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RESEARCH PAPER

Combining Ability of Highland Adapted Maize (*Zea Mays. L)* Inbred Lines For Desirable Agronomic Traits Under Optimum and Low Nitrogen Conditions

Zeleke Keimeso[1*] and Demissew Abakemal[1]

[1]*EIAR- Ambo Agriculture Research Center, PO Box 37, Ambo, Ethiopia.*
***Corresponding Author:** Email: zeleke.keimiso@gmail.com.*

Abstract

Low soil nitrogen is among the most important abiotic stresses limiting maize production in the highlands of Ethiopia. Information on hybrid performance and combining ability of maize inbred lines for grain yield and agronomic traits under low nitrogen stress is crucial to design appropriate breeding strategies for the development of enhanced maize cultivars. The objective of the present study was to estimate combining abilities of double haploid (DH) maize inbred lines for grain yield and related traits under optimum nitrogen and low nitrogen (N stress) condition. A total of 36 diallel crosses generated by crossing nine maize DH lines using half diallel mating scheme and four standard checks were studied for different desirable agronomic traits during 2017 cropping season at Ambo optimum nitrogen and Low nitrogen environments. The genotypes were evaluated in alpha lattice design replicated twice in both environments. Analyses of variances showed significant mean squares due to crosses for most traits studied. At optimum nitrogen condition, the highest grain yield was obtained from crosses L4 x L8 (9.57 t ha^{-1}), L4 x L7 (8.67 t ha^{-1}), L1 x L3 (8.36 t ha^{-1}), L6 x L8 (8.27 t ha^{-1}) and L3 x L4 (8.00 t ha^{-1}), whereas at low nitrogen condition, L2 × L4 (6.74 t ha^{-1}) and L4 × L8 (5.15 t ha^{-1}) were crosses with higher grain yield values. Mean squares due to general (GCA) and specific (SCA) combining abilities were significant for most of the traits under both conditions. This indicates that both additive and non-additive gene actions are important in the inheritance of these traits. Relatively larger GCA over SCA variances were observed in the current study for most studied traits revealing the predominance of additive gene action in controlling these traits. L3 and L8 were found as good combiners for grain yield at optimum N environment, whereas L2, L4 and L7 were good general combiners under low N stress condition. L4 and L8 were good combiners for grain yield in combine analysis across environments and hence were promising parents for hybrid cultivars development. Based on SCA effects, L1×L5, and L4×L7 were identified as promising hybrids for majority of traits studied in combined analysis across environments.

Keywords: Combining ability, General combining ability, Nitrogen stress, Specific combining ability.

Introduction

Maize (*Zea mays* L.*)* is a diploid (2*n*=20) crop and one of the oldest food grains in the world. It is a member of order *Poales*, family *Poaceae* and tribe *maydeae* (Eubanks, 1995; Acquaah, 2009). It is predominantly a cross-pollinating species, a feature that has contributed to its broad morphological variability and geographical adaptability. It contains approximately 72% starch, 10% protein, and 4% fat, supplying an energy density of 365 Kcal/100 g (Ranum *et al*., 2014).

Maize is one of the most important field crops to fulfill food security in Ethiopia. It contributes the greatest share of production and consumption along with other major cereal crops, such as tef, wheat and sorghum (CSA, 2018). It has a significant importance in the diets of rural Ethiopia and has gradually penetrated into urban centers. This is particularly evidenced by green maize cobs being sold at road sides throughout the country as a hunger-breaking food available during the months of May to August annually (Twumasi *et al.*, 2012). In spite of its wide adaptation and efforts made to develop improved maize technologies for different maize agro-ecological zones, many biotic and abiotic constraints still, limit maize production and productivity in different maize producing area of Ethiopia (Abate *et al.*, 2017). The major abiotic stresses in the highland areas are frost, hail and water-logging. Soils are characterized by undulating terrain, low fertility, and the region is characterized by wide variations in climatic conditions (Twumasi *et al.*, 2002). Low soil fertility is mainly due to low soil nitrogen (N) and its deficiency is common where N is applied at below-optimal levels because of high cost relative to economic returns, or where there are significant risks of drought and frost or of excessive leaching of nitrate (Lafitte and Edmeades, 1994).

