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Combining Ability of Maize (*Zea mays* L.) Inbred Lines under Low- Nitrogen Stress Condition

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Abstract: **Low-N stress is among the major abiotic stresses causing yield reductions in maize grown in the mid-altitude tropical environments of Africa. Therefore, development of maize varieties for low nitrogen might be one of the option to overcome the problem. The objectives of this study was, therefore, to estimate combining ability of maize inbred lines for yield and yield related traits under low N stress condition. Twenty six inbred lines (two testers and twenty four lines) were crossed using line × tester mating design and generated 48 F_1 hybrids and along with two hybrids used as checks (AMH853 and AMH 851), were evaluated using alpha lattice design with two replications for grain yield and yield related traits during 2017 cropping seasons. Analyses of variances showed significant mean squares due to crosses for all traits except for ear per plant. Among the crosses, L5xT2 (4.61tha^{-1}), L6xT2 (4.37tha^{-1}), L14XT2 (4.31tha^{-1}) and L23XT2 (4.14 tha^{-1}) better performed .The mean squares for general (GCA) and specific (SCA) combining ability were significant for most of the traits except SCA mean squares which is significant only for days to anthesis, days silking, anthesis silking interval, days to maturity and leaf senescence. Inbred lines L5 and L14 were good general combiners and hence were promising parents for hybrid varieties development. The study indicated the importance of both additive and non-additive gene effects in most cases, while non-additive gene effects are less important under low-N stress.**

Keywords: **Combining ability, GCA, Inbred line, low nitrogen, SCA and Yield.**

1. INTRODUCTION

Maize (*Zea mays* L.; 2n =20) is an important cereal crop of the world, belonging to the tribe Maydeae of the grass family Poaceae (George, 2007). It is an important stable crop for many people around the world. As the cultivation of early maize spread to different geographical regions from Mexico and Central America, where maize is widely believed to have originated, there was a rapid evolution of many races adapted to a wide variety growing conditions. Maize is a popular and widely cultivated food crop in Africa since its introduction to the continent around 1500 A.D. by Portuguese traders (McCann, 2005) and then arrived in Ethiopia slightly later, around the late 17th century (Huffnagel, 1961).

The major constraints to maize production in sub-Saharan Africa (SSA) are both biotic and abiotic factors. The main biotic factors are pests and diseases and the parasitic weeds, *Striga hermonthica* (IITA, 2009). The most common abiotic factors are drought, heat, low soil fertility particularly low soil nitrogen, high soil aluminum toxicity, flooding, and salinity (Tuberosa *et al.,* 2005). The low adoption of improved varieties by farmers (Sibiya *et al.,* 2013) and the non-use of appropriate farming techniques (Etoundi and Dia, 2008) are also important factors contributing to low yield).

Maize genotypes differ widely with regard to N nutrition, especially low N tolerance and nitrogen use efficiency (Akintoye *et al*., 1999). This variation in nitrogen use efficiency indicates that this trait may be genetically determined and could be improved by breeding (Mi et *al*., 2005). An appropriate breeding strategy could be used to develop genotypes that tolerate low N stress and produce high grain yield under both low soil N and optimal conditions. However, few studies have been conducted because it has often been assumed that there is no interaction between N levels and cultivars for grain yield (Mi *et al*., 2005). Important considerations in establishing a selection program for stress tolerance should be whether OPVs, hybrids or both types of products are needed, and what human, financial, and physical resources are available for experimental work. Additional important factors include the choice of germplasm, breeding methodology, selection environments, and essential data to collect.

So far, combining ability effects in maize inbred lines has been extensively studied under stressed conditions. In a comparative evaluation study of landraces and improved varieties under low N, (Lafitte *et al.*, 1997) reported that improved varieties out-yielded landraces but landraces were superior in grain N concentration. Thus, improving adapted, elite germplasm for low N tolerance is probably nearly always better than working with landraces. A compromise approach would be to create synthetic populations from local landraces and improved, adapted varieties (Kling *et al.*, 1997).

Another study done by (Miti *et al.*, 2010*)* using S1 selection for tolerance to low N among ninety-six maize landraces indicated that, some maize landraces that tolerated the stress caused by low N more than improved maize varieties and concluded that there was adequate genotypic variation for low N tolerance among maize landraces which could be improved by selection. Similarly Presterl *et al.*, 2002 developed hybrids under low and high N conditions and reported that the average yields of the hybrids developed at low N conditions were 11.5% higher in low N conditions than those selected under high N conditions. There was no significant difference in yield between the two hybrid types under high N conditions. In addition, the N-efficient hybrids showed significantly higher N uptake at low N levels than the hybrids selected under high N. No differences in N-utilization efficiency were observed (Presterl *et al.*, 2002). In the current study, therefore, an attempt was made to identify high yielding hybrids tolerant to low N soil, determine the combining abilities and mode of gene action of elite maize inbred lines for hybrid development under low nitrogen conditions.

2. MATERIALS AND METHODS

Description of the Study Area

The field experiments were conducted at Ambo Agricultural Research Centers during the 2017 main cropping season. Geographically, Kulumsa lies at 8^{o}57'N latitude, 38^{o}10'E longitude at an elevation of 2225 m.a.s.l. The average rainfall at the research center is 1110 mm per annum having peaks in July and August. The mean maximum and minimum temperatures are 26^{o}C and 11^{o}C, respectively. The soils are Vertisols. (http.//www.eiar.gov.et/index.php/research-centers).

Soil Sampling, Preparation and Analysis

Soil samples from the experimental sites were taken before planting. First, one representative composite soil sample was taken from ploughed and leveled field by collecting from three places diagonally across the plot (in zigzag method) with auger from 0 to 30 cm and 30-60cm depth of top soil and composited to make one representative soil sample for each depth before planting. The composited soil sample taken was subjected to analysis for soil before planting.

Organic matter content determined by the oxidation of organic carbon with acid potassium di-chromate ($K_2Cr_2O_7$) medium using the Walkley and Black method as described by Dewis and Freitas (1970). The pH of the soil determined by using potentiometric method at 1:2.5 (weight/ volume) soil to water dilution ratio using a glass electrode attached to digital pH meter (Page, 1982). Total nitrogen determined by using Kjeldahl method as described by Jackson (1967) and also available phosphorus determined by using the Bray II method (Bary and Kurtz, 1945). Results of the soil analysis before planting are presented in table 1.

