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Combing Ability Analysis ofamong Early Generation Maize Inbred Lines

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ከፍተኛ ምርትን ሊሰጡ የሚችሉ ድቃይ የበቆሎ ዝርያዎችን በምርምር ለማግኘት፣ የድቃይ በቆሎ ዝርያዎች ወላጅ የሆኑ ዘረ-መልን ልዕላዊ ባህሪይ አስቀድሞ በምርምር ማወቅ ያስፈልጋል፡፡ ምክንያቱም የድቃይ በቆሎ ወላጆች የሆኑ ዘረ-መል ባህሪ ጥናትን ማጥናት ምርታማ ለሚሆን ዝርያ መፈጠር በዋናነት አስፈላጊ በመሆኑ የዘረ-መልን የመዳቀል ባህሪ ማወቅ ቅድሚያ የሚሰጠው የድቃይ በቆሎ ዝርያ ምርምር ተግባር ነው፡፡ በዚህ መሰርት ይህ የምርምር ስራ የሚከተሉት ዓላማዎች ላይ ትኩረት በማድረግ ወደ ስራ ተገብቷል፡፡ ዓላማዎቹም (1) ከሀገር ውስጥና ከውጭ ሀገር የተገኙ የዘረ-መል ድቃዮች ከወላጆቻቸው በወረሱት ባህሪይ ምክንያት የምርታማነታችውንና በሽታን የመቋቋም ችሎታቸውን በማወቅ ለመለየት (2) በዘረ-መል ድቃዮች መካከል ከፍተኛ ምርት የመስጠትና በሽታን የመቋቋም ችሎታ ያላችው ምርጥ ድቃይ ዝርያዎችን በመለየት ለምርምር ተግባርና ከዚያም ባሻገር ተጨማሪ መረጃ ታክሎባችው ለምርታማነት ሊለቀቁ የሚችሉትን መለየት ናቸው፡፡ በጥናቱ ውስጥ 29 ዘረ-መል የተካተቱ ሲሆን የዘረ-መል ባህሪን ለማጥናት በምርምር የምንገለገልባችው ሁለት ዝርያዎች (አንድ ዘረ-መልና አንድ ዘረ-መል ካልሆነ አዳቃይ) ጋር በማዳቀል ለጥናቱ የሚጠቅም የሙከራ ድቃይ ዝርያዎችን በመፍጠርና ቀደም ሲል የተለቀቁ ሁለት ዲቃላ የበቆሎ ዝርያዎችን አካተን በሀዋሳ፣ ባኮና አረካ ግብርና ምርምር ግቢ ውስጥ ተዘርተው ጥናቱ ተካሂዷል፡፡ ለቡቃያው የሚያስፈልገውን እንክብካቤ በሙሉ፡ በጊዜ፡ በዓይነትና በመጠን በመለየት ወቅቱን ጠብቆ ተደረገ፡፡ በዚህም መሰረት ለጥናቱ አስፈላጊ የሆኑ መረጃዎች ተሰበሰቡ፡፡ የተሰበሰቡ መረጃዎችን ለማስላት አስፈላጊ የስታትሰቲክስ ፓኬጆችን በመጠቀም እንዲሰሉ ተደርጎ በሙከራ ዝርያዎቹ መካከል የተሰበሰሰበውን መረጃ ስሌት መንስዔ በማድረግ የባህሪ ልዩነት እንዳለ ተረጋገጠ፡፡ በመሆኑም የጥናቱን ውጤት መነሻ በማድረግ በጥናቱ ውስጥ ከተካተቱ 29 ዘረ-መል መካከል ዘረ-መል ቁጥር (እናት ዝርያ) 2፣8፣9፣15 እና 20 ለድቃይ በቆሎ ዝርያ ምርታማነት ከፍተኛ ጠቀሜታ እንዳላችው ታወቀ፡፡ እንዲሁም ዘረ-መል ቁጥር፡ 1፣5፣7፣23፣26 ሁለት ዋና ዋና የበቆሎ በሽታዎችን (ቅጠል አድርቅ) መቋቋም የሚችሉ መሆናችው፡ በጥናቱ መሰረት ተደርሶበታል፡፡ እነዚህ የተለዩ ዘረ-መል የተጠቀሱትን ባህሪያት ላማሻሻል ለበቆሎ ምርምር ጠቀሜታ እዳላችው ታምኖበታል፡፡ ከዚህ ባሻገር ዘረ-መሎቹን ከሁለቱ አዳቃዮች ጋር በማዳቀል ከተጠኑት ድቃዮች መካከል ቀደም ሲል በምርምር ከተለቀቁ ሁለት ዲቃላ ዝርያዎች ጋር ሲወዳደሩ በምርታማነታቸው የላቁ መሆናቸውን በጥናት ተደርሶበታል፡፡ ሆኖም እነዚህን የተሻሉ ድቃዮችን በአስተማማኝነት ለምርታማነት ለመልቀቅ ተጨማሪ ጥናት እንደሚያስፈልግ በጥናቱ ተጠቁሟል፡፡

