.

Estimation of GCA Effects:

$$a) \text{ Lines: } g_i = \frac{x_{i...}}{tr} - \frac{x_{...}}{ltr}$$

$$b) \text{ Testers: } g_j = \frac{x_{j...}}{tr} - \frac{x_{...}}{ltr}$$

where g_i = GCA effect for i th line, g_j = GCA effect for j th tester, $X_{j...}$ = sum of the j th tester in hybrids, $X_{i...}$ = Sum of the i th line in hybrids, $X_{...}$ = grand sum, l = number of inbred lines, t = number of testers and r = number of replications.

$$\sum g_i = \sum g_j = 0$$

Estimation of SCA effects:

$$s_{ij} = \frac{X_{ij...}}{r} - \frac{X_{i...}}{tr} - \frac{X_{j...}}{rl} + \frac{X_{...}}{rtl}$$

where S_i SCA effect of the ij th cross, $X_{...}$ = Grand mean, $X_{ij...}$ = $i \times j$ cross sum, $X_{i...}$ = i th inbred line sum in hybrids, $X_{j...}$ = j th tester sum in hybrids, l = number of inbred lines, t = number of testers and r = number of replications.

Standard errors for combining ability effects were calculated as:

(1) Standard error for general combining ability effects

$$a) \text{ InbredLine : } SE(\text{GCA for line}) = \frac{\sqrt{Mse}}{rt}$$

$$b) \text{ Tester : } SE(\text{GCA for tester}) = \frac{\sqrt{Mse}}{rl}$$

(2) Standard error for specific combining ability effects

$$SE(\text{SCA effects}) = \frac{\sqrt{Mse}}{r}$$

(3) T-tests for GCA and SCA

The significance of the GCA effects was tested using the formula described by Cox and Frey (1984):

$$t_{cal} = \frac{GCA}{SE\ gca(male)}, \text{ whereas } SE(gca\ male) = \frac{\sqrt{Me}}{rt}$$

$$t_{cal} = \frac{GCA}{SE\ gca(female)}, \text{ whereas } SE(gca\ female) = \frac{\sqrt{Me}}{rt}$$

$$t_{cal} = \frac{SCA}{SE\ sca(\text{Line by tester})}, \text{ whereas } SE(sca\ female) = \frac{\sqrt{Me}}{r}$$

Table 2. Skeleton of ANOVA line by tester as suggested by Singh and Chaudhary (1985).

Source of variance	Degree of freedom	Mean square (MS)
Replication (r)	r-1	
Genotype (g)	g-1	
Parents(p)	p-1	
parents vs crosses	1	
Line(L)	L-1	MS _l
Testers(T)	T-1	MS _t
Lines × Testers (L×T)	(L-1)(T-1)	MS _{lxt}
Error	(LT-1)(r-1)	MSe

r=Replication, g=genotype, p=parent, l= inbred lines, t=tester, MS=mean square and MSe=mean square error

Table 3. Analysis of variance for grain yield and yield components of test crosses generated using 13 lines and two testers evaluated at Bako in 2018 cropping season.

Source of variance	DF	GY	DA	DS	ASI	DM	PH	EH
Replication	2	2.64*	2.68 ^{ns}	2.58 ^{ns}	0.62 ^{ns}	10.71 ^{ns}	484.82 ^{ns}	850.30 ^{ns}
Block (Rep)	18	1.2 ^{ns}	0.73 ^{ns}	0.78 ^{ns}	0.37 ^{ns}	2.91 ^{ns}	150.66 ^{ns}	126.67 ^{ns}
Genotype	27	1.98**	11.27**	11.02**	1.26**	45.09**	699.32**	447.12**
Error	36	0.71	1.3	1.74	0.54	5.21	129.68	183.41
CV%		13.34	1.48	1.71	237.43	1.48	3.99	8.7
Mean		6.32	77.03	77.34	0.31	154.07	285.71	155.59

Source of variance	DF	PA	EA	NRPE	NKPR	EL	ED	TSW
Replication	2	0.24 ^{ns}	0.12 ^{ns}	0.06 ^{ns}	5.63 ^{ns}	10.35 ^{ns}	0.1**	569.61 ^{ns}
Block (Rep)	18	0.2*	0.19 ^{ns}	0.44 ^{ns}	15.77 ^{ns}	1.74 ^{ns}	0.03*	1127.64 ^{ns}
Genotype	27	0.26**	0.24 ^{ns}	2.03**	34.89*	5.65**	0.16**	1512.46**
Error	36	0.1	0.14	0.47	18.43	0.98	0.02	739.11
CV%		13.27	15.29	4.89	11.26	5.16	2.72	10.2
Mean		2.34	2.47	13.97	38.31	19.16	4.77	266.46

