American Journal of BioScience
2020; 8(3): 45-56
http://www.sciencepublishinggroup.com/j/ajbio
doi: 10.11648/j.ajbio.20200803.11
ISSN: 2330-0159 (Print); ISSN: 2330-0167 (Online)

General and Specific Combing Ability of Maize (*Zea mays* L.) Inbred Line for Grain Yield and Yield Related Traits Using 8×8 Diallel Crosses

Woldu Mogesse[1, *], Habtamu Zelleke[1], Mandefro Nigussie[2]

[1]School of Plant Science, College of Agriculture and Environmental Sciences (CAES), Haramaya University (HU), Haramaya, Ethiopia
[2]Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia

Email address:
weldum21@gmail.com (W. Mogesse), wubeno@gmail.com (H. Zelleke), mandefroaa@gmail.com (M. Nigussie)
[*]Corresponding author

To cite this article:
Woldu Mogesse, Habtamu Zelleke, Mandefro Nigussie. General and Specific Combing Ability of Maize (*Zea mays* L.) Inbred Line for Grain Yield and Yield Related Traits Using 8×8 Diallel Crosses. *American Journal of BioScience*. Vol. 8, No. 3, 2020, pp. 45-56.
doi: 10.11648/j.ajbio.20200803.11

Received: January 13, 2020; **Accepted**: February 25, 2020; **Published**: May 28, 2020

Abstract: Combining ability is the genotype's ability to pass the desired character to the offspring. Hence, combining ability information is needed to determine the crossed pairs in the formation of hybrid varieties. Therefore, this study was conducted to estimate general and specific combining ability effects of maize inbred lines for yield and yield-related traits. Eight maize inbred lines were mated through a half diallel mating design (Griffing's Method IV, Model I). The resulting twenty-eight F_1 hybrids for twenty one characters were evaluated using Alpha-Lattice Design with three replications during 2018 main cropping season at Haramaya University Research Site (Raare). Genetic analysis of variance due to mean squares revealed significant differences for general combining ability (gca) and specific combining ability (sca) effects indicated the presence of additive as well as non additive gene effects in governing the inheritance of these traits. These results confirm the possible involvement of both additive and non-additive gene actions in the inheritance of these characters and can be improved either by recurrent selection or even by heterosis breeding methods like production of hybrids, synthetics and composites. However, relative magnitude of these variances indicated that additive gene effects were more prominent for most of the characters studied since the ratio of GCA:SCA were more than unity in most of the traits. Parental line L3 and L8 were good general combiner for grain yield and L1, L2, L6 and L7 are desirable for earliness. The better performing four crosses L3×L6, L3×L8, L2×L5, and L6× L8 were good specific combiners for grain yield, which could be utilized for developing high yielding hybrid varieties as well as for exploiting hybrid vigor.

Keywords: Combining Ability, Diallel, GCA, SCA

1. Introduction

Maize (*Zea mays* L.) is monoecious plant and highly cross-pollinated species, which is belongs to the tribe Maydeae of the grass family Poaceae, Genus *Zea*, Species *mays* [1]. Maize is one of the most important cereal crops in the world agricultural economy as food for a human being, feed for animals and raw materials for industrial uses. Beyond its major agricultural and economic contributions, maize has been a model species for genetics since it was the first plant to have a genetic map. Globally maize is the third most popular cereal crop after wheat and rice due to diverse use, wider adaptability, and high yielding potential and genetic diversity.

Combining ability of inbred lines is especial and powerful tool for studying and comparing the potential usefulness of an inbred line to fit in crosses with a number of inbred lines or any one of the inbred lines for revealing desirable attributes in hybrid combinations and to determine the nature of gene action [7]. Hence, the final evaluation of inbred lines can be determined by hybrid performance [2] and the value of any population depends on its potential and it's combining ability in crosses [10]. Therefore, evaluation of crosses among inbred lines is an important step towards the development of hybrid maize [3]. One of the main concerns of plant breeders is the improvement of crops through hybridization and the selection of superior parents for yield and other desirable traits. Hence, maize breeding programs designed for specific-end uses; However, the development of commercial maize hybrids for grain yield, improve quality trait and tolerant to biotic or abiotic stress usually require good knowledge of combining ability of the breeding materials to be used since it provides information for breeder to select better parent as it discloses the mode of inheritance for various plant traits and to determine the nature and magnitude of gene action involved in the inheritance of the traits.

According to Allard [4] combining ability is a measure of the value of a genotype based on the performance of their offspring produced in some definite mating system. Maize breeders have employed several biometrical techniques to study the genetic architecture of quantitative traits including grain yield. Suitable means to achieve this goal beside others is the diallel mating system, a method whereby the progeny performance can be statistically separated into components related to the general combining ability (GCA) and specific combining ability (SCA) and thus elucidating the nature of gene action [5]. Moreover, diallel analysis has been widely used as the system which not only reduces the testing time but also provides match genetic information, which is helpful in formulation of effective breeding program [6]. Numerical approach suggested by Griffing [7] has been extensively used to determine the specific combining ability (SCA) and general combining ability (GCA) of lines derived from diallel cross technique [8].

The concept of combining ability in plant breeding as a measure of gene action was introduced by Sprague and Tatum [9] and its mathematical modeling was set about by Griffing [7] in his classical paper 'in conjunction with the diallel crosses'. According to Sprague and Tatum [9] who contribute to our understanding combining ability analysis is one of the most powerful tools in identifying the best combiners that may be used in crosses either to exploit heterosis or to accumulate productive genes that enable the breeder to design effective breeding plan for future improvement of the existing materials. Therefore, this study was conducted to estimate general and specific combining ability effects of maize inbred lines for yield and yield-related traits.