Abstract

Combining ability estimates are important genetic attributes ina maize breeding program aiming to develop stable andhigh yielding hybrids and synthetic varieties. The objectives of this study were to estimate combining ability effects of locally developed and introduced early generation maize inbred lines for grain yield, yield related traits, and reaction to gray leaf spot (GLS) and northern corn leaf blight (NCLB) diseases; and (2) identify promising hybridsthat could be used in the breeding programs or for commercial production. Twenty-nine early generation maize inbred lines were crossed to two testers(SC22 and Guto-LMS5) using line xtester mating design. The resulting F_1 progenies along with two check hybrids were tested across three locations (Hawassa, Arekaand Bako) in Ethiopia. Analysis of variance revealed significant difference among the hybrids for all studied traits. General combining ability (GCA) and specific combining ability (SCA) effects were also significant, indicating the contributions of both additive and non-additive gene actionsin controlling the traits studied. However, the relative magnitudes of GCA and SCA sum of squares indicated the preponderance of additive gene effects for all characters studied. Parental lines 2, 8, 9, 15 and 20 showed significantly positive GCA effects for grain yield. For GLS parents 1,7,23, and 26, and for TLB parents 5, 6and 7 revealed significantly negative GCA effects. These inbredlines couldbe good sources ofgenes for the improvement of the traitsunder considerationin the breeding programs.Five crosses, namely,L5 x GuttoLMS5,L7x Gutto LMS5, L8 x Guto LMS5, L15 x SC22 and L20 x TSC22) gave significantly higher grain yield advantage over the two standard checks. Further evaluation of these crosses can give reliable information about their performances to recommend the crossesfor commercial production.

Introduction

Maize plays a significant role in the crop husbandry of Ethiopians and currently there is significant increase in acreage of production and productivity per unit area. Total area cultivated to the maize crop has reached over 2.11 million hectares annually and yield wise maize has secured the highest amount of productivity as comported to the other major cereals, yielding 3.40 ton/ha (CAS, 2016). However, several challenges are affecting maize production and productivity in Ethiopia. Varieties which give reasonably good yield are mostly less amenable to adapt under vast range of environmental conditions. Disease and insect prevalence mainly in the humid high potential maize areas are predominantly affecting grain yield. Among the diseases, northern corn leaf blight (NLB) caused by *Exserohilumturcicum* Pass Leonard and Suggs and gray leaf spot(GLS) caused by *Cercosporazeae-maydis* Tehon and E.Y. Daniels are the most important diseases causing significant yield losses in major maize growing areas of Ethiopia (Tewabech *et al.,* 2012). Phonological and agronomic characteristics of the already released varieties do not easily adapt to the changing weather conditions provided with the low standard agronomic management practices and several factors that limit maize production and productivity.

In maize breeding programs, persistent investigations into the identification of good combining inbred lines in their hybrid performances in all respects is critical to enhance maize production and productivity. Most efficient use of such materials would be possible only when adequate information on the amount and type of genetic variation and combining ability effects of the materials is available. Combining ability is regarded as the potential of a line to fit in crosses with a number of lines or any one of the lines for revealing desirable attributes in hybrid combinations (Hallauer and Miranda, 1988). Others describe combining ability as the ability of a parent to produce inferior or superior combinations in one or a series of crosses (Sing and Chaudhary, 1999). It is especially a powerful tool to test methods for studying and comparing the performance of lines in hybrid combinations (Griffing, 1956).

Combining ability effects characterized by general combining ability (GCA) and specific combining ability (SCA) are important indicators ofthe potential values for inbred lines in hybrid combinations, and has become an important avenue in crop improvement General combining ability variance is usually considered to be an indicator of the extent of additive type of gene action, whereas specific combining ability variance is taken as the measure of non-additive type of gene actions which include dominance and epistatic deviations with respect to certain traits (Hallauer and Miranda, 1988).

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Several combining ability studies were reported in maize. Most of these studies showed significant GCA and SCA variances, indicating the presence of both additive and non-additive gene actions (Legessee *et al.*,2009; Wegary *et al.,* 2014;Gudeta*et al.,* 2015; Hailegebrial *et al.,* 2015).On the other hand, Habtamu (2015) reported the predominance of SCA effects, which showed the prevalence of non-additive gene actions. Studies conducted on the inheritance of GLS in maize revealed the importance of both additive and non-additive typesof gene action (Gevers*et al*., 1994; Menkir and Ayodele, 2005), while some others found GLS reaction to be under the control of additive gene action (Donahue *et al.,* 1991, Legesse, *et al*.,2009).

In maize breeding, development of high yielding F1'salong with other favorable traits are receiving considerable attention to provide desirable varietal options for the farming community. Suitable inbred lines and their specific combinations may be selected on the bases of combining ability effects and with desirable mean performances. The objectives of this study were to(1) estimate combining ability effects of locally developed and introduced early generation maize inbred lines for grain yield, yield related traits, and reaction to gray leaf spot (GLS) and northern corn leaf blight (NLB) diseases, and (2)identify promising hybrids that could be used in the breeding programs or for commercial production.