Table 1: Soil properties at two depths of the experimental fields at Ambo and Kulumsa, 2017

	Depth (cm)	PH	Available P(ppm)	% Nitrogen	%OC	% OM
low	0-30	7.209	10.447	0.115	1.413	2.435
	30-60	7.349	7.433	0.081	1.311	2.261

Analyzed by the EIAR, Kulumsa Agricultural Research center

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Experimental Materials

The experiment was consisted of 48 test-crosses produced by crossing 24 inbred lines to two testers in line x tester mating design and two standard checks (AMH851 and AMH853). The two testers, FS59 (Tester 1) and FS67 (Tester 2), are adapted lines locally developed at Ambo. Testers FS59 is heterotic group B while FS67 is heterotic group A. The lines x tester crosses were made by high land maize breeding program of the Ambo Plant Protection Research Center during the main season of 2016. The list and pedigrees of the inbred lines and testers used for the study are presented in Table 2.

Table 2: The Pedigree and source of the lines and testers used in the study

Line code	Pedigree	Source
L1	(LPSC7-F96-1-2-1-1-B-B-B*/OFP9)-3-1-1-1-1-B-B-#	CIMMYT/AHMBP
L2	(LPSC7-F96-1-2-1-1-B-B-B*/OFP39)-6-1-1-1-1-B-B-#	CIMMYT/AHMBP
L3	(LPSC7-F71-1-2-1-2-B-B-B*/OFP1)-B-14-4-1-B-B-B-#	CIMMYT/AHMBP
L4	(LPSC7-F71-1-2-1-2-B-B-B*/OFP2)-B-1-3-1-B-B-B-#	CIMMYT/AHMBP
L5	(LPSC7-F71-1-2-1-2-B-B-B*/OFP3)-B-18-1-1-B-B-B-#	CIMMYT/AHMBP
L6	CML539-B-#	CIMMYT/AHMBP
L7	(CML539*/OFP9)-4-1-1-2-1-B-B-#	CIMMYT/AHMBP
L8	(CML539*/OFP27)-2-1-2-1-1-B-B-#	CIMMYT/AHMBP
L9	(CML539*/OFP14)-2-1-1-2-1-B-B-#	CIMMYT/AHMBP
L10	(CML539*/OFP14)-2-1-3-1-2-B-B-#	CIMMYT/AHMBP
L11	CML539*/OFP1)-B-6-1-1-B-B-B-#	CIMMYT/AHMBP
L12	CML539*/OFP1)-B-11-2-1-B-B-B-#	CIMMYT/AHMBP
L13	(CML539*/OFP4)-B-12-1-1-B-B-B-#	CIMMYT/AHMBP
L14	CML442-#	CIMMYT/AHMBP
L15	(CML442*/OFP1)-B-14-4-2-B-B-B-#	CIMMYT/AHMBP
L16	(CML442*/OFP1)-B-18-2-2-B-B-B-#	CIMMYT/AHMBP
L17	(CML442*/OFP4)-B-4-1-2-B-B-B-#	CIMMYT/AHMBP
L18	(CML442*/OFP4)-B-17-3-2-B-B-B-#	CIMMYT/AHMBP
L19	(CML395*/OFP105)-1-2-3-1-2-B-B-#	CIMMYT/AHMBP
L20	(CML444*/OFP23)-6-3-1-1-2-B-B-#	CIMMYT/AHMBP
L21	([CML312/[TUXPSEQ]C1F2/P49-SR]F2-45-3-2-1-BB//INTA-F2-192-2-1-1-1-BBBB]-1-5-1-1-1-BBB-B-B-B*/OFP106)-1-2-2-2-2-B-B-#	CIMMYT/AHMBP
L23	(CML495*/OFP6)-B-3-3-3-B-B-#	CIMMYT/AHMBP
L24	(CML495*/OFP6)-B-27-1-1-B-#	CIMMYT/AHMBP
	TESTER	
T1	FS59	AMBO
T2	FS67	AMBO
	CHECKS	
1	KOLBA (AMH853)	AMBO
2	JIBAT (AMH 851)	AMBO

AHMBP = Ambo Highland Maize Breeding Program

Experimental Design

The hybrids planted in alpha-lattice design (Patterson and Williams, 1976) with two replicates. Design and randomization of the trials were generated using CIMMYT's computer software known as Field book (Banziger and Vivek, 2007). One row plots of 5.25m length and 75 x 25cm spacing between rows and plants were used, to achieve 53,333 plants per hectare. Two seeds were hand planted per hill and later thinned out to one plant per hill after seedlings established well.The Experiment was planted in a field that had been depleted of N by continuous cropping of maize for five seasons and removing the crop biomass after each season. No additional nitrogen fertilizer was applied for low-N experiment. All other crop management practices were carried out as per the recommendations for each location.

Data Collected

Data collection and analysis of variance (ANOVA): Data were recorded on seventeen quantitative characters. Data related to days to 50 % anthesis, 50 % days to silking, 50 % days to Maturity, 1000-kernel weight, grain yield and anthesis silking interval were recorded on the plot basis while data related to other characters were recorded on five randomly selected plants leaving border plants of each row. The mean values were subjected to line × tester analysis. Analyses of variances (ANOVA) were computed for grain yield and other agronomic traits by using SAS 9.2 software.

Combining ability analysis: Line × tester analysis was done for traits that showed statistically significant differences among the crosses using the adjusted means based on the method described by Kempthorne. General combining ability (GCA) and specific combining ability (SCA) effects for grain yield and other agronomic traits were calculated using the line × tester model. The F-test of mean square due to lines, testers and their interactions were computed against mean square due to error Significances of GCA and an F - test using the standard errors of GCA and SCA effects, determined SCA effects of the lines and hybrids

3. RESULTS AND DISCUSSION

Analysis of Variance

Hybrids exhibited highly significant (P<0.01) differences in most traits except number of plants per plot at harvest, ear aspect, ear length and number of kernels per row (table 3). About 72.92% of the 48 crosses had higher grain yield than the high yielding normal hybrid check. Low N stress reduced yield and field performance of the hybrids. Relative grain yield reduction was 58.21. In agreement with this finding, Dagne (2008) reported significant yield reduction due to low N stress which was 88.5% at Harare and 48.8% at Bako.

All traits exhibited highly significant (P< 0.01) differences among the hybrids. Significant differences observed among hybrids indicate the existence of a high level of variation for various characteristics that makes selection possible for improved grain yield and agronomic traits under low N stress condition. Similar results were reported (Bullo and Dagne, 2016; Keno *et al*., 2017; Mafouasson *et al*., 2017).