*=0.05 and **= 0.01 significant probability level. GY=Grain yield, AD = days to anthesis, DS = days to silking, ASI = anthesis silking interval, DM = days to maturity, PH = plant height, EH = ear height, PA=plant aspect, EA=ear aspect, RPE = number of rows per ear, KPR = number of kernels per row, EL = ear length, ED = ear diameter, TKW=thousand kernel weight, DF = degrees of freedom.

where Me is the error mean sum of squares; *r*, *t*, *l* are numbers of replications, testers and lines, respectively; SE is standard error.

RESULTS

Analysis of variance (ANOVA)

The analysis of variance revealed that there were highly significant differences among the genotypes ($P \leq 0.01$) for all the traits except for ear aspect which was non-significant at $p < 0.5$ (Table 3). The ANOVA for the parental inbred lines also revealed significant variation (at $p < 0.01$ or 0.05) for all traits studied except anthesis silking interval, ear height, number of row per ear, ear diameter and thousand seed weight (Table 4).

Estimation of combining ability for yield and yield traits

The variances for the crosses were partitioned into GCA (lines or testers) effects and SCA (lines by tester) effects. The ANOVA table for line by tester mating design for grain yield and yield related traits are presented in Table 5. Mean square due to line by tester was significantly different at ($P < 0.01$ or $P < 0.05$) for all the traits except days to anthesis, days to maturity, ear height, number of kernels per row, and number of row per ear. Mean squares due to lines were also significant at ($p < 0.01$ or 0.05) for all traits studied except anthesis silking interval, ear height, number of row per ear, ear diameter and thousand seed weight. Similarly, mean square due to

Table 4. Analysis of variance for grain yield and yield components of parental inbred lines composed of 13 lines and 2 testers evaluated at Bako in 2018 cropping season.

Source of variance	DF	GY	AD	SD	ASI	DM	PH	EH
Replication	2	0.26 ^{ns}	4.55 ^{ns}	17.84 ^{**}	1.31 ^{ns}	14.78 ^{ns}	0.27 ^{ns}	551.72 ^{ns}
Genotype	13	4.99 ^{**}	18.66 ^{**}	21.09 ^{**}	1.69 ^{ns}	71.79 ^{**}	0.0004 ^{**}	517.12 ^{ns}
Error	25	29.92	80.06	2.9457	3.34	13.18	403.39	325.2
CV %		29.93	2.07	1.96	257.92	2.1	1135	20.93
Mean		2.18	86.36	87.39	0.7	172.5	176.95	86.13

Source of variance	DF	PA	EA	NRPE	NKPR	EL	ED	TSW
Replication	2	0.62 ^{ns}	0.08 ^{ns}	9.87	12 ^{ns}	8.95 ^{ns}	1553.63 ^{ns}	8775.09*
Genotype	13	0.45*	0.6*	10.51 ^{ns}	26.28*	13 ^{**}	1430.02 ^{ns}	3571.12 ^{ns}
Error	25	0.2	0.25	12.61 ^{ns}	12.41	4.39	1501.44	2531.06
CV%		18.1	21.6	25.84	13.08	14.43	389.63	23.26
Mean		2.35	2.31	13.74	26.92	14.52	9.94	216.25

*=0.05 and **= 0.01 significant probability level. GY=Grain yield, AD = days to anthesis, DS = days to silking, ASI = anthesis silking interval, DM = days to maturity, PH = plant height, EH = ear height, PA=plant aspect, EA=ear aspect, NRPE = number of rows per ear, NKPR = number of kernels per row, EL = ear length, ED = ear diameter, TKW=thousand kernel weight, DF = degrees of freedom.

tester was significant for days to anthesis, days to silking, plant height, ear height and ear diameter. However, mean square due to tester showed insignificant difference for GY, AD, DM, NRPE, EL and ED. Proportion of variance for general combining ability was greater than that of specific combining ability for all traits studied except GY which showed almost equivalent proportions of GCA and SCA variances.