Materials and Methods

Experimental material

The study materials consisted of 29 maize inbred lines of which 26 were developed locally from a heterozygous inbred population, SC5522 and the remaining three were introductions from CIMMYT-Zimbabwe. The population (SC5522) was introduced to Ethiopia from the eastern African regional maize breeding program about three decades ago. The population, because of its good performances in the local breeding program, was serving as source material and later on subjected to further purification through simple mass selection followed by self-pollination for generating inbred lines. The inbred lines developed from this population were crossed with two testers (SC22, a line tester andGutoLMS-5, a population tester) in a Line xTester mating designs (Kempthorne, 1957) that resulted in to 58 F_1progenies.The F_1 progenies and two commercial check hybrids,BH540 and BH543, were evaluated in a trial across locations.BH540 is a very popular and widely adapted medium maturing single cross hybrid released for mid-altitude high potential ecology; and in some cases used in transitional highland areas whileBH543 is widely adapted to the mid -altitude agro-ecologies of the country. BH543 is mostly succumb to northern corn leaf blight when grown in high rainfall areas accompanied by high humidity. Details of the pedigree and genetic backgrounds of the inbred lines and the testers used for the study are given in Table1.

Experimental design and field evaluation

The 58 F1 crosses and the two checks were evaluated at three locations; namely, Areka, Hawassa and Bako Research Centres in 2011.Areka and Hawasa are located in the southern part while Bakois located inthe western part of Ethiopia. The locations lie between 1650 and 1800masl (meter above sea level) and receive mean annual rainfall ranging from 1100 to 1250mm, respectively. The soils of Hawasa and Areka are characterized as Andoso land that of Bako is Nitosol. The experimental design employed for the experiment was an alpha (0, 1) lattice (Patterson and Williams, 1996) with two replications at each location. The experimental unit consists of a single row of five meters length spaced at 75 cm between rows. Planting was done using two seeds per hill and 30 cm apart between hills. Thinning was performed at three to five leaf stages to attain a final plant density of 44,444 plants ha^{-1}. All other management practices including planting, fertilization, weeding and harvesting were performed as per the recommendations for each location. Grain yield (Mg ha^{-1}) adjusted to 12.5% moisture level, number of days to silking (days),plant height (cm), GLS and NL Bincidences (1-5 scoring scale, where 1 represents resistance while 5 represents susceptible) were recorded on plot basis.

Statistical analysis

Analysis of variances (ANOVA)was performed for each location for all traits studied. Then, combined analysis across locations was performed for traits that showed significant variations among the hybrids (genotypes). In this study, all the traits recorded showed significant differences among the genotypes; and hence, combined analysis was done for grain yield, days to silking, plant height, GLS and NLB. SAS statistical packages (SAS, 2004) was used for all the analysis.Combining ability analysis was done using a line x tester method (Kempthorne, 1957) and then general and specific combining ability effects of the lines were computed for characters that showed significant differences among crosses assuming the following statistical model(Singh and Chaundhary, 1999):

$Y_{hijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + R_h + \Sigma_{hijk}$;
where,
Y_{hijk} = the observation of the k^{th} full-sib progeny in a plot in h-replication of the i^{th} male parent and the j^{th} female parent; μ = the general mean; α_i = the effect of the i^{th} male parent; β_j= the effect of j^{th} female parent; $(\alpha\beta)_{ij}$ = the interaction of male and female parental genotypes; R_h = the effect of h^{th} replication and Σ_{hijk} = the environment effect and remainder of the genetic effect between full sibs on the same plot.

In the analyses, environment was considered as random and genotypes as fixed effect. Mean square of variance was determined for lines and testers and their interaction effects. The relative contribution of GCA and SCA effects to the variation among the hybrids were assessed following the method suggested by Kang(1994); that is, the proportion of GCA or SCA sum of squares to the total sum of squares. GCA effects for each parents (inbred line/tester) was estimated as the mean of all crosses involving that parent (inbred line/tester) minus the overall mean, and SCA was estimated as mean of a cross minus mean of all inbred line crosses involving that line, mean of all tester crosses involving that tester and the overall mean. The F-test for main effects such as entries and its partitions were tested against their respective interactions with environments, and the interaction with environment terms were tested against the pooled error. Significance of GCA and SCA effects were performed by computing the standard errors for lines, testers and crosses and then tested against t-test by taking the degree of freedom of the pooled error.