Efficient N uptake and use by maize plants is of fundamental importance to maize production systems (Muza *et al.*, 2004). Low N increases the anthesis-silking interval, enhances kernel abortion, reduces final grain number and then grain yield (Monneveux *et al.*, 2005). Improved maize varieties that tolerate low soil fertility will help maize farmers in stress-prone areas to obtain better harvests under the same stress conditions (CIMMYT, 2007). Selection for improved performance under low N stress based on grain yield alone has often been considered inefficient, but the use of secondary traits such as anthesis-silking interval, leaf senescence, ears per plant, kernels per plant and kernel weight whose variance increases under stress and whose heritability remains high, are used to improve selection efficiency under low N stress (Edmeades *et al.*, 2006).

So far, combining ability effects in maize inbred lines has been extensively studied under non-stressed conditions for different sets of new maize inbred lines developed/introduced and adapted at different times (Demissew *et al.*, 2011; Yoseph *et al*., 2011; Girma *et al*., 2015; Tolera *et al.*, 2017 and Dufera *et al.*, 2018). Even though The International Maize and Wheat Improvement Centre (CIMMYT) has made significant progress in developing maize germplasm tolerant to low N (Worku *et al.*, 2008; Dagne, 2008; Mafouasson *et al.*, 2017; Tesfaye *et al.*, 2019), information is still limited regarding combining ability of maize inbred lines to use when developing stress tolerant single and three-way cross hybrids for the highlands. Therefore, the objective of this study was to determine the combining abilities of elite maize inbred lines and their crosses under low and optimum nitrogen conditions.

Materials and Methods

Descriptions of Experimental Sites

The field experiment was conducted at Ambo Agricultural Research Center during the 2017 main cropping season. Geographically, Ambo is located at 8°57'N latitude, 38°7'E longitude and at an altitude of 2225 m.a.s.l with average annual rainfall of 1110 mm, maximum and minimum temperature of 26 and 11°C, respectively. The soil type of the experimental field is vertisols. The total precipitation during the growing season (May to December 2017) was 864.1 mm, and the mean minimum and maximum temperatures were 10.51 and 24.1°C, respectively (Ambo Agricultural Research Centers Meteorological Station, Unpublished Data).

Experimental materials

Nine inbred lines obtained from Ambo highland maize breeding program were crossed using diallel mating design during the main cropping season of 2016 and thirty-six single cross hybrids were generated. The list of inbred lines and their origin is presented in Table 1. The inbred lines used in the crosses were developed by CIMMYT-Zimbabwe through DH maize inbred line development approach and were locally selected based on previous field performances in test-cross evaluations for adaptation, disease reaction and general combining ability by the highland maize breeding program at Ambo agricultural research center. The thirty-six F_1 crosses together with four commercial hybrid checks: Arganne, Kolba, Jibat and Wenchi were used in the hybrid trial evaluations in 2017.

Table 1. The list of inbred lines used to make the diallel crosses for the study

Line	Pedigree	Seed Source
L1	(INTA-F2-192-2-1-1-1-B*9/CML505-B)DH-3060-B-B-#	AHMBP*
L2	(LPSC7-C7-F64-2-6-2-1-B/CML488)DH-3033-B-B-#	AHMBP*
L3	(CML444/CML539)DH-3091-B-B-#	AHMBP*
L4	(CML144/CML159)DH-3049-B-B-#	AHMBP*
L5	([LZ956441/LZ966205]-B-3-4-4-B-5-B*7-B/DTPWC9-F109-2-6-1-1-B)DH-3001-B-B-#	AHMBP*
L6	(CML545/CML505)DH-10-B-#	AHMBP*
L7	(CML545/CML505)DH-44-B-#	AHMBP*
L8	([CML312/[TUXPSEQ]C1F2/P49-SR]F2-45-3-2-1-BB//INTA-F2-192-2-1-1-1-B*4]-1-5-1-2-1-B*6/CML505)DH-11-B-#	AHMBP*
L9	(CML312/CML442)DH-3002-B-B-#	AHMBP*

*AHMBP = Ambo Highland Maize Breeding Program

Experimental design trial management and data collection

The 36 F_1 crosses plus the four hybrid commercial checks adapted to the highland agroecology of Ethiopia were planted using alpha lattice design (Patterson and Williams, 1976) with two replications each of which have eight blocks with five entries in each of the blocks. Design and randomization of the trials were generated using CIMMYT's Field book software (Bindiganavile *et al*., 2007).