Table 3: Line x tester analysis of variance for grain yield and yield related traits under low N condition at Ambo in 2017

Trait	Rep df= 1)	Hybrid df=49	Cross df=47	GCAL df=23	GCAT df=1	SCALxT df=23	error	% contr. GCA	% contr. SCA
GYF	1.53^{ns}	0.54^{*}	0.65^{*}	0.69^{*}	1.11^{ns}	0.60ns	0.39	55	45
DA	1.76^{ns}	7.6^{**}	9.34^{**}	15.22^{**}	1.76^{ns}	3.78*	2.1	80	20
DS	10.01^{ns}	18.6^{**}	21.08^{**}	16.95^{**}	263.3^{**}	14.69*	6.71	66	34
ASI	0.01^{ns}	0.03^{**}	0.03^{**}	0.02^{*}	0.48^{**}	0.03**	0.01	57	43
MD	10.01^{ns}	6.88^{**}	7.06^{**}	5.16^{ns}	71.76^{**}	6.15*	3.12	57	43
PH	1980^{*}	413.4^{**}	790.91^{**}	1045.22^{**}	5192.04^{**}	345.26^{ns}	374.12	79	21
EH	900.4^{*}	227.87^{**}	442.68^{**}	415.78^{**}	6402.7^{**}	210.45^{ns}	169.44	77	23
EPP	0.02^{ns}	0.03^{*}	0.03^{ns}	0.03^{ns}	0.13^{*}	0.03^{ns}	0.03	58	42
SEN	2.04^{*}	1.13^{**}	1.43^{**}	1.28^{**}	20.17^{**}	0.78^{*}	0.38	74	26
EA		0.16ns							
PA	0.17^{ns}	0.15^{*}	0.17^{**}	0.20^{ns}	0.04^{ns}	0.14^{ns}	0.19	58	42
ED	0.07^{ns}	0.07^{**}	0.08^{**}	0.13^{**}	0.20^{*}	0.02^{ns}	0.02	87	13
NRPE	0.02^{ns}	1.07^{**}	1.11^{**}	0.80^{ns}	25.32^{*}	0.38^{ns}	0.47	66	34
NKR		10.81^{ns}							
TKW	70.26^{ns}	2503.16^{**}	2910.92^{**}	1586.84^{ns}	53756.9^{**}	2024.32^{ns}	1213	83	17

*, **, = Significant at 0.05 and 0.01,GYF=grain yield t ha^{-1}; DA= days to anthesis (days); DS= days to silking (days); ASI=anthesis silking interval(days); MD=days to maturity(days), PH=plant height (cm); EH= ear height; EPP=ear per plant (#); NP=number of plants at harvest (#); EA=ear aspect (1-5 scale); PA=plant aspect (1-5 scale); EL=ear length (cm), ED=ear diameter (cm); NRPE=number of rows per ear (#); NKPR= number of kernels per row (#); TKW= thousand kernel weight(g).

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Mean performance of Genotypes

Mean grain yield for all genotypes were 3.23t/ha ranging from 2.13t/ha to 4.61t/ha (table 4). Among the crosses, L5xT2, L6 x T2, L14 x T2, L20 x T2 and L23 x T2 were crosses with high yield on the site (table 4). Maximum number of days to tasseling (115.6) was obtained from the cross of L10xT1 while relatively lower number of days to tasseling (107) was obtained from crosses of L3xT2 with over all mean of 110.7. Whereas, number of days to silking ranged from 108 to 120 days (table 4) in crosses of L17xT1 and L3xT2 respectively with over all mean of 112.8 days (table 4). Anthesis silking interval ranges from 1.01 to 1.5 (table 4) as in crosses L22 x T2, L20xT2, L5xT2, L2 x T2 and L17xT1, L7xT1, L24xT2 with over all mean of 1.23 respectively (table 4). The days to maturity ranged from 192.5(L5xT1) to 202 days (L15xT2) with overall mean of 196.26 days (table 4). The overall mean of Plant height was 209.42cm ranged from 164.1 cm to 237.6 cm (table 4) as in cross L14xT1 and L16xT2 respectively and the overall mean of ear height was 110.2cm ranged from 83.4cm to 134cm respectively as in L16xT2 and L10xT1 (table 4). In agreement with the present results, (Mafouasson *et al*., 2017) identified experiment variety performing better than the best check for yield and yield related traits.

Ear and plant aspect were ranged from 2.25 to 3.5 and 2.5 to 3.75 respectively (table 4). Over all mean of leaf senescence was 4.82 ranged from 3.1 to 6.2 (table 4). Maximum ear diameter 4.57cm was registered from the crosses (L5xT1) while, minimum ear diameter 3.8cm was obtained from the crosses L13xT2, L4xT2, L9xT2, with over all mean of 4.13cm (table 4). Number of kernels row per ear was ranged from 11 to 14.34 (table 4) as in cross L15xT2 and L20xT1 with over all mean of 12.63. The overall mean of thousand kernels weight were 305.33gm ranged from 242.4gm (L18xT2) to 377.2gm (L20xT2) for crosses (table 4). (Worku *et al*., 2008; Mafouasson *et al*., 2017) in their studies reported that experimental varieties showed better performance than the best check for yield and other traits.

Table 1: Mean values for grain yield and yield related traits at Ambo (low N)