Table 1. Pedigree and origin of maize inbred lines and tester parents, and the standard checks used for the study

No	Pedigree	Origin
1	SC-715-10-1-1	Ethiopia
2	SC-715-10-1-2	Ethiopia
3	SC-715-106-2-1	Ethiopia
4	SC-715-114-2-1	Ethiopia
5	SC-715-121-1-1	Ethiopia
6	SC-715-121-1-2	Ethiopia
7	SC-715-121-1-3	Ethiopia
8	SC-715-13-2-1	Ethiopia
9	SC-715-15-3-1	Ethiopia
10	SC-715-154-1-1	Ethiopia
11	SC-715-154-1-2	Ethiopia
12	SC-715-156-2-1	Ethiopia
13	SC-715-56-2-1	Ethiopia
14	SC-715-56-2-2	Ethiopia
15	SC-715-57-3-1	Ethiopia
16	SC-715-57-3-25	Ethiopia
17	SC-715-61-3-2	Ethiopia
18	SC-715-6-2-1	Ethiopia
19	SC-715-6-2-2	Ethiopia
20	SC-715-73-3-1	Ethiopia
21	SC-715-76-1-1	Ethiopia
22	SC-715-84-1-1	Ethiopia
23	SC-715-92-2-1	Ethiopia
24	SC-715-92-2-2	Ethiopia
25	SC-715-94-2-1	Ethiopia
26	SC-715-94-2-2	Ethiopia
27	ZimbF2-05-P#713-4-1-1	CIMMYT-Zimbabwe
28	ZimbF2-05-P#713-4-1-2	CIMMYT-Zimbabwe
29	ZimbF2-05-P#795-5-4-1	CIMMYT-Zimbabwe
30	Guto - LMS-5 (T1)	CIMMYT
31	SC22 (T2)	Ethiopia
32	BH543 (Check 1)	Ethiopia
33	BH540 (check 2)	Ethiopia

Results and Discussion

Analysis of variance and hybrid means

Analysis of variance for individual locations showed significant differences among the genotypes for all the traits studied (data not shown). Combined analysis of variance across locations showed highly significant ($P< 0.01$) location mean squares for days to silking, plant height, GLS and NLB, indicating that the environments used for the study are so diverse. Similarly, significant variations were observed due to crosses for all studied traits. This indicates the existence of higher variability among the crosses studied and the possibility of making selection to improve for the desired trait. Mean squares due to crosses x locations interaction were significant for plant height, GLS and NLB but non-significant for grain yield and days to silking (Table 3). The non-significant cross-by-location interaction effects for grain yield and days to silking indicated that the hybrids evaluated showed similar performances and adaptation across all testing locations.

General combining ability mean square due to lines showed significant differences for all studied traits. Tester GCA effects were significant for most studied traits except for grain yield and plant height. On the other hand, SCA mean squares were significant for most traits except for days to silking, which revealed non-significant differences (Table 2). In traits with significant GCA variances, the variations observed among the hybrids predominantly attributed to additive gene effects. The GCA/SCA variance ratio calculated for all traits further exhibited the predominance of additive gene action for the inheritance of these traits. This finding is in line with results of the studies conducted byother researchers (Bayisa *et al.,* 2008;Legesse*et al.,*2009;Haron*et al.,*2014,), who previously reported the significance of additive gene effects in the inheritance of several agronomic traits including foliar diseases such as GLS and NLB, which are economically important maize disease that hamper maize production in sub-Saharan Africa (Kanapmpiu *et al.,*2007).

Table 2.Linex tester analysis of variance in mid-altitude maize inbred line crosses evaluated for grain yield, days to silking, plant height, gray leaf spot (GLS) and northern corn leaf blight (NLB) disease incidences across three locations in Ethiopia.

		Mean Squares				
Source	DF	Grain yield ($Mg\ ha^{-1}$)	Silking (days)	Plant height (CMs)	GLS (1-5score)	NCLB (1-5 score)
Environment (E)	2	57199.03**	1783.48**	99377.14**	55.75**	21.87**
Replication/E	3	452.67	21.52	714.79	0.01	0.55*
Cross (C)	57	283.53*	25.42**	915.04**	0.25**	0.43**
GCA (L)	28	348.35*	40.43**	1386.41**	0.38**	0.51**
GCA (T)	1	167.86	0.49	2291.52**	0.06	2.59**
SCA (L x T)	28	222.84	11.30	394.50	0.13	0.27
C x E	114	273.23*	12.01	337.11	0.22**	0.33**
L x E	56	292.44*	11.56	338.48	0.33**	0.32*
T x E	2	494.33	2.49	165.04	0.03	3.80**
L x T x E	56	246.11	12.80	341.89	0.11	0.22
Error	177	194.56	11.03	273.96	0.10	0.20

**, * Significant at 0.01 and 0.05 probability levels, respectively.
L, and T represent, Lines and Testers with their corresponding GCA.
GCA and SCA represents general and specific combining ability effects

Location mean of crosses for grain yield, days to silking, plant height, GLS and NCLB is presented in Table 3. The highest mean grain yield of 9.04 $Mg\ ha^{-1}$ was recorded at Bako which had the lowestnumber of days tosilking and lower NCLB incidence. On the other hand, mean grain yield of the crosses at Areka was the least, despite very low mean diseases prevalence as compared to the rest two locations. Legesse *et al*.,(2009) reported highest GLS incidence at Bakoas compared to some other maize growing locations in Ethiopia, indicating that GLS is more prevalent in the mid-altitude locations having abundant rainfall, high temperature and high relative humidity, which constitute ideal conditions for GLS disease development (Dagne *et al.,* 2001). The tallest mean plant height was observed at Bako while the shortest plant height was recorded at Areka. In all circumstances, plant height among crosses ranged from 158 to 201 cm with overall mean values of 182 cm, indicating the presence of wider range of variability among the crosses that could be further exploited in the breeding program.