The trials were hand planted with two seeds per hill, which later thinned to one plant per hill at the 2-4 leaf stage to get a total plant population of 53,333 per hectare. Reliable moisture level of the soil was assured before planting so as to insure good germination and seedling development. Pre-emergence herbicide, Premagram Gold 660 at the rate of 5 lt ha^{-1}, was applied three days after planting of the seeds to control weeds followed by hand weeding at a later stage of crop emergence. Each entry was placed in a one-row plot of 5.25 m long and 0.75 m x 0.25 m apart between and within rows spacing, respectively. The hybrids were evaluated under optimal and low N conditions in adjacent fields with the same soil type in 2017. The experiment under low N-stress condition was laid in a field that had been depleted of N by continuous cropping of maize for several seasons and removing the crop residues after each season. 25% of the recommended amount of DAP fertilizer per hectare was applied at planting of seeds to simulate the low input farming system. No additional N fertilizer was applied. Under non-stress N conditions, the recommended rate of diammonium phosphate (DAP) fertilizer was applied once at planting using a rate of 100 kg ha^{-1} while Urea was applied in two splits, *viz*., half of it was applied when plants had six to eight leaves, and the remaining half was applied at flag leaf emergence before flowering. Other standard cultural and agronomic practices were followed in trial management as per recommendations for the area.

Soil sampling and analysis

Representative composite soil sample was taken from ploughed and leveled field at three places diagonally across the plot with auger. Samples were taken from 0 to 30 cm and 30 to 60 cm depth of top soil and composited to make one representative soil sample for each depth before planting. The composited soil samples were subjected to analysis before planting. Results of the soil analysis are shown in Table 2.

Table 2. Properties of soil at two depths of the experimental fields at Ambo, 2017.

Field	Depth (cm)	P^H	Available P (ppm)	N(%)	OC(%)	OM(%)
Optimum-N field	0-3	6.7	49.6	0.13	1.64	2.8
	30-60	6.9	37.8	0.09	1.49	2.6
Low-N field	0-30	7.2	10.5	0.11	1.41	2.4
	30-60	7.4	7.4	0.08	1.31	2.3

OC=Organic carbon, OM=organic matter

Data collected

The procedure of data collection followed CIMMYT's manual for managing trials and reporting data (CIMMYT, 1985). Data on grain yield and other important agronomic traits were collected on a plot and sampled plants base. Data collected on a plot basis include: days to 50% anthesis (DA), days to 50% silking (DS), anthesis-silking interval (ASI), grain yield (GY) (t $-ha^{-1}$), actual moisture content, field weight(kg/plot), plant aspect, ear aspect, ear rot and bad husk cover; while data collected on plant base include: ear height (EH) (cm), plant height (PH) (cm), number of ears per plant (EPP) and Leaf senescence (SEN) which was scored 10 and 12 weeks after planting on a scale from 0 to 10, dividing the percentage of the estimated total leaf area below the ear that is dead by 10, A score of 1 = less than 10% dead leaf and 10 = more than 90% dead leaf.

Data analyses

Before data analyses, anthesis-silking interval (ASI) was normalized using $\ln\sqrt{ASI + 10}$ as suggested by Bolanos and Edmeades (1996). Analysis of variance (ANOVA) per individual and across locations was carried out using PROC MIXED method = type3 procedure in SAS (2003) by considering genotypes as fixed effects and replications and blocks within replications as random effects for individual site analyses. In the combined analyses, environments, replications within environments and blocks within replications and environments were considered as random while genotypes remained as fixed effects following same procedure of Moore and Dixon (2015). Since significant and positive correlation was obtained between the two environments that also did not significantly affected rank difference of genotypes across environments, combined analyses was done for grain yield, days to anthesis, days to silking, plant height and ear height. In the combined analyses, entry and location main effects were tested using entry x location interaction mean squares as error term, while entry x location interaction mean squares were tested against pooled error. Relative reductions in grain yield and agronomic traits under low N was calculated as (1 - MV low N / MV optimum N), where MV low N are mean traits values obtained in experiment under low N and MV optimum N are mean traits values obtained in experiment under optimum N (Banziger *et al.*, 1997).