Crosses	GYF	AD	SD	MD	PH	EH	EPP	SEN	EA	PA	EL	ED	NRPE	TKW
L1XT1	2.49	110.3	113.2	197.5	213.7	115.1	1.1	5.1	3.2	3.4	14.1	4.3	13.0	246.3
L1XT2	3.53	108.6	108.8	198.0	198.1	102.8	0.9	5.0	3.0	3.5	12.7	4.1	12.7	344.4
L2XT1	3.35	108.9	111.5	194.0	223.1	128.7	1.0	4.6	2.8	3.4	15.5	4.5	13.7	270.3
L2XT2	3.40	110.4	108.2	196.0	196.0	101.3	1.1	3.5	3.0	2.9	13.6	4.3	12.7	296.4
L3XT1	3.24	108.8	109.0	195.0	181.4	106.5	1.1	6.0	2.8	3.2	15.1	4.0	12.7	292.1
L3XT2	3.86	107.0	108.0	196.0	192.9	97.3	0.9	3.8	2.5	2.9	15.0	4.0	12.0	317.7
L4XT1	2.13	111.3	116.7	196.0	202.2	111.6	0.7	6.1	3.2	2.9	14.9	3.9	13.3	242.4
L4XT2	3.33	112.9	111.5	195.0	183.9	98.7	1.1	4.6	3.2	3.2	15.9	3.8	11.3	303.9
L5XT1	3.81	112.3	117.5	192.5	193.9	111.5	1.0	4.6	2.5	3.0	16.7	4.6	14.0	304.9
L5XT2	4.61	112.5	108.4	199.0	211.0	103.9	1.1	3.5	2.3	2.9	16.0	4.5	12.3	376.4
L6XT1	2.23	109.8	115.7	197.5	216.1	108.3	0.9	5.5	3.3	3.1	14.8	3.9	13.3	260.6
L6XT2	4.37	108.9	109.5	195.5	218.6	109.9	1.2	4.9	2.7	2.6	15.5	4.3	12.3	335.3
L7XT1	2.34	108.2	116.5	194.5	226.1	113.4	0.8	5.5	3.2	2.7	14.8	4.4	13.0	259.8
L7XT2	3.97	107.5	109.9	198.5	217.4	102.3	1.3	4.5	2.7	3.3	15.6	4.2	12.3	342.9
L8XT1	2.92	108.4	111.7	194.0	197.5	98.9	0.9	4.4	2.5	3.1	15.1	4.4	13.3	282.2
L8XT2	2.83	108.5	110.8	199.0	197.6	99.5	1.0	4.0	2.8	2.8	14.2	4.4	12.7	341.5
L9XT1	2.78	113.1	116.3	196.5	212.4	108.5	0.8	5.6	3.2	3.0	14.7	4.0	12.7	265.2
L9XT2	2.55	114.4	114.1	199.0	212.9	119.4	0.9	5.6	3.0	3.3	15.4	3.8	11.3	313.9
L10XT1	3.94	115.6	119.8	195.5	222.4	134.1	1.0	4.7	2.3	3.5	16.4	4.3	13.0	298.9
L10XT2	2.88	112.9	112.7	198.5	210.6	118.9	1.0	4.4	3.2	2.7	14.3	4.0	12.0	280.1
L11XT1	2.96	110.0	112.7	196.0	223.0	127.6	1.0	6.0	2.7	3.5	15.1	4.1	12.7	273.9
L11XT2	3.11	110.6	111.0	197.5	229.1	120.4	1.0	5.5	3.2	2.5	14.8	4.1	12.3	312.1
L12XT1	3.06	109.4	117.1	196.5	236.2	120.3	0.9	6.1	3.0	2.9	15.8	4.3	13.3	306.6
L12XT2	2.67	111.4	113.1	197.5	211.2	109.5	0.9	4.2	3.5	3.7	14.3	4.2	13.0	307.4
L13XT1	2.66	112.1	116.7	194.0	211.0	122.6	1.1	6.0	3.2	3.7	15.4	3.9	13.0	249.0

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Table 4. Continued

Crosses	GYF	AD	SD	MD	PH	EH	EPP	SEN	EA	PA	EL	ED	NRPE	TKW
L13XT2	3.20	110.9	109.4	194.0	200.1	101.3	1.0	4.6	3.3	2.8	16.2	3.8	11.7	328.1
L14XT1	3.98	109.1	111.8	197.5	237.6	131.0	1.1	5.2	3.3	3.3	17.1	4.4	13.7	327.6
L14XT2	4.31	107.5	109.1	200.0	206.7	100.0	1.1	3.9	3.0	3.2	16.4	4.2	12.0	354.5
L15XT1	3.47	109.0	113.7	193.0	206.5	108.5	1.0	5.3	3.0	3.6	16.2	4.1	12.7	312.2
L15XT2	3.21	109.0	110.2	202.0	174.3	92.0	1.2	3.5	3.0	3.5	15.4	4.0	11.0	354.2
L16XT1	3.21	109.0	113.8	197.0	197.2	107.0	1.0	5.3	3.2	3.1	16.1	4.1	14.0	257.8
L16XT2	3.15	109.1	109.8	196.0	164.1	83.4	1.1	3.4	2.8	3.5	15.5	3.9	12.0	339.4
L17XT1	2.66	110.0	120.1	194.5	195.3	116.6	1.0	6.1	3.0	3.4	15.1	4.2	13.3	242.9
L17XT2	3.52	111.1	110.5	194.0	187.4	100.3	1.0	4.7	2.8	2.8	15.1	4.1	12.0	316.0
L18XT1	3.36	113.7	114.9	196.0	209.7	129.3	0.9	5.8	3.2	2.9	16.6	4.2	12.7	243.4
L18XT2	2.92	114.1	115.0	198.0	200.6	111.9	0.8	4.5	3.0	2.5	15.9	4.1	12.0	377.2
L19XT1	3.43	109.9	116.4	194.5	234.5	126.6	0.9	5.8	3.0	2.6	13.7	4.4	13.3	336.8
L19XT2	3.59	111.3	112.1	195.5	217.3	108.9	1.0	4.3	2.8	3.0	14.2	4.2	12.7	352.0
L20XT1	3.04	113.9	117.3	194.5	233.5	128.0	1.1	6.2	3.3	3.3	16.5	4.3	14.3	269.6
L20XT2	4.14	113.0	110.3	197.0	225.6	95.7	1.1	4.8	2.7	2.9	16.1	4.2	13.0	377.2
L21XT1	2.94	110.7	112.9	195.5	214.4	122.3	1.0	5.4	2.5	2.9	14.9	4.0	12.7	295.1
L21XT2	2.46	114.6	112.7	195.5	221.6	118.3	0.9	4.6	2.8	2.3	15.3	4.1	11.7	315.7
L22XT1	2.95	109.8	114.4	195.0	229.8	114.3	1.1	5.1	3.0	3.6	13.2	4.2	13.7	254.5
L22XT2	3.42	113.4	110.7	196.0	215.0	99.3	1.2	4.0	2.5	3.2	12.4	3.9	11.7	313.2
L23XT1	3.66	110.0	109.2	195.5	210.3	102.1	1.0	3.1	2.8	3.0	15.8	4.0	12.0	306.9
L23XT2	4.11	109.8	108.3	196.0	217.6	99.2	1.2	3.9	2.7	2.9	14.8	4.1	12.0	367.4
L24XT1	3.66	111.9	110.0	196.0	194.9	98.2	1.1	4.1	2.7	3.0	15.4	4.0	12.3	338.9
L24XT2	2.64	109.4	117.7	196.5	197.3	93.8	1.0	4.8	3.0	3.2	13.0	3.9	12.3	264.4
check1	2.89	109.6	115.3	198.0	227.6	133.5	1.0	4.7	3.0	3.5	15.1	3.9	12.7	291.2
check2	2.38	109.1	112.1	196.5	214.2	95.8	0.9	4.4	3.0	3.2	15.2	4.0	12.3	306.4