Table 3. Location means of crosses for grain yield, days to silk, plant height, gray leaf spot (GLS) and northerncorn leaf blight (NCLB) disease scores.

Location	Grain yield (Mg ha $^{-1}$)	Silking (days)	Plantheight (cm)	GLS (1-5 score)	NCLB (1-5 score)
Areka	48.55	82.23	181.8	1.2	2.0
Hawasa	79.69	80.3	218.6	1.0	2.7
Bako	90.4	75.0	238.6	2.2	1.8
Mean	72.8	79.1	213.0	1.5	2.17
S.E	1.25	0.23	1.66	0.04	0.03

[a]Disease score of 1 is resistant; and score of 5 issusceptible.

Hybrid yield response and reaction to diseases

Grain yield performances of some promising crosses as compared to the two hybrid checks is shown in Fig1. A number of line by tester crosses showed significantly higher grain yield performances as compared to the two check hybrids. Among the promising crosses, the highest grain yield of 9.04 t ha^{-1} was depicted by a cross SC-715-57-3-1/T2, indicating prevalence of high heterotic effects between the two parents. In addition,crossesSC-715-154-1-1/T2, SC-715-121-1-1/T2, SC-715-121-1-1/T2, SC-715-121-1-3/T1 andSC-715-10-1-2/T1gave significantly higher mean grain yield as compared to the two hybrid checks, BH 543 and BH540.The experimental hybrids also expressed good level of tolerance to GLS and NCLB, and most of their agronomic performances are in a desirable direction such as days to silking, plant and ear height and days to physiological maturity. These putative experimental hybrids, despite their superiority in grain yield and other characteristic features as compared tothe checks, it would be imperative to make further and rigorous evaluations across more number of locations and seasons to confirm their performances and stability over sites and years in order to identify more dependable experimental hybrids to be recommended for commercial production.

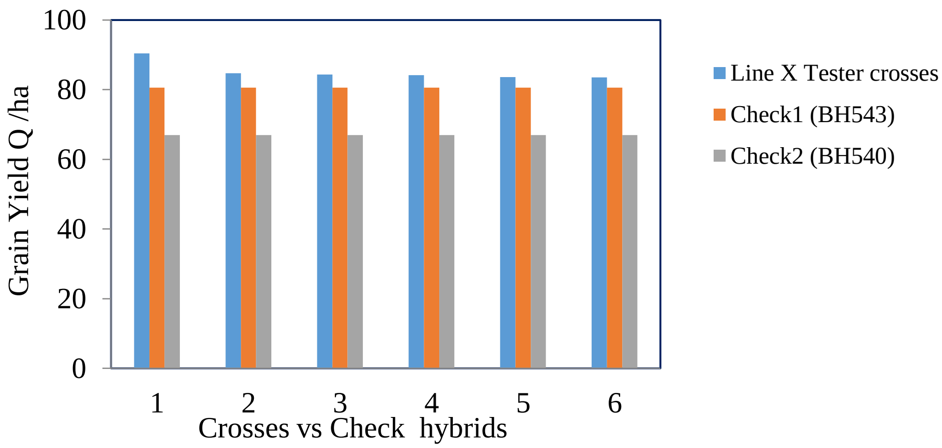

Figure 11. Mean performances of promising experimental crossesas compared to standardcheck hybrids

Where, no. refers to crosses = 1= SC-715-57-3-1/T2; 2= SC-715-154-1-1/T2;3= SC-715-121-1-1/T2;4 = SC-715-121-1-1/T2; 5= SC-715-121-1-3/T1;6= SC-715-10-1-2/T1
Checks =check 1 (BH543) and Check 2 (BH540)

General Combining Ability Effects

General combining ability estimates for grain yield, days to silking, plant height, GLS and NCLBfor each parental line with the respective standard errors are given in Table 4. GCA effects for grain yield of lines ranged from -12.93 to 9.18 Mg ha^{-1}. Lines SC-715-10-1-2, SC-715-121-1-1, SC-715-121-1-3, SC-715-154-1-1, SC-715-57-3-1andSC-715-73-3-1 revealed significantly positive GCA effects indicating the preponderances of additive gene action for grain yield inheritances in these parental lines. These inbred lines have desirable general combining ability for the formation of hybrids and synthetic varieties with higher grain yield. On the other hand, lines SC-715-92-2-1, ZimbF2-05-P#713-4-1-1, ZimbF2-05-P#713-4-1-2,andZimbF2-05-P#795-5-4-1 for days to female flowering and lines SC-715-10-1-1, SC-715-6-2-2 and ZimbF2-05-P#713-4-1-2 for plant height manifested highly significant negative GCA effects. Similarly, lines SC-715-10-1-1, SC-715-92-2-1andSC-715-94-2-2 for GLS and Lines SC-715-121-1-1, SC-715-121-1-2, SC-715-121-1-3, SC-715-121-1-3 and SC-715-156-2-1 for NCLB were good general combiners as they manifested significantly negative GCA effects. The inbred lines which manifested desirable GCA values for all the traits are anticipated to contain combination of favorable alleles that could be exploited in the breeding program for the improvement of the traits under consideration in the desirable direction. Significant GCA effects for grain yield, days to silking, plant height, GLS and NCLB were reported among several breeding materials in previous studies(Menkirand Ayodele, 2005; Bayisa *et al*., 2008; Legesse *et al.,* 2009;. Harson *et al.,*2014).