2. Materials and Methods

2.1. Description of Study Area

The study was conducted at Haramaya University Research site (Raare) in 2018 cropping seasons. The study area is located at an altitude of 1980 m.a.s.l. and lies at 9° 26' N latitude and 42°3' E longitude. The area receives average annual rainfall during 2018 main cropping season was 727 mm. The minimum and maximum mean annual temperatures were 8.99°C and 25.15°C, respectively (Haramaya University Weather Station, 2018).

2.2. Experimental Materials

The planting materials were comprised of eight maize inbred lines which were crossed in 8×8 half diallel mating design to produce twenty eight F_1 hybrids. The resulting twenty eight F_1 hybrids were evaluated in 2018 main cropping seasons at Haramaya University Research Site (Raare). List of lines used in the diallel cross is depicted in Table 1.

Table 1. *List of inbred lines used in the diallel cross.*

Inbred Lines	
Code	**Pedigree**
L1	[POOL9Ac7-SR(BC2)]FS211-1SR-1-1-1-#/CML144(BC2)-14-8-4-2-2-1-#-1-B-2
L2	[KIT/SNsyn[N3/TUX]]c1F1-##(GLS=2.5)-32-1-1-#/CML176BC1F1-12-1-3-4-2-#-2-B-1
L3	[POOL9Ac7-SR(BC2)]FS211-1SR-1-1-1-#/CML144(BC2)-14-8-4-3-3-4-#-1-B-4
L4	[POOL9Ac7-SR(BC2)]FS48-1-1-1-1-1-#/CML144(BC2)-6-22-1-1-1-4-#-3-B-1
L5	[POOL9Ac7-SR(BC2)]FS211-1SR-1-1-1-#/CML144(BC2)-14-8-4-3-2-2-#-1-B-1
L6	[POOL9Ac7-SR(BC2)]FS211-1SR-1-1-1-#/CML144(BC2)-14-21-1-3-2-2-#-2-B-4
L7	[POOL9Ac7-SR(BC2)]FS59-2-2-1-1-#/CML144(BC1)F1-3-2-1-2-1-#-1-B-2
L8	[KIT/SNsyn[N3/TUX]]c1F1-##(GLS=2.5)-17-1-1-#/CML144(BC1)F1-5-1-2-1-1-#-2-B-1

Source: Haramaya university maize research program 2017.

2.3. Experimental Design and Field Management

The resulting twenty eight F_1 progenies derived from the diallel cross of eight maize inbred lines were planted using alpha-lattice designs with three replications at Haramaya University Research site (Raare) during 2018 main cropping seasons. In all cases, two rows per plots were used, where the length of each row was 5.1 m with spacing of 0.75 m between rows and 0.3 m within rows. An alley of 1.5m left between the blocks. At planting, two seeds were planted per hill to ensure enough stand, and then thinned to one plant per hill after two weeks of emergence (when seedlings were 3-4 leaf stage) to attain a population density of 44,444 plants per hectare. Urea and NPS fertilizers were applied at the rates of 140kg/ha and 118kg/ha, respectively. Urea was applied in two equal splits. The first half application was done at sowing along with NPS fertilizer and the second was applied at the knee high stage of the crop. More over all other necessary field management practices were carried out as per the recommendation for the study area and the crop.

2.4. Data Collection

Data on grain yield and other important agronomic traits were collected on plot and individual plant basis. Characters were recorded on plant basis by taking five random plants. The average was taken as the mean of the treatment.

2.4.1. Data Collected on the Plot Basis

Days to anthesis (DA): The number of days from planting up to the date when 50% of the plants started pollen shedding.

Days to silking (DS): The number of days from planting to the date when 50% of the plants produced about 2-3cm long.

Anthesis-silking interval (ASI): This was calculated as the difference between number of days to anthesis and number of days to silking (ASI = DA – DS).

Plant aspect (PA): It was recorded based on a scale of 1 to 5 where, 1 = best genotype (consider ear size, uniformity, disease infestation, husk cover) and 5 = poor genotype within each plot.

Days to physiological maturity (DM): It was recorded as the number of days after sowing to when 50% of the plants in the plot form a black layer at the point of attachment of the kernel with the cob.

Stand count at harvest (SH): It was recorded as the total number of plants at harvest from each experimental unit.

Husk cover (HC): It was recorded as on a scale of 1 to 5; where 1 = tightly covered husk extending beyond the ear tip and 5 = ear tips exposed.

Number of ears harvested (NEH): was recorded as the total number of ears harvested from each experimental unit.

Ear aspect (EA): Was recorded based on a scale of 1 to 5, where 1 = clean, uniform, large, and well filled ears and 5 = ears with undesirable features at time of harvesting from each plot.

Thousand kernel weight (TKW): After shelling, random kernels from the bulk of shelled grain in each experimental unit were taken and a thousand kernels were counted using seed counter and weighted in grams and then adjust to 12.5% grain moisture.

Grain moisture: moisture content (%) present in the grain measured at harvesting by taking a sample of ears and shelling separately for each plot using portable digital moisture tester.

Above ground biomass yield (AGB): Plants from the experimental unit were harvested at physiological maturity and weighed in kg after sun drying and converted to hectare basis.