Combining ability analyses

Combining ability analyses was done for traits that showed significant differences among genotypes. Griffing's Method IV (crosses only) and Model I (fixed) of diallel analyses (Griffing, 1956) was used to estimate combining ability effects and associated standard errors using a modification of the DIALLEL-SAS program (Zhang *et al.*, 2005) in SAS (2003). The significance of GCA and SCA effects were tested against the respective standard errors of GCA and SCA effects, respectively, using t-test (Griffing, 1956; Singh and Chaudhary, 1985). In the across environments combining ability analyses, the significance of GCA and SCA mean squares were tested using the corresponding interactions with site as error term. The mean squares attributable to all the interactions with sites were tested against pooled error.

Results and Discussion

Analyses of variance (ANOVA)

The hybrids exhibited significant differences in all traits measured under low and optimum N conditions except anthesis silking interval, number of ear per plant and leaf senescence under low N (Table 4). Combined analysis of variances revealed significant differences among the hybrids for all traits studied (Table 5). Significant differences observed among hybrids for individual and across environments indicating the presence of inherent variation among the materials, which makes selection possible. Desirable genes from these genotypes can effectively be utilized to develop high performing hybrids under low N stress and non-stress conditions. Similarly, several previous studies reported significant differences among genotypes for grain yield and yield related traits in different sets of maize genotypes (Dagne *et al.*, 2008; Demissew, 2014; Amare *et al*., 2016; Tolera *et al.*, 2017 and Dufera *et al.*, 2018).

Genotypes performances

The mean grain yield under optimum N ranged from 4.60 to 11.24 t ha^{-1} with a mean value of 7.10 t ha^{-1} (Table 3). Cross combination L4 x L8 (9.57 t ha^{-1}) showed higher grain yield than the three hybrid checks except Kolba which showed the highest grain yield of 11.24 t ha^{-1}. Under low N condition, mean grain yield for all hybrids was 3.47 t ha^{-1} ranging from 1.19 to 6.65 t ha^{-1} (Table 3). At low N condition, L2 × L4 (6.74 t ha^{-1}) was a cross with higher yield. Whereas, L5 × L9 (1.19 t ha^{-1}) is the cross which showed the least yield under low N environment. The presence of crosses having mean values better than the standard checks indicated the possibility of obtaining good hybrid (s) for future use in breeding program or for commercialization. In line with this, Dagne *et al* (2010), Amare *et al*., 2016; Beyene, 2016, Dufera *et al.*, 2018 identified genotypes performing better than check for grain yield. Mean relative grain yield loss under low N was 51%. Mean relative loss of days to anthesis, days to silking and anthesis-silking interval increased by 10.4, 8.6 and 145%, respectively. Mean Plant height, ear height and ears per plant decreased by 15, 16 and 18%, respectively (Table 3). The level of yield loss between low and optimum N varied depending on the degree of N depletion in the soil (Banziger and Lafitte, 1997). In line with this findings Worku *et al.* (2008) and Tesfaye *et al.*, 2019 reported that low-N stress reduced grain yield by 64 and 58.2%, respectively.