In case of GCA effects of testers, the range of variation for most of the traits studied were narrow except for plant height which manifested significant effects (data not shown). For grain yield the range of variation was moderate but the effects were not significant. For GLS and NCLB, despite their narrow ranges of effects, the value for tester (T1) is in a desirable direction.

Table 4. General combining ability effects forgrain yield, days to silking, plant height, grey leaf spot (GLS) and northern corn leaf blight (NCLB) diseases score based on combined data analysis across three locations.

LINE[a]	DFF	PHT	GLS	TLB	YLD
	DAYs	CMs	Scores		Mg h-1
1	-1.25*	-9.14**	-0.19*	0.13	3.36
2	0.34	1.20	-0.03	-0.12	7.79*
3	-0.66	2.78	-0.11	-0.12	-1.47
4	1.00*	7.70**	0.06	0.04	1.13
5	2.42**	8.20**	-0.15	-0.37**	6.65*
6	0.67	6.28*	-0.15	-0.21*	-2.33
7	2.50**	22.03**	-0.23*	-0.25*	7.15*
8	1.67*	-3.89*	0.39**	0.13	2.80
9	0.17	-1.80	0.10	0.09	-1.62
10	-0.33	-4.72*	-0.07	-0.21*	9.18**
11	1.34*	14.89**	0.06	-0.04	-3.40
12	1.00	0.45	-0.15	-0.25*	-4.40
13	-1.33*	-2.30	-0.07	0.21*	-2.76
14	0.34	-4.55*	-0.07	-0.16	-4.88
15	-0.58	7.95**	-0.03	-0.08	9.01**
16	0.25	13.64**	0.06	-0.12	-0.01
17	1.17*	11.55**	0.02	-0.12	-4.60
18	0.50	-6.89*	0.06	0.00	2.32
19	0.00	-8.64**	0.35**	0.13	2.07
20	-0.25	12.61**	-0.15	-0.08	7.60*
21	1.17*	1.78	-0.11	0.04	-0.08
22	2.09**	16.61**	0.39**	0.25*	-9.11**
23	-2.25**	-3.05	-0.19*	-0.12	2.38
24	-0.58	-1.64	-0.15	0.04	-1.02
25	2.09**	13.45**	-0.03	-0.08	-0.94
26	0.92	13.28**	-0.19*	0.00	-3.31
27	-3.58**	-2.80	0.27**	0.42**	-12.93**
28	-3.75**	-8.80**	0.18*	0.29*	-5.74*
29	-5.08**	16.05**	0.14	0.54**	-2.83
SE (Li)	0.96	3.48	0.16	0.16	4.85

* and ** = refers to significant to highly significant difference from zero; [a]Pedigrees of the parental lines are as explained in Table 1.

Specific Combining Ability Effects

Specific combining ability effects for grain yield, days to silking, plant height, GLS and NCL Bare presented in Table 5. SCA effects for grain yield among crosses ranged from -4.9 (SC-715-13-2-1 xSC22) to 9.7 Mgha^{-1} (SC22-13-2-1xGottoLMS).Several crosses involving both testers manifested significantly positive SCA effects for grain yield. Most of the inbred lines included in the study do have closer pedigree relationship with the tester parent, SC22, as they were originally derived from the same source material, SC5522. Nevertheless, a number of crosses revealed positive SCA effects with this tester, manifesting good level of heterotic response among intera-population inbred lines, Han *et al.* (1991) reported a tendency of obtaining intra-population inbred parents possessing significantly positive SCA effects for grain yield. In a similar manner, some lines showed significantly higher SCA values for grain yield when crossed with population testers (Gutto-LMS5). This is to be expected among parents of unrelated source germplasm. The result is in line with the findings of other researchers (Mandal *et al.*, 2001; Salim *et al.*, 2006;Kanagarasu*et al.*,2010) who reported significantly positive SCA effects for grain yield and yield related traits in inbred lines of diverse origin.

On the other hand, SCA effects for days to silking and plant height is not in a desirable direction particularly among crosses involving the tester,SC22. With Gutto LMS5, there are some indications signifying the effects of non-additive gene action, however, it appear that there might be less reliable to pose good responsiveness in selection and inheritance studies. With regards to GLS and NCLB, none of the crosses revealed desirable GCA effects implying that inheritances of these traits are mainly associated with additive gene effect as it was manifested by the predominance of GCA variances over the SCA variances. In GLS and NCLB inheritance study conducted by several researchers using different inbred line crosses and testing sites unveiled the importance of both additive and non-additive genetic variances (Legesse *et al*.,2009;Haron*et al.*,2014), which is partially in agreement with the findings of this study.