General combining ability effect (GCA)

General combining ability effects of 13 newly developed inbred lines were estimated to determine their breeding values for use in hybrid formation. Estimates of GCA effects for line (GCA_L) and GCA for tester (GCA_T) are presented in Table 6. All inbred lines showed significant positive or negative GCA effects ($P < 0.01$ or $P < 0.05$) for GY except two inbred lines. Four inbred lines displayed highly positive significant GCA_L for GY whereas seven inbred lines showed negative significant GCA_L for the same trait. Significant positive GCA effects on GY were recorded for L2, L4, L6 and L12. Inbred line 6 (1.5) had the highest significant positive GCA effect while inbred lines 2 (0.24) had the lowest significant positive GCA_L . Four inbred lines (L1, L2, L4 and L3) showed highly significant positive GCA_L for ear length (EL). The highly significant positive GCA_L ($P < 0.01$) for this trait was 2.2 for L1 whereas the lowest was 1.07^{**} for L3. Four inbred lines showed highly significant GCA_L . L6 (0.35) and L5 (0.23) showed positive significant GCA_L and L4, L1 showed negative significance for ear diameter. Only L5 (-1.36) exhibited highly negative significant differences GCA_L for number of kernel per row. None inbred line displayed significant GCA_L for DM, TKW and NRPE. Except L1 all inbred lines displayed highly significant

GCA_L for AD, SD and ASI. L6 (2.68), L11 (2.05) and L8 (0.87) displayed the highest positive GCA_L for AD, SD and ASI, respectively. L9 (-2.65^{**}), L9 (-2.28^{**}) and L6 (-0.79^{**}) had the lowest negative GCA_L for AD, SD and ASI, respectively. L1 showed the highest positive significant GCA_L for plant height (19.94 cm).

Specific combining ability effects

Estimates of SCA effects of the twenty-six crosses for various traits are shown in Table 7. The crosses showed considerable variation in SCA effects for the different traits. All crosses showed significant SCA effects for grain yield. The highest positive SCA value for GY was obtained from L1 × TA (0.77*) whereas the lowest SCA value for the same trait was from L4 × TB (0.03^{**}). L4 × TA expressed the highest negative SCA value for GY whereas the lowest value for the same trait was detected from L1 × TA. Only four crosses exhibited significant SCA effects for ear length in both directions. L4 × TB and L13 × TA showed positive and significant SCA for this trait with values of 0.79 and 0.80, respectively. Whereas L4 × TA and L13 × TB showed significant negative SCA effects. L1 × TB, L4 × TB, L6 × TA, L9 × TA, L11 × TB, L12 × TA and L13 × TB showed significant positive SCA effects for ED. However, crosses L1 × TA, L4 × TA, L6 × TB, L9 × TB, L11 × TA, L12 × TB and L13 × TA showed significant negative SCA effects for this trait.

Two crosses exhibited significant SCA effects for NKPR. L9 × TB (5.19) displayed significant positive SCA for NKPR, while L9 × TA (-5.19) showed negative and is significant for this trait. For DS, crosses L2 × TB, L5 × TB, L10 × TB, L8 × TA, L11 × TA and L13 × TA showed positive and significant SCA effect with value of 1.53^{**},

Table 5. Analyses of variance line by tester for grain yield and yield related traits of 26 crosses and 13 inbred lines evaluated in 2018 main season at Bako, Ethiopia.

Source	Df	Mean square						
		GY	DA	SD	ASI	DM	PH	EH
REP	2	0.67 ^{ns}	381.05**	2.51 ^{ns}	10.05 ^{ns}	0.16 ^{ns}	0.06**	638.78*
CROSSES	25	1.85**	1477.92**	15.90**	63.60**	0.39**	0.11**	596.51**
LINE (GCA)	12	1.89**	889.10 ^{ns}	13.85**	55.38**	0.56**	0.12**	730.24**
TESTER (GCA)	1	1.04 ^{ns}	23796.8 ^{ns}	197.13**	788.51**	0.00 ^{ns}	0.81**	2832.05*
LINE × TESTER (SCA)	12	1.87**	206.82 ^{ns}	2.85*	11.4*	0.25 ^{ns}	0.05**	276.5 ^{ns}
ERROR	32	0.49	550.4751	1.14	4.56	0.15	0.02	144.78
GCA%		50.27	81.13	82.93	82.93	69.14	70.59	72.54
SCA%		49.73	18.87	17.07	17.07	30.86	29.41	27.46