Combining ability analyses

Diallel analyses for grain yield and related agronomic traits are presented in Table 4 for both optimum N and low-N conditions. Combining ability analyses across the two environments is presented in Table 5. The results showed that both general combining ability (GCA) and specific combining ability (SCA) mean squares were significant for days to anthesis, days to silking, anthesis-silking interval and number of ears per plant under optimum N condition. Under low-N environment, both GCA and SCA mean squares were significant for only grain yield. Mean squares due to GCA and SCA were significant for grain yield, days to anthesis, days to silking and ear height across the two locations (Table 4 and 5). This indicates that both additive and non-additive gene actions are important in the inheritance of these traits. Reports on similar studies by Dagne *et al.* (2007) showed importance of both additive and non-additive gene actions for ear height, plant height and days to maturity. Similarly, Yoseph *et al.* (2011) observed significant GCA and SCA for anthesis date, anthesis silking interval, ear height and plant height in elite maize inbred lines developed by CIMMYT for insect resistance.

GCA sums of squares were larger than SCA sum of squares for most of the traits under low, optimum N and across environments (Tables 4 and 5), indicating the relative importance of additive gene action to non-additive gene

Table 3. Mean values and range of grain yield and yield related traits of diallel crosses evaluated at Ambo under Optimum and low nitrogen stress condition, 2017.

Environment	Statistics	GY t ha^{-1}	DA Days	DS Days	ASI Days	PH cm	EH cm	EPP #	SEN Scale
Optimum N	Minimum	4.60	88	87	1.04	198.5	104.5	1.03	-
	Maximum	11.24	106	106	1.3	278	160.5	1.7	-
	Cross mean	6.91	92.81	93.96	1.201	229.25	121.17	1.36	-
	Grand mean	7.10	92.5	93.6	1.19	231.8	123.3	1.37	-
	CV(%)	11.00	1.07	1.41	4.32	7.67	9.29	9.3	-
	LSD(5%)	1.61	2.03	2.71	0.11	36.6	21.38	0.26	-
Low N	Minimum	1.19	92.00	93	-0.50	155.50	79.50	0.71	1.25
	Maximum	6.74	109.00	119.5	10.50	224.00	127.00	1.59	3.00
	Cross mean	3.82	98.90	155.66	56.76	170.69	102.46	1.13	1.98
	Grand mean	3.47	98.78	101.69	2.91	196.63	103.61	1.12	2.01
	CV(%)	20.95	1.94	2.99	91.04	6.20	6.98	21.06	24.27
	LSD(5%)	1.50	3.94	6.25	5.46	25.12	14.89	0.49	1.00

GYF=Grain yield; DA=days to anthesis; DS=days to silking; ASI=anthesis silking interval; PH=plant height; EH=ear height; EPP=ears per plant; SEN=leaf senescence action for this trait. Similar results were reported by other authors in their study on combining ability for yield and yield related traits in maize (Chandel and Mankotia, 2014; Amare *et al*., 2016; Beyene, 2016, Bitew *et al.*, 2017 and Tolera *et al.,* 2017). They reported predominance of additive gene action over non-additive for most of the traits they studied.

Significant GCA × environment (GCA × E) mean squares for grain yield, days to anthesis and days to silking was detected indicating, GCA effects associated with parents were not stable for these traits over the two environments (Table 5). But the interaction was not significant for plant height and ear height. SCA × environment (SCA× E) mean squares were significant for days to anthesis showing that SCA effects of this trait associated with crosses was not consistent over the two environments, while, SCA × environment showed non-significant mean squares for the rest of traits. Similar findings were reported by Tesfaye *et al.* (2019) in their study on combining ability of highland adapted maize inbred lines for grain yield and yield related traits under optimum and low nitrogen conditions.

Table 4. Mean squares due to hybrids, general (GCA) and specific (SCA) combining ability for grain yield and agronomic traits evaluated under optimum and low N stress condition at Ambo, 2017.

	Optimum N			**Low N**		
Trait	**Hybrid Df=35**	**GCA df=8**	**SCA df=27**	**Hybrid Df=35**	**GCA df=8**	**SCA df=27**
GY	2.26**	6.63**	1.15	2.49**	3.82**	2.61**
DA	17.88**	93.15**	5.34**	40.82**	159.23**	5.74
DS	23.79**	124.21**	4.32**	75.18**	284.98**	13.02
ASI	3.77**	7.95**	2.53*	11.15	26.03*	6.74
PH	541.49*	1325.64**	340.61	485.14*	1508.07**	182.05
EH	229.82*	719.93**	106.87	187.25*	570.07**	89.92
EPP	0.06**	0.14**	0.05*	0.09	0.14	0.09
SEN	-	-	-	0.31	0.88*	0.27

* * *P*< 0.05; ** *P*< 0.01; GY=Grain yield; DA=days to anthesis; DS=days to silking; ASI=anthesis silking interval; PH=plant height; EH=ear height; EPP=ears per plant; SEN=leaf senescence

Table 5. Combined analysis of variance for grain yield and agronomic traits of maize hybrids evaluated across optimal and low N stress environments at Ambo, 2017.