Table 5. Specific combining ability effects for grain yield (GY), days to silking (DS), plant height (PHT), gray leaf spot (GLS)andnorthern corn leaf blight (NCLB) in line by tester crosses of evaluated at three locations in Ethiopia

LINE	Days to silking (days)		Plant height (cm)		Grey leaf spot (1-5 score)		Leaf blight (1-5 scores)		Grain yield (t ha^{-1})	
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
1	0.05	-0.05	8.06	-8.06	0.05	-0.05	0.13	-0.13	1.06	-1.06
2	0.87	-0.87	0.77	-0.77	0.03	-0.03	0.12	-0.12	6.56*	-6.56
3	0.87	-0.87	7.31	-7.31	0.11*	-0.11	0.04	-0.04	3.75	-3.75
4	0.70	-0.70	3.94	-3.94	0.05	-0.05	0.21*	-0.21	2.38	-2.38
5	0.88	-0.88	3.73	-3.73	0.01	-0.01	0.04	-0.04	-5.92	5.92*
6	1.87*	-1.87*	2.69	-2.69	0.07	-0.07	0.13	-0.13	4.23	-4.23
7	0.87	-0.87	6.44	-6.44	0.01	-0.01	0.08	-0.08	5.37*	-5.37
8	0.46	-0.46	1.19	-1.19	0.11*	-0.11	0.12	-0.12	9.26**	-9.26
9	1.46*	-1.46*	5.94	-5.94	0.01	-0.01	0.25*	-0.25	8.22*	-8.22
10	0.70	-0.70	0.52	-0.52	0.01	-0.01	0.13	-0.13	-5.56	5.56*
11	1.04	-1.04	4.64	-4.64	0.05	-0.05	0.12	-0.12	3.05	3.05
12	0.20	-0.20	0.98	-0.98	0.07	-0.07	0.08	-0.08	2.21	-2.21
13	1.96*	-1.96*	3.61	-3.61	0.07	-0.07	0.04	-0.04	1.25	-1.25
14	0.04	-0.04	1.48	-1.48	0.15*	-0.15	0.17	-0.17	-3.28	3.28
15	0.29	-0.29	3.36	-3.36	0.11*	-0.11	0.16	-0.16	-7.84*	7.84*
16	0.55	-0.55	5.06	-5.06	0.03	-0.03	0.21*	-0.21	-5.70	5.70*
17	1.13*	-1.13*	0.48	-0.48	0.07	-0.07	0.21*	-0.21	-3.94	3.94
18	0.87	-0.87	1.36	-1.61	0.05	-0.05	0.08	-0.08	-1.18	1.18
19	0.54	-0.54	3.61	-3.61	0.07	-0.07	0.04	-0.04	2.71	-2.71
20	0.62	-0.62	5.02	-5.02	0.01	-0.01	0.09	-0.09	-6.44	6.44*
21	1.13*	-1.13*	7.86	-7.86	0.03	-0.03	0.12	-0.12	-5.68	5.68*
22	0.55	-0.55	3.48	-3.48	0.11*	-0.11	0.25*	-0.25	1.46	-1.46
23	0.12	-012	1.36	-1.36	0.05	-0.05	0.21	-0.21	3.91	-3.91
24	0.12	-012	0.11	-0.11	0.10	-0.10	0.21	-0.21	1.77	-1.77
25	1.71*	-1.71*	7.31	-7.31	0.05	-0.05	0.09	-0.09	5.97*	-5.97
26	1.45*	-1.45*	3.14	-3.14	0.05	-0.05	0.00	0.00	2.76	-2.76
27	0.88	-088	2.44	-2.44	0.01	-0.01	0.16*	-0.16	-1.33	1.33
28	0.45	-0.45	0.11	-0.11	0.10	-0.10	0.12	-0.12	1.20	-1.20
29	0.88	-0.88	4.64	-4.64	0.39**	-0.39	0.21*	-0.21	-0.59	0.59
SE(Sij)	1.01		3.93		0.10		0.13		4.45	

* and ** = refers to significantlyand highly significantly different from zero.

Conclusions

Based on the results of the study, it is apparent that several inbred lines with desirable combining ability effects for grain yield, days to silking, plant height, GLS and NCLB were identified. These inbred lines would be of great importance for the national breeding program in developing desirable cross combinations.A number of promising single cross hybrids that have significantly higher grain yield as compared to the two hybrid checks, BH540 andBH543, were observed. Some of these single crosses involved parental lines that were derived from the same genetic background, suggesting possibility of identifying high yielding intra-population inbred line crosses. Such crosses could be used as best parental single cross in the development of three-way cross commercial hybrids. Desirable crosses identified in this study could be further evaluated across wide range of locations and can bere commended for commercial production. In general, the investigation suggests that some of the inbred lines identified in the study represent a highly valuable genetic material that could be successfully used in the breeding programs.