Grain yield/plot (GY): Grain yield per plot adjusted to 12.5% moisture were recorded in kg/plot using the formula below.

$$\text{Adjusted grain yield (kg plot}^{-1}) = \frac{\text{Field of weight (kg/plot)} \times (100 - \text{MC}) \times \text{shelling\%}}{(100 - 12.5) \times \text{Area harvested (plot size)}}$$

Grain yield/ha (GY): This was obtained by converting grain yield per plot into a hectare basis.

Harvest index (HI): The harvest index was calculated by dividing grain yield (kg/ha) by aboveground biomass yield (kg/ha) and expressed in percentage [11].

2.4.2. Data Collected on Plant Basis

Ear height (EH): The height was measured from the ground level to the uppermost useful ear- bearing node of five randomly taken plants.

Plant height (PH): The height was measured from the soil surface to the tassel starts branching of five randomly taken plants.

Ear length (EL): Length of ears from the base to the tip of ear was measured in centimeters.

Ear diameter (ED): This was measured at the midsection along the ear length, as the average diameter of five randomly taken ears using a caliper.

Number of kernel rows per ear (NKRE): This was recorded as the average number of kernels row per ear from the five randomly taken ears.

Number of kernels per row (NKR): Number of kernels per row was counted and the average recorded from five randomly taken ears.

2.5. Method of Data Analysis

For the statistical analysis of variance (ANOVA) parameters like ear rot and husk covers were transformed using square root transformation, $X' = \sqrt{x+0.5}$, as most of the plots had zero values [48]. Data obtained for twenty one traits from field measurements were subjected to analysis of variance using PROC GLM procedure of SAS, version 9.0 (SAS, 2002) in order to test the significant differences among the genotypes. The trait which show significant difference were subjected to further genetic analysis of variance using AGD-R (Analysis of Genetic Designs in R), in order to estimate the effects of general combining ability and specific combining ability for genotypes evaluated under the experimental trials. Mean separation was done by using Least Significant Difference test (LSD).

Diallel Analysis of variance was conducted to estimate general combining ability (GCA) and specific combining ability (SCA) following Model I (fixed), Method IV [n (n−1)/2], which only includes one, set of crosses with neither reciprocals nor parents as suggested by Griffing [7] statistical model which is the most appropriate for obtaining unbiased estimates of combining abilities and gene action.

$$Yijk = \mu + gi + gj + sij + rk + eijk,$$

Where Yijk is the individual plant observation on cross i x j in the k^{th} replication. μ is the overall mean, gi and gj are the parental effects or general combining ability (GCA) effects of the i^{th} and the j^{th} parents; S_{ij} is the specific combining ability of i^{th} and j^{th} parents, which is the non-additives of the parental effects; rk is replication effect, and eijk is the error associated with the ijkth plant.

Significance of GCA and SCA effects were tested dividing the corresponding SCA and GCA values by their respective standard error and comparing the obtained t with tabular t-value at error degree of freedom.

Table 2. *Skeleton of ANOVA for Diallel method IV model I.*

Source	df	MS	SS	Expected mean square Model I
GCA	p-1	Mg	sg	$\alpha^2 + (p-2)(\frac{1}{p-1})\sum_i gi^2$
SCA	P(p-3)/2	Ms	ss	$\alpha^2 + \frac{2}{p(p-3)\sum ij \sum iSij^2}$
Error	m	Me	se	α^2

Source: Griffing, 1956b

3. Result and Discussion

Mean square due to general combining ability (GCA) and specific combining ability (SCA) for grain yield and yield related traits showed significant differences at (P<0.05 and/or P<0.01) for all traits studied (Table 3). This result indicated the presence of adequate genetic variability in the experimental materials under study and used to screen the importance of both additive and non-additive components of genetic variance in inheritance these traits. This enables the breeder to conduct appropriate selection of the most desirable crosses combination. Gudeta [12] and Demissew [13] in separate study suggested that both gca and sca effects are significant and important for grain yield and most other traits studied.

The analysis of variance due to mean squares for general combining ability and specific combining ability were significant for grain yield, biomass yield, days to anthesis, days to silking, plant and ear height, bad husk cover, plant aspect, ear aspect, common rust *(puccinia sorghi*), days to maturity, thousand kernel weight, kernels per row, harvest index, and Turcicum leaf blight (TLB), which indicated that both additive and non-additive gen action were important controlling such characters. The result were comparable with several studies on combining ability in maize that showed significant GCA and SCA variances, indicating the presence of additive and non- additive gene actions for yield and yield contributing traits in maize [45, 14, 15, 16, 17, 18, 19]. However, only significant sca effect were observed in ear length, ear diameter, kernel rows per ear, anthesis silking interval, which suggested that non-additive gene actions were important for inheritance of such characters in the progeny. On the other hand ear rot showed highly significant only for GCA variance that implies additive gene action is important in controlling the inheritance of this trait.

The ratio of GCA variance to SCA variance showed that grain yield, number of ear per plant, *puccinia sorghi* (common rust), ear aspect, harvest index, *turcicum* leaf blight, ear rot, thousand kernel weight, days to maturity, plant height, biomass yield and husk cover are more than a unity; therefore, additive gene action is important for controlling these traits. Wende [20] and Tamirat *et al*. [21] in separate study reported the importance of additive gene action than non-additive gene action for grain yield in maize. On the contrary, the magnitude of SCA mean squares was higher than that of GCA mean squares (the GCA/SCA ratio was less than unity) for days to anthesis, days to silking, anthesis silking interval, ear length, plant aspect, number of kernel row, number of kernel row per ear, ear diameter and ear height so, non-additive (dominance and epistasis) is more important than additive variance in controlling their inheritance, indicating that heterosis breeding is the best choice for improving these traits. A similar conclusion was reported by [22, 23]. The same author (Melkamu *et al*.[24] and Sugiharto *et al*. [25] reported that non-additive gene action to be more important than additive gene effects for all trait studied except hundred seeds weight, ear weight, and seed weight per ear.