Table 4. Continued

Statistics	Traits														
	GYF	DA	DS	MD	PH	EH	EPP	NP	SEN	EA	PA	EL	ED	NRPE	TKW
Minimum	2.13	107	108	192.5	164.1	83.4	0.69	13.5	3.1	2.25	2.5	12.4	3.8	11	242.4
Maximum	4.61	115.6	120	202	237.6	134	1.28	17	6.2	3.75	3.75	17.1	4.57	14.34	377.2
Cross mean	3.24	110.7	112.7	196.2	208.73	109.8	1.01	15.32	4.83	2.9	3.09	15.14	4.14	12.64	305.49
Check mean	2.83	109	113.2	197.3	226	119.3	0.95	15.25	4.5	3	3.1	15.17	3.98	12.5	301.33
Grand mean	3.23	110.7	112.8	196.3	209.4	110.2	1.01	15.32	4.82	2.93	3.1	15.14	4.13	12.63	305.33
CV (%)	15.6	1.15	2.1	0.88	6.18	6.17	16.04	6.66	11.17	12.26	9	7.35	3.31	5.3	9.92
LSD (5%)	1.02	2.59	4.81	3.51	26.28	13.81	0.35	ns	1.09	ns	0.57	ns	0.29	1.36	61.51

GYF=grain yield t ha^{-1}; DA= days to anthesis (d); DS= days to silking (d); MD=days to maturity (d), PH=plant height (cm); EH= ear height; EPP=ears per plant; NP=number of plants at harvest (#); SEN=leaf senescence; EA=ear aspect (1-5 scale); PA=plant aspect (1-5 scale); EL=ear length (cm), ED=ear diameter (cm); NRPE=number of rows per ear (#); EL= ear length (cm); TKW= thousand kernel weight (g)

Combining Ability Analyses

The partitioning of significant crosses mean squares into general combining ability (GCA) and specific combining ability (SCA) showed that line GCA means squares were significantly different for grain yield (table 3). Similar result was reported by Gudeta (2007) carried out line x tester analysis of QPM versions of early generation highland maize inbred lines and reported significant GCA mean squares due to lines at Holeta and Kulumsa but non- significant at Ambo and

Haramaya. Significant GCA and SCA mean squares implied that importance of both additive and non-additive gene actions in governing grain yield. In agreement with the present study Shushay *et al*., 2013 found highly significant mean squares due to GCA and SCA for grain yield in line x tester analysis involving 48 testcrosses. Girma *et al*. (2015) and Amare *et al*. (2016) have also reported the importance of both additive and non-additive gene actions in governing grain yield in maize. Similarly, Bullo and Dagne (2016) reported highly significant GCA mean squares and SCA mean squares for grain yield.

GCA sums of squares were larger than SCA sums of squares for grain yield (55%) (table 3). The predominance of GCA sums of squares to SCA sums of squares for grain yield indicated the relative importance of additive gene action to non-additive gene action for this trait (Beck *et al*. 1990). In line with this study Tamirat *et al*. (2014) reported the preponderance of additive gene action in the inheritance of grain yield while in contrast to these findings, Melkamu (2013) previously reported dominant role of SCA gene action in the grain yield of maize.

Mean squares due to crosses for anthesis and silking date were highly significant ($P < 0.01$). Line GCA, tester GCA and SCA mean squares were significant for anthesis and silking date except tester GCA mean squares of days of anthesis (table 3 implied the importance of both additive and non-additive gene actions in governing these traits. Results of this study are in accordance with the findings of Girma *et al*. (2015) who reported significant mean squares due to GCA and SCA for days to anthesis and silking.

General combining ability sums of squares were larger than SCA sums of squares for anthesis and silking dates (table 3). The predominance of GCA sums of squares to SCA sums of squares for these traits indicates the relative importance of additive gene action to non-additive gene action for the inheritance of these traits. In line with this study Amare *et al*. (2016) reported the preponderance of additive gene action in the inheritance of days to anthesis and days to silking. While in contrast to these findings, Kanagarasu *et al*., 2010 previously reported dominant role of SCA gene action in the days to anthesis and days to silking.

Mean squares due to crosses for plant and ear height were highly significant ($P < 0.01$). Combining ability analysis revealed highly significant GCA effects of lines and testers for plant and ear height while SCA mean squares were non-significant (table 3). In line with these findings, Gudeta (2007) reported significant GCA and non-significant SCA mean squares for plant height. In contrast to these findings, Demissew *et al*. (2011) found significant GCA and SCA mean squares for plant and ear height. GCA sums of squares were larger than SCA sums of squares for plant and ear height (table 3). Similar to the present findings Amare *et al*. (2016) reported the preponderance of additive gene action in the inheritance of plant height.

For number of rows per ear, mean squares due to crosses and tester GCA were highly significant but line GCA and SCA were non- significant (table 3). In the current study, the importance of additive genetic components was clearly observed. The present results in contrast with the Assefa *et al*. (2017) who found additive and non-additive gene actions in the inheritance of number of rows per ear. GCA sums of squares were larger than SCA sums of squares for number of rows per ear. (table 3). These results indicated preponderance of additive gene action than non-additive gene action in the inheritance of these traits. In contrast to present findings Chandel and Mankotia (2014) reported Variance due to SCA was greater than GCA variance for number of rows per ear, indicated that non additive gene action was important than additive gene action in the inheritance of these traits.

Estimates general combining ability

The estimates of line GCA effects of the inbred lines for various traits under low N condition at Ambo are presented in table 5. Inbred lines L5 and L14 had significant positive line GCA effects for grain yield while none of inbred line had significant negative line GCA effects. L3, L7, L8 and L14 had highly significant negative line GCA effects for days to anthesis while inbred lines L9, L10, L18, L20 and L21 showed highly significant positive line GCA effects for this trait. The female parents L3 and L23 were negative and highly significant difference (P<0.01) GCA effect for days to silking while the female parent L10 and L17 had high positive and significant GCA effects for these traits. Significant positive line GCA effects for ASI were observed for L7 and L12 while highly significant negative line GCA effects were observed for L23. The female parent L13 and L17 were negative and significant difference GCA effect for days to maturity while highly significant positive line GCA effects were observed for L14. The result of this study is in accordance with

Mafouasson *et al*., 2017, who found desirable GCA effects for these traits in combining ability and gene action of tropical maize inbred lines under low and high nitrogen conditions.