Reference

Bayisa, A., M. Hussen and Z. Habtamu, 2008.Combining ability of transition highland maize inbred lines. East African crop sci.j. 2: 19-24.

CSA, 2016. Central Statistical Agency, Ethiopian Agricultural Sample Survey for 2013/2014. Statistical Bulletin 532, Addis Ababa, Ethiopia

Dagne, Wogari., Fekede Abebe, Legesse Wolde, and Gemechu Keneni, 2001.Gray leaf spot disease: a potential threat to maize production in Ethiopia. Pp.78-85. In: proc. Ninth Annual Conf. of crop Scioci. Of Ethiopia (CSSE), 22-23 June 1999, Addis Abeba, Ethiopia.

Donahuee P.J., E.L. Stromsburg and S.L. Myers, 1991 Inheritance ofreaction to gray leaf spot in a diallel crosses of 14 maize inbreds.Crop Sci. 41: 926-931.

Gevers H.O., J.K. Lake and T. Hohls, 1994 Diallel cross analysis ofmaize for resistance to gray leaf spot in maize. Plant Dis.Rep. 634: 515-558.

.Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Australian J. Biol. Sci. 9: 463-93.

GudetaNapir,DagneWogari andHabtamu Zeleke.2015.Heterosis and combining ability of highland quality protein maize inbred lines. Maydica Electron. Pub. 60:

Habtamu, Zeleke. 2015.Heterosis and Combining Ability for yield and yield component traits of maize in Eastern Ethiopia. Sci. Technol. Arts Res.4(3): 32-37.

HailegebrialKinfe., GetachewAlemayehu, LegesseWolde and . Yemane Tsehaye2015.Combining Ability and Gene Action Estimation in Elite Maize(Zea mays L.) Inbred Lines at Bako, EthiopiaJ. of Bio., Agr. and Healthcare 5.:16

Hallauar, A.R., J.B. Miranda, 1988.Quantitative genetics inmaize. Iowa State Univ. Press, Ames.

Han G.C., S.K. VasaL and D.L. Beck, E. Elias, 1991. Combining abilityanalysis of maize inbred lines derived from CIMMYT (zeaMays l.) germplasm. Maydica36: 57-64.

Haron, K,. N. Kairie, M.Stephen, E.S.Aregal, F.Kanapiu and J. Nedritu.2014. Combining ability of maize (zea mays) inbred lines resistance to Striga hermontica (Del) Benth evaluated under artificalstriga infestation. African J. of Agr. Research 9: 1287-1295

Kanagarasu,S., G. Nallathambi and K.N. Ganeson. 2010. Combining ability analysis for yield and component traits in maize (Zea mays L.) Eletro. J. P. Bred. 1:915-920.

Kanapmpiu, F., A. Diallo and H. Karaya. 2007. Herbicide seed coating technology: a unique approach for Striga control in maize. Afri. Crop. Sci. Confer. Procceed. 8:1095-1098.

Kang, M.S. 1994. Applied quantitative genetics. M.S. Kang Publishing, Baton Rouge, LA.

Kempthorne, O. 1957. An introduction to genetic statistics. John Wiley and Sons, New work. p 545

Legesse Wolde., K. V. Pixely and A.M. Botha. 2009. Combining and heterotic grouping of highland transition maize inbred lines.Maydica 54): 1-9 .

Mandal, S.S., H.K. MandaL, D.K. Verma, S.A. Akhtat, 2001. Combining ability for grain yield and component traits in maize (Zea mays L.) Jour. of Interacademicia. 5: 132-137.

Patterson, H.D. and E.R. Williams, 1976. A new class resolvable incomplete block designs. Biometrika 63: 83-92.

Menkir Abebe. and, M. Ayodele. 2005. Genetic analysis of resistance togray leaf spot of mid-altitude maize inbred lines. Crop Sci. 45:163-170.

SAS, 2004. SAS proprietary software. SAS Institute, Cary, NC

Singh R.K. and, B.D.Chaudhary. 1999. Biometrical methods in quantitative genetic analysis. Kalyani Publishers, New Delhi

Shalim U., M. Firoza Khatun, S. AHMED, M. R. AL, and S. A.Bagum, 2006.Heterosis and combining ability in corn (Zea mays L). Bangladesh J. Bot. 35(2): 109-116, 2006.

Tewabech Telahun, .Dagne Wogari, Girma Demisse, Meseret Negash, Solomon Admasu , and HabteJifar . 2012..Maize Pathology Research in Ethiopia in the 2000s: A Review. Pp 193 – 202. In:Worku, M., Twumasi-Afriyie, S., Wolde, L., Tadesse, B., Demisie G., Bogale, G., Wegary, D. and Prasanna, B.M. (Eds.). Meeting the Challenges of Global Climate Change and Food Security through Innovative Maize Research. Proceedings of the Third National Maize Workshop of Ethiopia, Addis Ababa, Ethiopia.

WegaryDagne, B.S.Vivekans M.T, Labuschagne. 2014. Combining ability of certain agronomic traits in quality protein maize under stress and non stress environments in Eastern and Southern Africa. Crop Sci 54: 1004–1014