Source	Df	Mean square						
		PA	EA	NRPE	NKPR	EL	ED	TKW
REP	2	4.30**	0.63 ^{ns}	3.85 ^{ns}	0.05 ^{ns}	0.09 ^{ns}	329.17 ^{ns}	2.46 ^{ns}
CROSSES	25	6.13**	0.46 ^{ns}	37.78*	2.34**	0.25**	861.65**	15.07**
LINE(GCA)	12	9.85**	0.54 ^{ns}	56.73**	2.57**	0.42**	1437.82**	12.46**
TESTER (GCA)	1	20.28**	1.67*	20.10 ^{ns}	23.47**	0.15 ^{ns}	169.55 ^{ns}	169.55**
LINE × TESTER (SCA)	12	1.23*	0.29 ^{ns}	20.29 ^{ns}	0.36 ^{ns}	0.10*	343.16**	4.8**
ERROR	32	1.01	0.29	18.3	0.41	0.08	125.50	1.37
GCA%		88.90	65.06	73.66	87.71	80.77	80.73	72.19
SCA%		11.10	34.94	26.34	12.29	19.23	19.27	27.81

*P=0.05 and **P = 0.01 significant probability level, ns =Non-significant, DF = degrees of freedom, MS = mean square, GY=grain yield, DA = days to anthesis, DS = days to silking, ASI = anthesis silking interval, DM = days to maturity, PA = plant aspect, EA = ear aspect EH = ear height, PH = plant height, EL = ear length, ED = ear diameter, NRPE = number of rows per ear, NKPR = number of kernel per rows, TKW=thousand kernels weight, GCA %= general combining ability percentage, SCA %=specific combining ability percentage.

1.19**, 1.19**, 0.97* and 0.97*, respectively. While, crosses L2 × TA, L5 × TA, L10 × TA, L8 × TB, L11 × TB and L13 × TB showed negative and significant SCA effects.

Similarly, for AD crosses L2 ×TB, L5 × TB, L7 × TB and L12 × TA showed significant and positive SCA estimate, while L2 ×TA, L5 × TA, L7 × TA and L12 × TB showed significant SCA estimate for days to anthesis. Traits like NRPE, TKW, DM, PH and EH showed non-significant SCA effects.

DISCUSSION

Estimate of GCA and SCA for grain yield and yield related traits

The significance of the mean squares due to lines and testers indicated considerable variation among the inbred lines variation and the testers in their performance. Meanwhile, significant line × tester interaction suggests that inbred lines performed uniquely according to the testers they were crossed to. These results are consistent with the findings of Makumbi et al. (2011) and Bullo and Dagn (2016). This result revealed that the mean squares of GCA and SCA were highly significant for grain yield, days to anthesis, days to silking, anthesis-silking interval,

days to maturity, plant height, plant aspect, number of row per ear (NRPE), ear length, ear diameter and a thousand seed weight. Only the mean square of number of kernel per row (NKPR) was significant (P ≤0.05) whereas the mean square of the GCA and SCA of the ear traits were insignificant. The magnitude of GCA_L is a measure of the level of the performances of the inbred lines in hybrid combinations. Positive significant GCA_L indicates that the performance of the inbred lines is higher than the collective mean of all crosses. Thus, significant positive GCA_L is desirable for yield and yield components. Significant GCA and SCA mean squares indicate the complementary roles of both additive and non-additive gene actions in determining grain yield. Hadji (2004), Mohamed et al. (2016) and Silvestro et al. (2018) also found highly significant GCA and SCA for grain yield in diallel study of maize inbred lines. Moreover, researchers like Dagne (2008), Mokenen (2015) and Tulu et al. (2018) reported the parts played by additive and non-additive gene actions in controlling grain yield in maize. In this study, the contribution of GCA variance was much greater than the contribution of SCA for all the characters studied. The higher percentage relative contribution of GCA of mean square over SCA showed the predominant role of additive gene action over non-additive action in the inheritance of all traits studied. Two

Table 6. Estimates of general combining ability (GCA) effects for grain yield and other agronomic traits of 13 maize inbred lines crossed using line x tester mating design and evaluated at Bako in 2018 main cropping season.