Significant negative line GCA effects for plant and ear height were observed for L3, L4, L16, and L24 while significant positive GCA effects were observed for L11. Inbred lines L2, L5 and L23 showed highly significant negative line GCA effects for leaf senescence while L9, L11 and L20 had significant positive GCA effects for this trait. Line GCA effects for plant aspect was positive and significant for L1 but negative and significant for L21. For ear diameter, highly significant positive GCA effects were observed for L2, L5, L8 and L19 while highly significant negative line GCA effects were observed for L4, L9, L13 and L24. Inbred lines L20 had positive highly significant GCA effects for number of rows per ear but negative and significant for L15. For thousand kernel weight, L5 and L14 showed significant positive GCA effects. Worku *et al*., (2008) reported similar results for these traits.

Table 5: General combining ability effects (GCA) of 24 inbred lines and two testers for grain yield and yield related traits under low N conditions at Ambo, 2017

Lines	GYF	AD	SD	ASI	MD	PH	EH	SEN	ED	NRPE	TKW
L1	-0.32	-1.47*	-1.49	0.02	1.53	-7.73	-4.79	0.17	0.07	0.19	-6.69
L2	0.23	-1.22	-2.99*	-0.07	-1.22	10.77	15.71*	-0.83**	0.27**	0.53	-15.05
L3	0.21	-2.72**	-3.74**	-0.03	-0.72	-28.23**	-16.54*	-0.08	-0.15*	-0.31	-5.53
L4	-0.58	1.28	1.51	0.01	-0.72	-21.73*	-13.29*	0.42	-0.31**	-0.31	-30.16
L5	1.11**	1.78*	0.01	-0.05	-0.47	-3.48	2.46	-0.83**	0.37**	0.53	36.30*
L6	0.08	-1.47*	-0.24	0.04	0.28	15.02	6.21	0.42	-0.02	0.20	-12.09
L7	-0.09	-2.72**	0.26	0.12*	0.28	15.52	0.71	0.17	0.15*	0.03	-8.96
L8	-0.19	-2.22**	-1.49	0.05	0.28	-5.48	-4.04	-0.58	0.26**	0.36	9.31
L9	-0.49	3.03**	2.26	-0.03	1.53	7.02	5.46	0.67*	-0.22**	-0.64	-16.86
L10	0.12	3.78**	3.51*	0.00	0.78	4.02	11.71	-0.33	0.00	-0.14	-11.71
L11	-0.16	-0.72	-1.24	0.00	0.53	19.52*	16.96*	0.92**	-0.03	-0.14	-11.78
L12	-0.35	-0.22	2.51	0.1*	0.78	17.02	8.21	0.17	0.10	0.53	-0.63
L13	-0.34	0.78	0.51	-0.01	-2.22*	-5.48	-1.04	0.42	-0.3**	-0.30	-8.51
L14	0.77*	-2.47**	-1.99	0.03	2.53**	8.27	0.96	-0.33	0.13	0.19	35.04*
L15	0.15	-1.72*	-1.24	0.03	1.28	-12.23	-5.79	-0.33	-0.06	-0.80*	29.60
L16	0.08	-1.72*	-1.24	0.03	0.28	-25.73*	-15.04*	-0.33*	-0.12	0.36	-1.55
L17	-0.27	0.03	2.76*	0.09	-1.97*	-24.23*	-8.29	0.67	0.00	0.03	-30.25
L18	-0.31	3.03**	2.51	-0.03	0.78	-13.23	1.71	0.42	-0.04	-0.31	1.87
L19	0.20	0.03	1.51	0.07	-1.22	14.52	6.46	0.42	0.19**	0.36	34.49
L20	0.38	2.53**	0.76	-0.08	-0.47	26.27**	8.71	0.67*	0.15*	1.03**	14.64
L21	-0.53	2.03**	0.26	-0.07	-0.72	5.77	8.46	0.17	-0.10	-0.47	1.86
L22	-0.04	0.78	-0.24	-0.06	-0.72	17.27	5.46	-0.33	-0.08	0.03	-22.70
L23	0.58	-0.47	-3.99**	-0.16**	-0.47	6.02	-9.04	-1.33**	-0.07	-0.64	25.72
L24	-0.24	0.03	1.51	0.04	0.03	-19.48*	-21.3**	-0.33	-0.2**	-0.30	-6.32
S.E. (gi)	0.31	0.72	1.30	0.05	0.88	9.67	6.51	0.31	0.07	0.34	17.41
SE(d)	0.44	1.02	1.83	0.07	1.25	13.68	9.20	0.44	0.10	0.49	24.63
Testers											
T1	-0.11	-0.14	1.66**	0.07**	-0.86**	7.35*	8.17**	0.46**	0.05	0.51**	-23.66**
T2	0.11	0.14	-1.66**	-0.07**	0.86*	-7.35*	-8.17**	-0.46**	-0.05	-0.51**	23.66**
S.E. (gi)	0.09	0.21	0.37	0.01	0.25	2.79	1.88	0.09	0.02	0.10	5.03
SE(d)	0.13	0.30	0.53	0.02	0.36	3.95	2.66	0.13	0.03	0.14	7.11

* $P< 0.05$; ** $P< 0.01$; GYF=grain yield t ha^{-1}; DA= days to anthesis; DS= days to silking; ASI=anthesis silking interval; MD=days to maturity, PH=plant height (cm); EH= ear height SEN= leaf senescence; PA=plant aspect; ED=ear diameter (cm); NRPE=number of rows per ear; TKW= thousand kernel weight (g)

Specific combining ability estimates

Days to anthesis and Silking

At Ambo low N, cross L21xT2 (-2.11) showed significantly negative SCA effects for days to anthesis and cross L24xT1 (-5.41) showed highly significantly negative SCA effects for days to silking and Anthesis silking interval. Which were desirable for earliness (table 6). In contrast to present findings, Abakemal *et al*. (2016) reported non-significant positive and negative SCA effects for days to anthesis silking interval. L15xT1 showed significantly negative SCA effects for days to maturity at Ambo (low N). Crosses with low estimate of SCA effects for days to anthesis and silking are desirable as they had earlier anthesis and silking than what have been expected based on GCA of their parents. These findings are in agreement with the findings of several researchers who reported significant positive-and-negative SCA effects for days to anthesis and silking (Girma *et al*., 2015 and Keno *et al*., 2017) while Assefa *et al*., 2017 reported non-significant positive and negative SCA effects for days to anthesis and silking.