Table 3. *Mean square due to GCA, SCA and Cross for grain yield and yield related traits of maize evaluated at Haramaya, Eastern Ethiopia.*

Source of variation	DF	Mean Square										
		GY	DA	DS	ASI	EPP	EL	PA	PS	EA	HI	ET
Rep	2	5.37	2.58	2.58	0.15	0.02	2.69	0.01	0.01	0.01	20.93*	0.03
GCA	7	10.67**	4.50**	3.77**	0.05	0.27**	6.26	0.14*	0.25**	1.68**	42.87*	0.24**
SCA	20	6.05**	12.6**	11.35**	0.15*	0.1**	10.45*	0.18**	0.07*	0.49**	40.09*	0.10*
Cross	27	6.89	10.5*	9.38*	0.12*	0.14*	9.36	0.17*	0.11*	0.8*	35.28*	0.13**
Error	46	1.67	1.02	1.19	0.07	0.02	5.44	0.05	0.03	0.08	18.99*	0.05
GCA:SCA		1.76	0.36	0.33	0.33	2.70	0.60	0.77	3.57	3.42	1.01	2.40

Table 3. *Continued.*

Source of variation	DF	Mean Square									
		ER	NKR	NKRE	ED	TKW	MD	PH	BM	EH	HC
Rep	2	0.99	1.75	0.65	0.13	3876.87	0.35	90.92*	28.58**	211.01	0.87*
GCA	7	1.00**	12.70**	2.95	0.29	13155.72**	201.13**	1402.93**	85.57**	364.58**	4.89**
SCA	20	0.3	36.14**	8.64*	0.83*	10910.78**	70.81**	1147.75**	44.63**	422.8**	1.54**
Cross	27	0.46*	30.07*	7.16	0.69	11492.80**	95.49*	1150.77*	51.90**	407.71*	2.12*
Error	46	0.21	3.96	4.43	0.42	4234.55	0.64	114.95	15.82	63.79	0.22
GCA:SCA		3.33	0.35	0.34	0.35	1.20	2.84	1.22	1.91	0.86	3.17

** = Significant at P<0.01 level of probability, * = Significant at P<0.05 Level of probability, GY= grain yield, DA = number of days to anthesis, ED = ear diameter, EH = ear height, EL = ear length, EPP =number of ear per plant, NKR = number of kernels per row, PH = plant height, NKRE = Number of kernel rows per ear, BM=Biomass yield, DS = number of days to silking, TKW = thousand kernels weight, MD=maturity date, PA=plant aspect and EA=ear aspect, HC=husk cover, ASI= anthesis silking interval, HI=harvest index, ER=ear rot, ET=*Turciccum* leaf blight and PS=*Puccinia* sorghi (rust)

3.1. Estimates of General Combining Ability (GCA) Effects

Estimates of gca effects for eight maize parental inbred lines for various traits with their respective standard errors are presented in Table 4. The estimates of gca effects showed significant difference for all traits, except number of kernel rows per ear, ear diameter, ear length, and anthesis silking interval. Adequate genetic variability is important to make selection progress in breeding programs targeting improved grain yield. Hybrids evaluated in this study manifested considerable variation that were presented and discussed for each trait as follows.

Biomass yield: Highly significant and negative gca effect for biomass yield was observed in parental lines- L1 and L4. In contrary parents, L3, L6 and L8 exhibited positive and significant gca effects for biomass yield. This indicated that the tendency of the parents to enhance high biomass yield to their progeny (Table 4). As a result high biomass yield are desirable for grain yield improvement, silage production, for construction and fuel purpose for small scal farmer.

Grain yield: among all the parental inbred lines, positive and highly significant gca effects for grain yield were observed in L3 and L8, which are high combiner for grain yield while L2 and L6 showed positive and non-significant gca effect for grain yield that considered as average combiner; therefore, parental lines (L3, L8, L2 and L6) were good general combiners to improve grain yield; Therefore, these parental lines could be used in hybrid breeding program with a view to increasing the yield level. On the other hand, L1 and L4 showed negative and highly significant gca effects for grain yield followed by L5 and L7 that exhibited negative and non-significant gca effects; Therefor, these lines were considered as poor general combiners to improve grain yield. The result were comparable with the findings of several authors [26, 27, 28, 29, 30, 36] who reported both negative and positive gca effects for grain yield.

Days to anthesis: The estimate of general combining ability for days to 50 percent anthesis was positive and significant for parents; L2 and L7, those parents indicated tendency for the lateness in their hybrid progenies. On the other hand, parental lines L3 exhibited negative and highly significant gca effects these parents might be useful in developing early hybrid variety(s) (Table 4). For days to anthesis negative estimates are considered desirable as those were observed to be associated with earliness. As a result earliness is a desirable character as it is useful in multiple cropping and increases water and land use efficiency. These results were comparable with the finding of [44, 37, 30, 36] who reported both negative and positive values for days to anthesis.