Source of variation	**DF**	**GY**	**DA**	**DS**	**PH**	**EH**
Environment (E)	1	444.82**	1338.34**	2170.01**	41820.25**	12600.06**
Hybrids	35	3.52*	60.22**	95.69**	799.01**	371.13**
GCA	8	7.45**	241.40**	384.46**	2726.84**	1189.93**
SCA	27	2.36**	6.53**	10.13**	227.79	128.52*
Hybrids X E	35	1.76**	6.01**	11.22**	251.89	75.53
GCA X E	8	3.00**	10.98**	24.74**	106.87	100.06
SCA X E	27	1.39	4.53**	7.22	294.86	68.26
Error	42	0.67	2.24	4.86	203.52	70.5

* * *P*< 0.05; ** *P*< 0.01; GY=Grain yield; DA=days to anthesis; DS=days to silking; ASI=anthesis silking interval; PH=plant height; EH=ear height; EPP=ears per plant; GCA X E= Interaction of general combing ability with environments; SCA X E= Interaction of specific combining ability with environments.

General combining ability effects

The estimates of GCA effects of 9 inbred lines evaluated in a diallel cross for grain yield and agronomic traits under optimum N at Ambo are presented in Table 6. The inbred lines varied significantly in their GCA effects for all traits. GCA effects for grain yield varied from – 0.59 to 0.62 t ha^{-1}. Inbred lines L3 and L8 showed highly significant positive GCA effects for grain yield, indicating the potential advantage of these inbred lines for the development of high-yielding hybrids and/or synthetic varieties, as the lines can contribute desirable alleles in the synthesis of new varieties. In contrast, L5, L6, L7 and L9 had non-significant negative GCA effects for grain yield (Table 6), indicating these lines were poor combiners for grain yield.

Table 6. General combining ability effects (GCA) of 9 inbred lines for grain yield and agronomic traits under optimum nitrogen condition at Ambo, 2017.

Line	GY	DA	DS	ASI	PH	EH	EPP
L1	0.14 ns	-1.22*	-0.90*	0.54*	-7.35	-10.76**	-0.09**
L2	0.09 ns	-1.26*	-1.87**	-0.96**	-6.32	-8.26**	0.01
L3	0.61*	2.92**	3.42**	0.83**	10.58**	10.02**	0.19**
L4	0.26	-2.69**	-2.51**	0.11	-1.57	0.38	-0.08*
L5	-0.44	3.85**	4.14**	0.33	14.00**	1.81	-0.06
L6	-0.54	-2.90**	-3.44**	-0.89**	-19.85**	-5.62**	-0.02
L7	-0.15	-1.47**	-1.12**	0.75**	-3.21	1.17	-0.06
L8	0.62*	-1.72**	-2.26**	-1.03**	4.83	1.95	0.01
L9	-0.59	4.49**	4.56**	0.33	8.89*	9.31**	0.08*
SE(g_i)	0.31	0.57	0.44	0.19	4.45	1.65	0.034

* $P< 0.05$; ** $P< 0.01$; GY=Grain yield; DA=days to anthesis; DS=days to silking; ASI=anthesis silking interval; PH=plant height; EH=ear height; EPP=ears per plant