Line	Traits											
	GY	AD	SD	ASI	DM	PH	EH	NRPE	NKPR	EL	ED	TKW
L1	0.94	0.51	0.72	0.21	1.03	19.94**	2.82	-0.09	5.04	2.2**	-0.19**	4.82
L2	0.24**	-0.82**	-1.45**	-0.63*	-1.64	15.77**	8.65	0.31	2.04	1.51**	0.01	19.76
L3	-0.41	0.85**	0.05**	-0.79*	1.69	11.60	6.99	0.51	1.61	1.07**	-0.08	-5.66
L4	0.50**	0.01**	-0.45**	-0.46*	0.03	11.60	1.99	-0.23	1.61	1.11**	-0.12**	9.78
L5	-0.35**	-0.99**	-1.12**	-0.13*	-1.97	-7.56	-1.35	1.31	-1.36**	-0.93	0.23**	4.11
L6	1.50**	2.68**	1.88**	-0.79*	5.36	5.77	15.32**	0.51	0.54	-0.64	0.35**	2.47
L7	-0.58**	-2.65**	-1.95**	0.71*	-5.31	-35.90	-18.01	-0.43	-0.39	-0.34	-0.01	-2.05
L8	-0.90**	0.51**	1.38**	0.87*	1.03	-5.90	-1.35	-0.36	2.61	0.51	0.08	-6.20
L9	-0.62**	-2.65**	-2.28**	0.37*	-5.31	-17.56	-18.85	-0.49	-7.26	-0.63	-0.10	2.13
L10	-0.26**	-0.32**	-0.45**	-0.13	-0.64	-11.73	-15.51	0.37	-1.13	-0.21	0.03	-19.11
L11	-0.44**	1.51**	2.05**	0.54*	3.03	4.10	8.65	-1.49	0.71	-1.27	-0.07	-21.4
L12	0.60**	0.35**	0.22**	-0.13*	0.69	0.77	1.15	-0.09	-3.89	-3.14	-0.03	-5.86
L13	-0.21**	1.01**	1.38**	0.37*	2.03	9.10	9.49	0.17	-0.13	0.75	-0.09	17.21
SE	0.34	0.43	0.47	0.28	0.86	4.48	5.02	0.25	1.65	0.39	0.05	9.23
SE (gi-gj) line	1.62	3.51	3.33	1.30	7.02	35.75	25.48	1.54	7.10	3.24	0.34	28.01
TB	-0.11	1.59	1.47	-0.12	3.18	1.47	-6.03	0.56*	0.51	-0.53	0.11	-17.89
TA	0.11	-1.59	-1.47	0.12	-3.18	-1.47	6.03	-0.56	-0.51	0.53	-0.11	17.89
SE(GCA)	0.10	0.12	0.13	0.08	0.25	1.29	1.45	0.07	0.48	0.11*	0.01	2.66
SE (gi-gj) tester	5.89	86.04	79.80	6.24	172.08	79.80	326.13	30.25	27.48	28.78	5.93	968.05

*P=0.05 and **P= 0.01 significant probability level. GY=Grain yield, AD = days to anthesis, S D= days to silking, ASI = anthesis silking interval, DM = days to maturity, EH = ear height, PH = plant height, EL = ear length, ED = ear diameter, NRPE = number of rows per ear, NKPR = number of kernel per rows, TKW=thousand kernels weight, SE (gi) = standard error of general combining ability effects of lines.

factors are given priority consideration in the evaluation of an inbred line for possible use in the production of maize hybrid: characteristics of the line itself and behavior of the line in a given hybrid combination. As the present study results illustrates, the inbred lines displayed superior performance in their GCA effects, especially for grain yield and other prominent traits that contribute to grain yield, that is, PH, EH, PA EA, ER, NRPE, NKPR, EL, ED, and TSW. Numerous researchers have reported similar results in their works on GCA for yield and yield related traits in maize (Hadji, 2004; Bayisa et al., 2008; Chandel and Mankotia, 2014; Dagne et al., 2008; Shushay, 2014; Amare et al., 2016). Amare et al. (2016), in particular, found highly significant mean squares due to GCA and SCA for GY in L x T crosses of 17 maize inbred lines. Similarly, they observed highly significant GCA and SCA mean squares for days to anthesis, days to silking and days to maturity, indicating the significance of additive and non-additive gene actions in controlling the inheritance of the concerned traits. Amiruzzaman et al. (2011), Aminu and Izge (2013) and Tolera (2013) reported highly significant GCA and SCA mean squares for AD and SD in combining ability analysis of maize inbred lines. Other breeders also reported consonant results of mean squares due to GCA of lines and SCA of crosses for AD, SD and DM (Gudata, 2007).