Number of kernel per row: The GCA estimates of parental line L3 revealed positive and highly significant GCA followed by L1 which showed positive and significant gca effects for number of kernel per row depicting good general combiner to improve grain yield. Conversely, parental lines L4 and L8 had negative and significant gca effects indicating, that these lines had transferred undesirable characters for number of kernel per row (table 4). These results were comparable with the finding of [38, 39, 37, 41, 30].

Table 4. *Estimates of General Combining Ability Effects (gca) for yield and yield trait of maize inbred lines evaluated at Haramaya, Eastern Ethiopia.*

Parents	HI	PA	NKR	ET	ER	BM	DA	DS	TKW	PS	GY
L1	1.95*	0.08	0.74*	0.05	-0.13	-3.48**	-0.12	-0.15	-27.90*	-0.03	-1.06**
L2	2.57**	-0.01	0.58	-0.01	0.03	-0.8	0.65**	0.51*	2.87	0.10**	0.23
L3	0.19	-0.12*	1.37**	-0.20**	0.07	3.41**	-0.96**	-0.82**	46.69**	-0.23	1.31**
L4	-1.32	0.05	-0.98*	-0.03	0.38**	-1.73*	-0.13	-0.04	-40.01**	-0.01	-0.75**
L5	-1.33	-0.03	0.1	-0.06	-0.05	-0.29	-0.18	-0.21	-1.2	-0.03	-0.39
L6	-1.63*	0.13**	-0.51	0.16**	-0.02	1.51*	0.32	0.46*	10.15	0.10**	0.18
L7	-0.22	0.02	-0.43	0.13**	0.17	-0.47	0.49*	0.46*	-9.44	0.13**	-0.19
L8	-0.22	-0.12*	-0.87*	-0.03	-0.44**	1.83*	-0.07	-0.21	18.83	-0.03	0.68*
SE(gi)	0.68	0.04	0.31	0.04	0.07	0.62	0.16	0.17	10.15	0.03	0.2

Table 4. *Continued.*

Parents	EH	PH	MD	EA	EL	NKRE	ED	EPP	HC	ASI
L1	-5.21**	0.9	-2.47**	0.09	-0.59	0.52	-0.07	-0.03	-0.45**	-0.06
L2	1.18	3.27	-2.59**	-0.30**	0.77	0.53	0.07	-0.12**	0.70**	0.00
L3	8.68**	11.64**	5.48**	-0.33**	0.36	-0.02	0.12	0.17**	0.49**	0.06
L4	-1.04	8.16**	1.80**	0.53**	-0.51	-0.31	-0.08	0.01	0.59**	0.06
L5	2.00	3.25	0.36*	0.06	0.84	0.27	0.21	-0.07*	-0.03	-0.06
L6	-5.21**	-13.22**	-1.95**	0.03	0.00	-0.52	0.00	-0.13**	-0.38**	0.06
L7	-1.87	-11.94**	-4.09**	0.23**	-0.36	-0.09	-0.10	-0.04	-0.32**	-0.06
L8	1.46	-2.07	3.41**	-0.33**	-0.51	-0.38	-0.16	0.20**	-0.61**	0.00
SE(gi)	1.25	1.67	0.12	0.04	0.36	0.33	0.1	0.02	0.07	0.04

** = Significant at P<0.01 level of probability, * = Significant at P<0.05 Level of probability, GY= grain yield, BM=biomass yield, DA = number of days to anthesis, EH = ear height, EPP =number of ear per plant, NKR = number of kernels per row, PH = plant height, DS = number of days to silking, TKW = thousand kernels weight, MD=maturity date, PA=plant aspect and EA=ear aspect, HC=husk cover, HI=harvest index, ER=ear rot, ET=*Turcicum* leaf blight and PS=*Puccinia* sorghi (rust)

Days to maturity: GCA estimates for days to maturity showed negative and highly significant gca effect for parental lines L1, L2, L6 and L7 indicated that these lines were contribute desirable allele of earliness towards their respective crosses. Accordingly, earliness is a desirable character in multiple cropping system and increases water and land use efficiency. In contrary parents, L3, L4, L5 and L8 exhibited positive and significant gca effects for days to maturity. This indicated that the tendency of these parents to enhance lateness to their progeny.

Ear Per Plant: Concerning number of ear per plant the effect of general combining ability (GCA) were positive and highly significant for parents L3 and L8, suggesting that these lines are good general combiner to improve the number of ear per plant in maize to produce highly prolific maize varieties. On the other hand parents L2, L6 and L5 showed negative highly significant gca effect, these lines are regarded as poor general combiners to improve this trait. These results were comparable with the finding of [28, 29, 31], who reported highly significant positive and negative gca effect for ear per plant in their study on combining ability and heterosis for yield.

Ear aspect: Parental lines, L2, L3 and L8 exhibited negative and highly significant gca effects, for ear aspect on the desired direction, which indicated the lines were good general combiners for good ear characters; whereas L4 and L7 showed positive and highly significant gca effects, followed by L1, L5 and L6, which showed positive and non-significant gca effect towards undesirable direction for ear aspect, which indicates poor general combining ability of the lines for the trait under study.

Thousand kernel weight: Highly significant and positive gca effect was obtained by line L3. This line could be considered as potential parent for genetic improvement of grain yield through thousand kernel weight. Contrarily, lines L4 and L1 showed negative and highly significant gca effects indicating that they are poor general combiners for thousand kernel weight (Table 4). Aminu *et al*. [42]; Gudeta *et al*. [18] and Amare *et al*. [43] also reported positive and negative significant gca effects for thousand kernel weight in their study on maize.