Results of the current study are similar to the findings of several authors (Girma *et al*., 2015; Amare *et al*., 2016; Dufera *et al.*, 2018; Tesfaye *et al.*, 2019) who reported significant positive and negative GCA effects for grain yield in maize germplasm. GCA effects for days to anthesis and silking were lower for L1, L2, L4, L6, L7 and L8, indicating that these lines were good general combiners for early maturity and higher for L3, L5 and L9. Desirability of negative GCA for days to anthesis and silking for earliness and desirability of positive GCA for these traits for lateness was suggested by various authors such as (Umar *et al*., 2014; Girma *et al*., 2015 and Beyene, 2016). Inbred line L6 showed highly significant negative GCA effects for ear and plant height, implying the tendency of this line to reduce plant height, which is very important for development of genotypes resistant to lodging while L3 and L9 had highly significant positive GCA effects for both traits. L3 and L9 had significantly high positive GCA effects for ears per plant while L1 and L4 showed significantly negative GCA effect.

The estimates of GCA effects of the inbred lines for various traits under low N conditions at Ambo are presented in Table 7. Inbred lines L2, L4 and L7 had significant positive GCA effects for grain yield while L5 had significant negative GCA effects. L2, L4, L6, L7 and L8 had significant negative GCA effects for days to anthesis and silking while L3, L5 and L9 showed significant positive GCA effects for these traits. Highly significant negative GCA effects for plant height were observed for L1, L6 and L7 while highly significant positive GCA effects were observed for L3, L4, L5, L8 and L9. Highly significant negative GCA effects for ear height were observed for L1 and L2 while highly significant positive GCA effects were observed for L3, L5 and L9. Inbred line L2 showed significant negative

GCA effects for leaf senescence while L3 and L5 had significant positive GCA effects for this trait.

Across the two environments, highly significant positive GCA effects for grain yield were observed for L4 and L8 while the other inbred lines showed negative GCA effects for the same trait (Table 8). Highly significant negative GCA effects for days to anthesis and silking were observed for L1, L2, L4, L6, L7 and L8 while inbred lines L3, L5 and L9 showed positive and significant GCA effects for these traits. Inbred lines L1, L2 and L6 showed highly significant negative GCA effects for plant and ear heights whereas, L3, L4, L5 and L9 showed positive significant GCA effects for these traits.

Table 7. General combining ability effects (GCA) of 9 inbred lines for grain yield and agronomic traits under low N stress environment at Ambo, 2017

Line	GY	DA	DS	PH	EH	SEN
L1	-0.21	-1.25**	-0.68	-12.83**	-12.45**	-0.083
L2	0.42*	-1.75**	-2.97**	-1.90	-6.67**	-0.51**
L3	-0.05	3.68**	3.89**	8.67**	4.26**	0.20*
L4	0.89**	-1.10*	-1.18*	8.95**	1.62	0.024
L5	-0.95**	4.54**	6.11**	10.31**	5.76**	0.38**
L6	-0.07	-4.39**	-6.11**	-14.40**	0.83	-0.15
L7	0.41*	-2.89**	-2.61**	-11.76**	-2.67	-0.05
L8	-0.28	-1.46**	-3.18**	5.52*	1.40	0.06
L9	-0.15	4.61**	6.74**	7.45**	7.90**	0.13
SE(g_i)	0.14	0.34	0.48	2.18	1.31	0.08

* *P*< 0.05; ** *P*< 0.01; GY=Grain yield; DA=days to anthesis; DS=days to silking; ASI=anthesis silking interval; PH=plant height; EH=ear height; SEN=leaf senescence

Table 8. General combining ability effects (GCA) of 9 inbred lines for grain yield (t ha^{-1}) and agronomic traits across low N stress and optimal environments at Ambo, 2017.

Line	GY	DA	DS	PH	EH
L1	-0.03	-1.48**	-0.92**	-11.38**	-11.61**
L2	0.22	-1.55**	-2.64**	-4.81*	-7.46**
L3	0.14	3.17**	3.68**	8.23**	7.14**
L4	0.75**	-1.73**	-1.71**	6.12**	1.00
L5	-0.99**	4.09**	5.04**	10.87**	3.79**
L6	-0.28*	-3.12**	-4.42**	-14.85**	-2.39*
L7	0.16	-2.23**	-1.71**	-8.63**	-0.75
L8	0.46**	-1.41**	-2.78**	5.83**	1.68
L9	-0.46**	4.24**	5.47**	8.62**	8.61**
SE(g_i)	0.11	0.19	0.28	1.79	1.06