Table 6: Estimates of specific combining ability (SCA) of line x testers crosses for grain yield and yield related traits under low N conditions at Ambo, 2017

Crosses	AD	SD	ASI	MD	SEN
L1xT1	0.89	0.09	-0.03	0.61	-0.46
L1xT2	-0.89	-0.09	0.03	-0.61	0.46
L2xT1	-0.86	-0.41	0.04	-0.14	0.04
L2xT2	0.86	0.41	-0.04	0.14	-0.04
L3XT1	1.14	-1.66	-0.12	0.36	0.79
L3XT2	-1.14	1.66	0.12	-0.36	-0.79
L4xT1	-0.86	0.59	0.07	1.36	0.29
L4xT2	0.86	-0.59	-0.07	-1.36	-0.29
L5xT1	0.64	3.59	0.10	-2.39	0.04
L5xT2	-0.64	-3.59	-0.10	2.39	-0.04
L6xT1	0.39	0.84	0.00	1.86	-0.21
L6xT2	-0.39	-0.84	0.00	-1.86	0.21
L7xT1	0.64	2.34	0.05	-1.14	0.04
L7xT2	-0.64	-2.34	-0.05	1.14	-0.04
L8xT1	0.14	-1.41	-0.06	-1.64	-0.21
L8xT2	-0.14	1.41	0.06	1.64	0.21
L9xT1	-0.61	-0.16	0.04	-0.39	-0.46
L9xT2	0.61	0.16	-0.04	0.39	0.46
L10xT1	1.64	1.59	0.00	-0.64	-0.46
L10xT2	-1.64	-1.59	0.00	0.64	0.46
L11xT1	-0.36	-1.66	-0.05	0.11	-0.21
L11xT2	0.36	1.66	0.05	-0.11	0.21
L12xT1	-1.36	0.09	0.04	0.36	0.54
L12xT2	1.36	-0.09	-0.04	-0.36	-0.54
L13xT1	0.64	2.09	0.07	0.86	0.29
L13xT2	-0.64	-2.09	-0.07	-0.86	-0.29
L14xT1	0.89	-0.41	-0.05	-0.39	0.04
L14xT2	-0.89	0.41	0.05	0.39	-0.04
L15xT1	0.14	0.34	0.01	-3.64**	0.54
L15xT2	-0.14	-0.34	-0.01	3.64**	-0.54
L16xT1	0.14	0.84	0.03	1.36	0.54
L16xT2	-0.14	-0.84	-0.03	-1.36	-0.54
L17xT1	-0.61	2.84	0.12	1.11	0.04
L17xT2	0.61	-2.84	-0.12	-1.11	-0.04
L18xT1	-0.11	-1.91	-0.09	-0.14	0.29
L18xT2	0.11	1.91	0.09	0.14	-0.29
L19xT1	-0.61	0.09	0.02	0.36	0.29

Appendix Table 6. Continued

Crosses	AD	SD	ASI	MD	SEN
L19xT2	0.61	-0.09	-0.02	-0.36	-0.29
L20xT1	0.39	1.34	0.07	-0.39	0.04
L20xT2	-0.39	-1.34	-0.07	0.39	-0.04
L21xT1	-2.11*	-2.16	0.01	0.86	0.04
L21xT2	2.11*	2.16	-0.01	-0.86	-0.04
L22xT1	-1.86	-0.16	0.09	0.36	0.04

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L22xT2	1.86	0.16	-0.09	-0.36	-0.04
L23xT1	0.39	-1.41	-0.08	0.61	-0.96*
L23xT2	-0.39	1.41	0.08	-0.61	0.96*
L24xT1	1.39	-5.41**	-0.27**	0.61	-0.96*
L24xT2	-1.39	5.41**	0.27**	-0.61	0.96*
SE	1.02	1.83	0.07	1.25	0.44
SE(d)	1.45	2.59	0.09	1.77	0.62

* *P*< 0.05; ** *P*< 0.01*; DA= days to anthesis; DS=days to silking; ASI=anthesis silking; days to maturity; leaf senescence

4. SUMMARY AND CONCLUSION

The current study was conducted with the objective of estimating the general (GCA) and specific (SCA) combining abilities of highland maize inbred lines using Line x Tester mating design. Fifty maize hybrids including 48 testcrosses developed by crossing 24 elite maize inbred lines with two testers and two standard checks were planted at Ambo (low N) during the 2017 cropping season in alpha lattice design replicated twice. Data were recorded on the plot and plant basis.

Analysis of variance indicated hybrids exhibited highly significant (P<0.01) differences in most traits. Mean squares due to crosses were significant for all traits except ear per plant. Among the crosses N, L5 x T2 (4.61t ha^{-1}), L6 x T2 (4.37tha^{-1}), L14 x T2 (4.31tha^{-1}), L20 x T2 (4.14tha^{-1}), and L23 x T2 (4.11tha^{-1}) were crosses with high yield. Cross combination, L3 x T2 was the earliest cross for anthesis and silking with corresponding values of 107 and 108 days, respectively under N stress condition. Shorter plant and ear heights were recorded for crosses L15xT2, L3XT1 and L4XT2 under N stress condition.

Combining ability analysis is important in identifying the best parents or parental combinations for a hybridization program. Line GCA and SCA mean squares where significant for most traits except SCA across low N stress environment, which showed significant mean squares only for days to anthesis and silking, anthesis silking interval, days to maturity and leaf senescence. It is concluded that non-additive gene effects are less important for the inheritance of characters under low N stress condition.

Based on combining ability analysis L5 and L14 were best general combiners under low N stress condition. Inbred lines with a high GCA effect for grain yield are desirable for synthetic and open pollinated varieties development as well as for inclusion in breeding program. For days to anthesis and silking, L3, L8, and L16 were the best combiners under N- stress condition, indicating that these lines had favorable alleles for early maturity. In general, the study indicated the importance of both additive and non-additive gene effects in most cases, while non-additive gene effects are less important under low-N stress.

REFERENCES

[1] Goerge, *Principles of plant genetics and breeding*. Blackwell Publishing Ltd. pp. 485, 2007

[2] JC. McCann, Maize and grace. Africa’s encounter with a new world crop, 1500–2000, 2005. Cambridge. Harvard University Press.

[3] HP. Huffnagel, Agriculture in Ethiopia. Rome. FAO. Kassie, M., Teklewolde, H., Jaleta, M., Marenya, P., & Erenstein, O. 2015. Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy*, 42:400–411,1961.

[4] International Institute of Tropical Agriculture (IITA), Research and Development: Cereals and legume system). (2009).

[5] S. Julia, T. Pangirayi, D, John and M. Itai, “Farmers’ desired traits and selection criteria for maize varieties and their implications for maize breeding,” A case study from KwaZulu-Natal Province, South Africa. J. Agr. Rural Develop. Trop. Subtrop. 114 - 1 (2013) 39–49, 2013.

[6] ES. Ntsama Mireille and Kamgnia Dia, Bernadette, "*Determinants of the adoption of improved varieties of Maize in Cameroon,"case of cms 8704.* Published in: Proceedings of the African Economic Conference (2008): pp. 397-413, 2008.