Days to silking: Positive and significant gca effects for days to silking were observed for parental lines L2, L6 and L7 that revealed the lateness of the genotype. Hence, these inbred lines had the tendency to increase late maturity. In contrast negative and highly significant gca effects were obtained for parent L3 that contributes towards earliness in their respective crosses. Consequently, the parents with positive and significant gca effects are considered as poor general combiners, while those with negative and significant gca effects are considered good general combiners in breeding for an early maturing variety for short rainy season and dry areas (Table 4). These results agreed with the finding of [28, 44, 29, 37, 30] and [36] who reported both negative and positive values for days to silking.

Plant height: Parental lines, L6, and L7 showed negative and highly significant gca effects, while Parental line L8 showed negative and non-significant gca effects for plant height on the desired direction as the view of the best general combiner as well as the most suitable parent in breeding that contribute desirable gene for short stature of plant and resistance to lodging. On the other hand, parental lines, L3, and L4 exhibited positive and highly significant gca effects whereas L1, L2 and L5 showed positive and non-significant gca effect for plant height towards tallness; as a result, these lines significantly contributed to taller plant stature, which causes susceptibility to lodging in their respective crosses (Table 4). Generally, in maize breeding program shorter plants are needed to reduce the lodging problems. The result in line with several researchers report [45, 37] and [30].

Ear height: Parental lines, L1 and L6 exhibited negative and highly significant gca effects, while parents L7 and L4 showed negative and non-significant gca effect on the desired direction that indicated these lines were good general combiners to improve ear placement; whereas L3 showed positive and significant gca effects, while L2, L5 and L8 showed positive and non-significant on the undesirable direction, which indicates poor general combining ability of the lines for the trait under study (Table 4). Generally, shorter plant height with medium ear placement is desirable for lodging resistance and mechanized agriculture. The result is in line with several researchers report [45, 37*]* and [30].

Plant aspect: Parental lines, L3 and L8 exhibited negative and significant gca effects followed by L2 and L5 which showed negative and non-significant gca effect for plant aspect towards the desirable direction of good plant characters; Whereas L6 showed positive and highly significant gca effects, followed by L1, L4 and L7, which showed positive and non-significant for plant aspect on the undesirable direction, which indicates these lines are poor general combiner to improve these trait. Negative or low GCA estimates for plant aspects imply that plants had a good performance such as free or less disease occurrence, uniform ear height and good grain filling.

Concerning disease reaction parental line L3 showed negative and highly significant gca effect for turccicum leaf blight, while L6 and L7 revealed positive and highly significant gca effect for turccicum leaf blight. Similarly, L3 showed negative and highly significant gca effect for rust, whereas L2, L6 and L7 revealed positive and highly significant gca effect for rust. This indicates that L3 have the potential for tolerance to TLB and common rust (*puccinia sorghi*). On the contrary, L6 and L7 contribute disease susceptible alleles in the synthesis of new hybrid varieties. On the other hand, L8 showed negative and highly significant gca effect for ear rot, while L4 revealed positive and highly significant gca effect for ear rot. Negative or low gca effects indicate that the ears were not damaged by ear rots. The reduction of ear rots infections is also important because it results in the reduction of mycotoxins in the grain making it safer for consumption [34]. On the other hand L1, L6, L7 and L8 showed negative and highly significant gca effect for husk cover, while L2, L3 and L4 revealed positive and highly significant general combiner for husk cover. Negative gca effect for husk cover are desirable for protection from bird attack, rain, ear rot and other yield loss factors. Generally inbred lines with negative and significant GCA estimation were considered as a good general combiner for disease tolerant variety development; whereas lines with positive and significant gca effects are poor general combiner that results vulnerability for disease. The results were comparable with the finding of other authors [46, 26] [29].

3.2. Estimates of Specific Combining Ability (SCA) Effects

The sca effect is an important criterion to determine the potential and effectiveness of hybrids. The estimate of specific combining ability (sca) effects of twenty-eight crosses for yield and different yield contributing characters are presented in table 5. The estimates of sca effects exhibited that there was a significant difference among crosses revealing specific combiner for all traits studied except ear rot. These results were comparable with the finding of [47] in their combining ability and heterosis study of maize who found highly significant sca effect for maturity, plant height, number of kernel rows per cob, number of kernels per cob, cob weight, and 1000 kernel weight. Hybrids evaluated in this study manifested considerable variation for specific combining ability (sca) effects in all studied yield and yield related traits except ear rot. The results were presented and discussed for each trait as follows.

Number of ear per plant: In the present study, the highest sca effects for number of ear per plant was recorded from L1×L3, L3× L6, L5×L8 and L7×L8 that revealed positive and significant sca effect for number of ear per plant, which were prolific hybrids as they showed higher number of ears per plant. Therefore, these hybrids are desirable to enhance grain yield since which is directly associated with grain yield. On the other hand, negative and significant sca effects were exhibited by L1×L5, L2×L5 and L4 × L5, indicating they were poor specific combiner for number of ear per plant (Table 5).

Ear length: Concerning ear length out of all the hybrids evaluated only one cross (L1 × L7) showed significant positive sca effects for ear length towards the desirable direction. On the contrary, L1 × L5, L3 × L5 and L6 × L7 showed significant negative sca effects indicating that these hybrids had poor specific combination for ear length. These results agreed with the finding of [32, 33, 35] who reported significant positive and negative sca effect for ear length.