General combining ability

General combining ability is estimated by the additive effects of genes and it can differentiate the genetic component of an inbred line and indicate its potential for utilization in breeding. The magnitude of GCA_L is an indication of the level of the performances of the inbred lines in hybrid combinations. Consequently, significant positive GCA_L is needed for grain yield and yield components. BKINT2012F2-16-2-1-1(L6) had the highest positive GCA which indicates that the line had a higher favorable allele frequency for grain yield. This fact is substantiated by the mean yields obtained from its crosses (the second highest yielding hybrid) which is L6 x TB had one of these lines as its parent. Concerning grain yield, L6 was the best combiner, followed by L1 and L12 while L5, L7, L8, L9, L10, L11 and L13 showed negative GCA effects and were poor combiners for GY. Pavan et al. (2011), Ram et al. (2015), Amare et al. (2016), Ju-lin et al. (2018) reported similar results for yield and yield related traits.

Inbred lines that show the highest and positive significant GCA for the traits like TKW, ED, EL, NRPE and NKPR can be used to improve grain yield. For ear length, ear diameter, number of row per ear, number of kernel per ear and thousand kernel weights, L1, L6, L5, L1 and L2 were the best combiners of GCA_L , respectively.

Table 7. Estimates of SCA effects for yield and yield components of 13 maize inbred lines crossed with two testers in line × tester mating design and evaluated at Bako in 2018 main cropping season.

Crosses	Traits							Crosses	Traits				
	GY	AD	SD	ASI	DM	PH	EH		NRPE	NKPR	EL	ED	TKW
L1×T1	-0.77*	-0.26	-0.64	-0.38	-0.51	-1.47	-0.64	L1×TB	0.17	-0.71	0.32	0.09*	10.92
L1×T2	0.77*	0.26	0.64	0.38	0.51	1.47	0.64	L1×TA	-0.17	0.71	-0.32	-0.09*	-10.92
L2×T1	-0.2**	1.41**	1.53**	0.12	2.82	-0.64	-8.14	L2×TB	-0.09	-0.04	0.13	0.06	7.06
L2×T2	0.2**	-1.41**	-1.53**	-0.12	-2.82	0.64	8.14	L2×TA	0.09	0.04	-0.13	-0.06	-7.06
L3×T1	-0.14**	0.08	0.69	0.62	0.15	11.86	3.53	L3×TB	0.37	-0.47	0.11	0.01	1.34
L3×T2	0.14**	-0.08	-0.69	-0.62	-0.15	-11.86	-3.53	L3×TA	-0.37	0.47	-0.11	-0.01	-1.34
L4×T1	0.03**	-0.09	-0.14	-0.05	-0.18	10.19	3.53	L4×TB	0.17	0.39	0.79*	0.19**	-7.89
L4×T2	-0.03**	0.09	0.14	0.05	0.18	-10.19	-3.53	L4×TA	-0.17	-0.39	-0.79*	-0.19**	7.89
L5×T1	0.70*	0.91*	1.19**	0.28	1.82	11.03	15.19	L5×TB	-0.16	-0.44	0.28	-0.18	-3.73
L5×T2	-0.70*	-0.91*	-1.19**	-0.28	-1.82	-11.03	-15.19	L5×TA	0.16	0.44	-0.28	0.18	3.73
L6×T1	0.32**	-0.42	0.19	0.62	-0.85	-7.31	-4.81	L6×TB	-0.29	-0.01	0.02	-0.10*	6.88
L6×T2	-0.32**	0.42	-0.19	-0.62	0.85	7.31	4.81	L6×TA	0.29	0.01	-0.02	0.10*	-6.88
L7×T1	-0.06**	0.91*	0.03	-0.88	1.82	-7.31	-1.47	L7×TB	0.24	-2.21	-0.25	0.02	-3.31
L7×T2	0.06**	-0.91*	-0.03	0.88	-1.82	7.31	1.47	L7×TA	-0.24	2.21	0.25	-0.02	3.31
L8×T1	0.37**	-0.26	-0.97*	-0.72	-0.51	-7.31	-1.47	L8×TB	0.17	-0.34	-0.66	0.01	-4.69
L8×T2	-0.37**	0.26	0.97*	0.72	0.51	7.31	1.47	L8×TA	-0.17	0.34	0.66	-0.01	4.69
L9×T1	-0.08**	-0.76	-0.64	0.12	-1.51	-7.31	-5.64	L9×TB	-0.36	5.19*	-0.11	-0.10*	-2.06
L9×T2	0.08**	0.76	0.64	-0.12	1.51	7.31	5.64	L9×TA	0.36	-5.19*	0.11	0.10*	2.06
L10×T1	-0.38**	0.24	1.19*	0.95	0.49	-8.14	-5.64	L10×TB	-0.43	0.19	0.66	-0.07	-4.88
L10×T2	0.38**	-0.24	-1.19*	-0.95	-0.49	8.14	5.64	L10×TA	0.43	-0.19	-0.66	0.07	4.88
L11×T1	0.26**	-0.59	-0.97*	-0.38	-1.18	1.03	5.19	L11×TB	-0.03	1.16	-0.58	0.10*	-5.26
L11×T2	-0.26**	0.59	0.97*	0.38	1.18	-1.03	-5.19	L11×TA	0.03	-1.16	0.58	-0.10*	5.26
L12×T1	-0.17**	-0.76*	-0.47	0.28	-1.51	-0.64	-7.31	L12×TB	0.17	-0.24	0.12	-0.13*	5.96
L12×T2	0.17**	0.76*	0.47	-0.28	1.51	0.64	7.31	L12×TA	-0.17	0.24	-0.12	0.13*	-5.96
L13×T1	0.12**	-0.42	-0.97*	-0.55	-0.85	6.03	7.69	L13×TB	0.04	-2.47	-0.80*	0.10*	-0.34
L13×T2	-0.12**	0.42	0.97*	0.55	0.85	-6.03	-7.69	L13×TA	-0.04	2.47	0.80*	-0.10*	0.34
SE(sca)	0.34	0.43	0.47	0.28	0.86	4.48	5.02	SE(sca)	0.25	1.65	0.39	0.05	9.23
SE (Sji-Skl)	0.33	11.06	0.50	1.01	0.18	0.07	5.67	SE (Sji-Skl)	2.02	0.30	0.13	5.28	0.55