* *P*< 0.05; ** *P*< 0.01; GY=Grain yield; DA=days to anthesis; DS=days to silking; ASI=anthesis silking interval; PH=plant height; EH=ear height

Specific combining ability effects

The specific combining ability effects at individual and across environments were computed for traits that showed significant SCA mean squares in combining ability analysis. Under optimum N, 50% of the crosses showed positive SCA effects for grain yield out of which two crosses, namely; L1 × L5 and L4 × L7 showed positive and significant SCA effects for grain yield with SCA values of 1.38 and 1.23 t ha^{-1}, respectively (Table 9). Whereas, at Ambo low-N, crosses L3 × L1, L4 × L2, L7 × L5, L9 × L6 and L9 × L8 showed positive and significant SCA effects for grain yield. Thus, these crosses could be selected for their specific combining ability to improve grain yield. Crosses with higher value of SCA effects also showed higher values of mean grain yield, indicating good correspondence between SCA effects and mean grain yield. Hence such cross combinations could effectively be exploited in hybrid breeding program in maize research. On the other hand, two cross combinations L1 × L7 and L3 × L7 expressed negative and significant SCA effects for grain yield under optimum condition, which are undesirable as these crosses showed a tendency to reduce grain yield performance. The finding of this study is in agreement with the findings of Mohamed *et al.* (2014), Mafouasson *et al.* (2017) and Tesfaye *et al.* (2019) who reported significant positive and negative SCA effects for grain yield and yield related traits under low and optimal N conditions.

Table 9. Estimates of specific combining ability (SCA) effects for grain yield (t ha^{-1}) of 36 crosses evaluated under optimum nitrogen condition (above diagonal, SE(sij)= 0.53) and Low-N stress environment (below diagonal, SE(sij)= 0.47)

Cross	L1	L2	L3	L4	L5	L6	L7	L8	L9
L1		0.42	0.99	-0.78	1.38*	-0.74	-1.07*	-0.44	0.25
L2	-0.92		0.64	-0.44	0.21	-0.27	0.40	-0.22	-0.73
L3	1.53**	0.67		0.14	-0.56	0.65	-1.21*	-0.67	0.004
L4	0.15	1.96**	-0.57		-0.34	-0.84	1.23*	0.83	0.18
L5	-0.21	0.91	0.13	0.36		-0.68	0.66	-0.11	-0.57
L6	-1.71**	0.14	-0.87	-0.14	-0.67		0.43	0.64	0.80
L7	0.02	0.41	-0.24	-1.11*	1.19*	0.59		-0.27	-0.17
L8	0.85	-2.325**	-0.45	0.86	-0.61	0.78	-0.71		0.24
L9	0.29	-0.84	-0.18	-1.51	-1.09*	1.88**	-0.15	1.59**	

* $P < 0.05$; ** $P < 0.01$; P1= parent 1; P2= parent 2; P3= parent 3; P4= parent 4; P5= parent 5; P6= parent 6; P7= parent 7; P8= parent 8; P9= parent 9; SE(sij)= standard error of SCA

Conclusion

Mean square due to crosses showed significant differences for most traits under low and optimum N conditions except anthesis silking interval, number of ear per plant and leaf senescence under low N. Significant differences observed among hybrids for individual and across environments indicated the existence of a high level of variation for various characteristics which makes selection possible for improved grain yield and agronomic traits under opitimum and stress N conditions. Among the crosses, L4 x L8 showed higher grain yield than the checks at both opitimum and stressed N conditions implying possibility of growing this hybrid under optimum and N-stressed environment which is the general situation on farmers' fields. From the study, it can be concluded that good performing inbred lines with desirable GCA, cross combinations with desirable SCA effects and crosses with higher level of heterosis than the standard check for grain yield and other related traits were identified under both optimum and low N conditions. These genotypes serve as a source of favorable alleles that could be used for future breeding work in the development of maize cultivars with desirable traits' composition for highland sub-humid agroecology of Ethiopia.

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