Thousand kernel weight: Among the hybrids evaluated in this experiment, L3×L6 showed positive and highly significant sca effects followed by L1×L3, L1×L8, and L5× L8 which showed positive and significant sca effects for thousand kernel weight, indicating the hybrids combined well to give higher thousand kernel weight and could be selected for their high sca effect to improve the grain yield. Hybrid L1 × L5 showed negative and highly significant sca effects, followed by L1 × L2, and L4 × L5 which showed negative and significant sca effects, indicating the tendency of the hybrid to decrease the trait (Table 5). These results agreed with the finding of [32, 35] who reported highly significant positive and negative sca effect for thousand kernel weight.

Ear height: Hybrids L2 × L8, L3 × L8, L4 × L5 and L6 × L7 showed negative and highly significant sca effects, while L3 × L5, L7 × L8 showed negative and significant sca effects for lower ear height towards the desirable direction of resistance to lodging. On the other hand, L4 × L7 showed positive and highly significant sca effects, while L1 × L6, L1 × L7, L3 × L4, L5 × L8, and L6 × L8 showed positive and significant sca effects for ear height towards undesirable direction for susceptible to lodging (Table 5). These results agreed with the finding of [28, 32, 31] who reported highly significant positive and negative sca effect for ear height.

Biomass yield: With respect to biomass yield, hybrids L1×L2, L3×L6 and L3×L8 showed positive and highly significant sca effects towards the desired direction to enhance this trait whereas L1×L5, L1× L6. L3 × L7 and L4 × L5 depicted negative and significant sca effect towards undesired direction (Table 5). As a result, high biomass yield are desirable for grain yield improvement, and for different alternative uses like fencing, livestock feed, and fuel purpose.

Table 5. *Estimates of specific combining ability (sca) effects for yield and yield related trait of maize inbred lines evaluated at Haramaya, eastern Ethiopia.*

Cross	GY	EL	NKRE	PA	PS	ET	ED	HI	ASI	BY	TKW
L1×L2	0.67	-2.35	-2.47*	0.16	-0.004	-0.09	-0.44	-7.91**	-0.04	5.73**	-30.27*
L1×L3	1.01	2.26	1.69	-0.23	-0.171	-0.07	0.4	2.11	0.24	0.77	67.80*
L1×L4	-2.14**	-1.11	-0.58	0.27*	0.107	-0.07	-0.38	-4.26	-0.1	-3.81	-67.91
L1×L5	-3.32**	-2.89*	-1.34	0.13	0.33**	0.18	-0.54	-1.35	-0.15	-6.41**	-133.50**
L1×L6	-1.13	0.44	-0.9	-0.14	-0.004	0.24*	-0.1	3.59	-0.1	-4.66**	-34.37
L1×L7	0.57	2.51*	3.02**	-0.2	-0.032	-0.23*	0.96**	4.66*	0.02	-0.55	-3.05
L1×L8	1.19	1.32	1.2	-0.23	-0.032	-0.07	0.13	3.12	-0.04	1.15	70.21*
L2×L3	-0.14	1.34	0.09	0.19	0.024	-0.01	0.23	-1.76	-0.15	0.01	5.83
L2×L4	0.56	-1.19	1.29	0.02	0.135	0.15	0.23	-0.28	-0.15	1.87	22.08
L2×L5	1.38*	0.29	0.25	-0.03	-0.06	-0.15	-0.02	0.19	0.18	3.41	62.04
L2×L6	-0.32	0.97	1.9	-0.23	-0.143	-0.04	0.44	6.09**	0.52**	-3.75	7.26
L2×L7	-0.68	0.21	-0.28	-0.12	-0.004	-0.01	-0.6	-2.39	-0.04	-0.67	25.03
L2×L8	-0.38	1.47	-0.04	0.02	-0.004	-0.01	0.26	2.5	-0.1	-2.26	0.67
L3×L4	0.18	1.18	1.26	0.05	-0.17	-0.01	0.47	-1.26	-0.15	0.7	-19.99
L3×L5	-0.26	-3.34**	-2.66*	0.22	0.19*	-0.01	-1.11**	-4.58*	-0.21	2.14	2.53
L3×L6	2.66**	0.16	-1.26	-0.03	-0.198	0.18	-0.1	1.12	0.46**	6.00**	103.92**
L3×L7	-1.09	1.18	0.5	0	-0.17	-0.15	0.47	4.12	-0.1	-4.87*	-33.11
L3×L8	1.41*	-0.83	0.15	0.58	0.16	-0.01	0.2	-3.03	0.24	5.25*	40.49
L4×L5	-1.93**	1.35	1.09	0.22	0.11	0.05	0.29	2.39	-0.1	-6.01**	-85.77*

Cross	GY	EL	NKRE	PA	PS	ET	ED	HI	ASI	BY	TKW
L4×L6	0.41	1.09	-0.26	-0.28*	-0.03	-0.01	0.1	0.88	-0.21	0.68	-6.58
L4×L7	-0.93	-0.58	-0.53	-0.17	-0.06	-0.15	-0.12	-0.04	-0.1	-2.15	-27.78
L4×L8	0.29	-0.45	-0.5	-0.06	-0.004	0.02	-0.12	3.75	-0.04	-0.93	-30.61
L5×L6	-0.29	0.49	0.49	-0.2	0	-0.15	0.01	-1.7	-0.1	-0.35	10.66
L5×L7	0.37	-0.36	-1.82	-0.09	-0.03	0.21	-0.43	-1.79	0.02	1.56	49.72
L5×L8	0.6	0.76	-0.29	0.05	-0.20*	-0.29*	0.17	-1.67	0.29*	1.99	71.88*
L6×L7	-0.18	-3.07*	-1.96	0.36**	0.135	0.29*	-0.57	-1.31	0.02	1.37	-2.4
L6×L8	1.14	1.29	2.98**	-0.28*	0	-0.12	0.65**	0.33	-0.1	2.37	-13.48
L7×L8	0.35	-2.13	-1.04	0	0.13	0.35**	-0.48	-1.53	-0.04	1.43	-51.3
SE(ij)	0.63	1.14	1.03	0.11	0.09	0.11	0.32	2.13	0.13	1.94	31.75