Crosses	Traits					Crosses	Traits				
	NRPE	NKPR	EL	ED	TKW		NRPE	NKPR	EL	ED	TKW
L1XTB	0.17	-0.71	0.32	0.09*	10.92	L8XTB	0.17	-0.34	-0.66	0.01	-4.69
L1XTA	-0.17	0.71	-0.32	-0.09*	-10.92	L8XTA	-0.17	0.34	0.66	-0.01	4.69
L2XTB	-0.09	-0.04	0.13	0.06	7.06	L9XTB	-0.36	5.19*	-0.11	-0.10*	-2.06
L2XTA	0.09	0.04	-0.13	-0.06	-7.06	L9XTA	0.36	-5.19*	0.11	0.10*	2.06
L3XTB	0.37	-0.47	0.11	0.01	1.34	L10XTB	-0.43	0.19	0.66	-0.07	-4.88
L3XTA	-0.37	0.47	-0.11	-0.01	-1.34	L10XTA	0.43	-0.19	-0.66	0.07	4.88
L4XTB	0.17	0.39	0.79*	0.19**	-7.89	L11XTB	-0.03	1.16	-0.58	0.10*	-5.26
L4XTA	-0.17	-0.39	-0.79*	-0.19**	7.89	L11XTA	0.03	-1.16	0.58	-0.10*	5.26
L5XTB	-0.16	-0.44	0.28	-0.18	-3.73	L12XTB	0.17	-0.24	0.12	-0.13*	5.96
L5XTA	0.16	0.44	-0.28	0.18	3.73	L12XTA	-0.17	0.24	-0.12	0.13*	-5.96
L6XTB	-0.29	-0.01	0.02	-0.10*	6.88	L13XTB	0.04	-2.47	-0.80*	0.10*	-0.34
L6XTA	0.29	0.01	-0.02	0.10*	-6.88	L13XTA	-0.04	2.47	0.80*	-0.10*	0.34
L7XTB	0.24	-2.21	-0.25	0.02	-3.31	SE(sca)	0.25	1.65	0.39	0.05	9.23
L7XTA	-0.24	2.21	0.25	-0.02	3.31	SE (Sji-Skl)	2.02	0.30	0.13	5.28	0.55

*P=0.05 and **P= 0.01 significant probability level. SE (L × T) = standard error of specific combining ability effects offline by testers, SE (sji-Skl) = standard error of the difference of specific combining ability GY=Grain yield, AD = Days to anthesis, SD = Days to silking, ASI = Anthesis silking interval, DM = days to maturity, EH = ear height, PH = plant height, EL = ear length, ED = ear diameter, NRPE = number of rows per ear, NKPR = number of kernel per rows, TKW=thousand kernels weight.