[7] HA. Akintoye *et al*. "N use efficiency of single, double and synthetic maize lines grown at four N levels in three ecological zones of West Africa". *Field Crops Research* 60.3, 189- 199, 1999.

[8] Mi G., *et al*. "Physiological and genetic mechanisms for nitrogen-use efficiency in maize". *Journal of Crop Science Biotechnology* 10.2, 57-63, 2005.

[9] HR. LAFITTE, G.O. EDMEADES, Association between traits in tropical maize inbred lines and their hybrids under high and low soil nitrogen. Maydica 40: 259-267,1995.

[10] JG. KLING, S. OIKEH, HA. AKINTOYE, HT. HEUBERGE, WJ. HORST, Potential for developing nitrogen use efficiency maize for low input agricultural systems in the moist savanna of Africa. pp. 490-501,1997. *In:* G.O. Edmeades *et al.* (Eds.), Developing Drought- and Low N-Tolerant Maize. CIMMYT/UNDP. Mexico, D.F.

[11] F. Miti, *et al*. "S1 selection of local maize landraces for low soil nitrogen tolerance in Zambia". *African Journal of Plant Science* 4.3: 67-81.2010.

[12] T. Presterl, S. Groh, M. landbeck, G.Seitz,W. Schmidt and H.H Geiger, Nitrogen uptake and Utilization Efficiency of European maize hybrids development under conditions of low high nitrogen input. Plant Breed. 121:480-486, 2002

[13] http.//www.eiar.gov.et/index.php/research-centers/access/date of access 20/3/2017

[14] AL. Page, Methods of soil analysis. Part II. Chemical and Microbiological Properties. Madison, 1982.

[15] Jackson, M.L. 1967. Soil Chemical Analysis. Constable and & Co.Letd London.

[16] R.H Bray and L.T Kurtz, Determination of total organic and available form of phosphorus is soils. *Soil Science*, 59: 39-45, 1945.

[17] M. Banziger, and B. S. Vivek, Fieldbook Software for managing a maize breeding programme. CIMMYT, 7:1103-1109, 2007.

[18] O. Kempthorne, *An introduction to genetic statistics*. John Wiley, New York1957.

[19] Dagne Wegary, Genotypic variability and combining ability of quality protein maize inbred lines under stress and optimal conditions. Doctoral Dissertation, University of the Free State, South Africa, 2008

[20] N.T. Bullo and Dagne Wegary, Combining ability of inbred lines in quality protein maize (QPM) for varietal improvement. *International Journal of Plant Breeding and Crop Science*, 3(1): 079-089, 2016.

[21] Tolera Keno, Mosisa Worku and Habtamu Zeleke, Combining ability and heterotic orientation of mid altitude sub-humid tropical maize inbred lines for grain yield and related traits. *African Journal of Plant Science*, 11(6):229-239, 2017.

[22] Mafouasson Apala Hortense Noëlle, Kenga Richard, Gracen Vernon, Yeboah Agyei Martin, Mahamane Nasser Laouali, Tandzi Ngoune Liliane and Ntsomboh-Ntsefong Godswill, Combining Ability and Gene Action of Tropical Maize (*Zea mays* L.) Inbred Lines under Low and High Nitrogen Conditions. *Journal of Agricultural Science*, 9(4):222-235,2017

[23] Mosisa Worku, M. Banziger, D. Friesen, G. Schulte, W.J. auf'm Erley, Horst, B.S. Vivek. Relative importance of general combining ability and specific combining ability among tropical maize (*Zea mays* L.) inbreds under contrasting nitrogen environments. *Maydica,* 53:279-288, 2008

[24] Gudeta Nepir, Heterosis and combining abilities in QPM versions of early generation highland maize (*Zea mays* L.) inbred lines. MSc. Thesis. School of Graduate studies, Alemaya University, Ethiopia, 2007.

[25] Girma C. Hosana, Sentayehu Alamerew, Berhanu Tadesse & Temesgen Menamo, Test Cross Performance and Combining Ability of Maize (Zea Mays L.) Inbred Lines at Bako, Western Ethiopia. *Global Journal of Science Frontier Research*. Agriculture and Veterinary, 15:4-6, 2015.

[26] Amare Seyoum, Dagne Wegary and Sintayehu Alamerew, Test Cross Performance and Combining Ability of Elite Highland Maize (*Zea Mays* L.) Inbred Lines at Jimma, Southwest Ethiopia. *International Journal of Trend in Research and Development*, 3(2): 2394-9333, 2016.

[27] D.L. Beck, S.K. Vasal, and V. Crossa, Heterosis and combining ability of CIMMYT's tropical early and intermediate maturity maize germplasm. *Maydica*, 35:279-285, 1990.

[28] Tessema Tamirat, Sentayehu Alamerew, Dagne Wegary and Temesgen Menamo, Test Cross Mean Performance and Combining Ability Study of Elite Lowland Maize (*Zea mays* L.) Inbred Lines at Melkassa, Ethiopia. *Advanced Crop Science Technology*, 2:140, 2014.

[29] Melkamu Elmyhum, Estimation of combining ability and heterosis of quality protein maize inbred lines. *African Journal of Agricultural Research*, 8(48): 6309-6317, 2013.

[30] S. Kanagarasu, G. Nallathambi, and K.N. Ganesan, Combining ability analysis for yield and its component traits in maize (*Zea mays* L.). *Electronic Journal of Plant Breeding*, 1(4): 915-920, 2010.

[31] Demissew Abakemal, Habtamu Zelleke, K. R. Kanuajia, and Dagne Wegari, Combining ability in maize lines for agronomic traits and resistance to weevil. *Ethiopian Journal of Agricultural science*, 2:37-48, 2011.

[32] Teshale Assefa, Habtamu Zeleke, Thomasi -Afriye and P. Otyama, Line ×Tester Analysis of Tropical High Land Maize (*Zea mays* L.) Inbred Lines Top Crossed with Three East African Maize Populations. *American Journal of Plant Sciences*, 8: 126-136, 2017.

[33] U. Chandel, and B. S. Mankotia, Combining Ability in Local and Cimmyt Inbred Lines of Maize (*Zea mays* L.) for Grain Yield and Yield Components Using Line × Tester Analysis. *SABRAO Journal. Breed. Genet*, 46 (2): 256-264, 2014.

[34] Demissew Abakemal, Hussein Shimelis and John Derera, Analyses of Combining Ability and Genotype-By-Environment Interaction of Quality Protein Maize Inbred Lines Adapted to Tropical-Highlands. *Crop science*, 56:3078-3089, 2016.