However, L12, L1, L11, L9 and L10 are the poorest combiner of GCA_L , respectively. Minimum and negative significant of GCA for AD, SD, and DM were obtained from L7, L9 and L7, L9, respectively. The minimum negative significant GCA effects for such traits suggests for their potential usefulness in the development of early maturing hybrid which can be planted for drought escape. These findings corroborate the prior results of Amiruzzaman et al. (2011), Khan et al. (2014) and Alamerew and Warsi (2015).

For morphological traits, L1, L2 showed positive and significant of GCA for plant height and L2 showed positive and significant GCA for ear height. These two traits are desirable for developing tall hybrids. Inbred lines that show significantly high negative GCA for PH and EH are useful in developing dwarf hybrids. Inbred lines 7, 9 and 10 showed negative significant GCA; therefore, they may be suitable for developing short hybrid. Also, short inbred lines produce hybrids that are amenable to mechanized harvest, contributing traits of shorter plants with low ears. Other researchers have reported similar results (Aminu et al., 2014; Alamerew and Warsi, 2015; Ju-lin et al., 2018; Sun et al., 2018).

Specific combining ability effects

Specific combining ability is determined by the non-additive effect of genes, which is influenced by the environment and cannot be inherited sustainably. It is used as a reference when shifting through hybrid combinations (Ju-lin et al., 2018). The crosses showed considerable variation in SCA effects for the different traits. All crosses showed highly significant SCA for grain yield. This indicates that the inbred lines involved in these hybrids are genetically divergent and hence could be regarded as discrete heterotic groups. Among the crosses with good SCA, estimates showed high mean grain yield, which implied good correspondence between SCA effects and mean GY. Many researchers reported significant positive and negative SCA for GY (Bayisa et al., 2008; Dagne, 2008; Kamara et al., 2014; Girma et al., 2015; Ram et al., 2015).

Only four crosses exhibited significant SCA effects for ear length in both directions. Seven crosses showed positive and significant SCA for ear diameter. Crosses that showed positive SCA for ear diameter can be used to improve width of ear cob. Two crosses exhibited significant SCA for number of kernel per row for both directions. Cross L4 × TB showed positive and significant SCA for both ear length and ear diameter, which could be used for the improvement of grain yield through recycling breeding method. The hybrids with negative SCA for AD and SD are desirable for early maturity that would be expected based on GCA of their parents. This finding agrees with the reports of Berhanu (2009); Kanagarasu et al. (2010), Aminu and Izge (2013), and Aminu et al. (2014).

Conclusion

The combining ability of new parental inbred lines and their performance in hybrid combinations are crucial information for a breeding program. The present study was conducted to estimate the combining ability of 13 newly developed normal white inbred lines for grain yield and yield related traits and to classify them into heterotic groups. Highly significant differences were observed among the inbred lines and line by testers for all traits which indicates their suitability for selection for the improvement of yield and yield related traits.

GCA mean squares component was greater than SCA sum of squares for all of the studied traits, suggesting that variations among the crosses were mainly due to additive rather than non-additive gene effects. Hence, selection would be effective in improving grain yield and other agronomic traits. Among parents, BKINT2012F2-16-2-1-1(L6) showed highly desirable GCA effects for grain yield which suggests that it could serve well if selected for the development of hybrids. Inbred lines L1, L2, L4, L6 and L12 were the best general combiners for grain yield.

The results obtained in this study could be helpful for the design of appropriate breeding strategy for developing hybrids and synthetics adapted to the mid altitude sub-humid agro-ecologies of Ethiopia.

Recommendation

From this research study, the following were recommended:

- (1) Crosses L6 × TB and L1 × TA which had yield advantage and better in plant aspect and ear aspect than best standard check BH 547 can be evaluated again and released as new hybrids for mid altitude of Ethiopia.
- (2) Identified inbred lines with desirable positive GCA effects for grain yield and other grain yield related traits will be used for breeding to develop hybrid.
- (3) However, the present study was conducted at one location and the result is only an indication and definite conclusion cannot be reached. Therefore, we recommend that further research should be conducted.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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