** = Significant at P<0.01 level of probability, * = Significant at P<0.05 Level of probability, GY= grain yield, ED = ear diameter, EL = ear length, NKRE = Number of kernel rows per ear, TKW = thousand kernels weight, PA=plant aspect ASI= anthesis silking interval, HI=harvest index, ET=*tercicum* leaf blight and PS=*pusiniasorgi* (common rust)

Table 5. *Continued.*

Cross	PH	EH	EA	DS	MD	DT	EPP	HC	NKR	ER
L1×L2	0.17	3.13	-0.21	-1.63**	-3.20**	-1.73**	-0.03	0.158	0.33	-0.2
L1×L3	5.14	3.97	-0.35*	-0.63	0.38	-0.79	0.182*	-0.757**	2.14*	-0.31
L1×L4	-18.05**	-4.64	0.12	3.25**	-2.60**	3.38**	-0.08	-0.692**	-3.57**	-0.17
L1×L5	-2.39	-1.03	0.23	2.75**	-4.75**	2.83**	-0.457**	-0.604*	-0.18	0.08
L1×L6	16.66**	9.52*	0.29*	-0.58	1.82**	-0.4	-0.02	0.454	0.82	0.41
L1×L7	13.71*	9.52*	-0.24	-0.25*	2.30**	-0.23	-0.09	0.394	2.42*	0.05
L1×L8	10.51	-0.48	-0.02	-1.25	3.13**	-1.34*	0.12	0.34	1.52	0.1
L2×L3	2.64	0.91	0.37*	1.03	0.88*	1.10*	-0.1	0.551*	-4.10**	-0.19
L2×L4	-5.55	-4.37	0.17	-1.08	-0.43	-1.06*	0.07	0.979**	1.72	0.29
L2×L5	9.19	3.69	-0.46**	-2.36**	0.89*	-2.67**	-0.189*	-0.469	-0.43	-0.22
L2×L6	5.83	6.47	-0.16	0.42	0.99*	-0.17	0.06	-0.729**	1.38	0.05
L2×L7	9.55	3.13	-0.19	0.09	2.80**	-0.01	0.002	-0.016	0.9	0.27
L2×L8	-15.32**	-13.53**	0.37*	2.42**	0.29	3.21**	-0.01	-0.623*	-0.79	-0.19
L3×L4	20.26**	9.52*	0.04	-1.19*	3.65**	-1.12*	0.07	1.233*	-0.03	0.64
L3×L5	-14.22*	-9.36*	-0.30*	-1.25*	0.68	-1.23**	-0.11	-0.523*	0.59	-0.41
L3×L6	0.73	-3.53	0.2	-0.75	-1.58**	-1.12*	0.440**	1.531**	-0.27	0.48
L3×L7	-4.19	-1.03	0.01	-0.91	4.75**	-0.73	-0.06	-0.720**	0.98	-0.04
L3×L8	-43.21**	-27.14**	0.98**	3.48**	-16.52**	3.33**	-0.03	-0.019	-10.41**	-0.01
L4×L5	-22.56**	-15.20**	0.65**	3.31**	-2.68**	3.44**	-0.202*	-0.655**	-4.41**	-0.07
L4×L6	6.41	7.02	-0.49**	-1.02	-0.37	-0.73	0.03	-0.492*	3.87**	-0.38
L4×L7	29.83**	17.02**	-0.19	-1.36*	2.71**	-1.23*	-0.06	-0.202	3.10**	0.06
L4×L8	2.69	4.25	-0.35*	-1.25**	-1.32**	-1.34*	0.001	-0.32	0.57	-0.03
L5×L6	8.27	3.97	-0.35*	0.14	5.69**	0.33	-0.003	0.077	3.79**	-0.3
L5×L7	21.99**	7.3	-0.21	-1.86**	3.84**	-1.84**	-0.03	0.357	2.98**	-0.02
L5×L8	5.45	10.63*	0.01	-1.19*	-3.33**	-1.62**	0.210**	-0.084	-0.11	-0.1
L6×L7	-28.14**	-21.03**	0.43**	1.09	-1.82**	1.10*	-0.09	0.103	-3.66**	0.13
L6×L8	12.29*	10.08*	-0.16	-0.25	3.70**	-0.06	0.11	0.523*	0.84	0.39
L7×L8	-27.69**	-8.81*	-0.16	0.81	0.12	0.71	0.258**	0.207	0.03	-0.31
SE(ij)	5.23	3.9	0.14	0.53	0.39	0.49	0.07	0.23	0.97	0.22

** = Significant at P<0.01 level of probability, * = Significant at P<0.05 Level of probability, DA = number of days to anthesis, EH = ear height, EPP =number of ear per plant, NKR = number of kernels per row, PH = plant height, DS = number of days to silking, MD=maturity date EA=ear aspect, HC=husk cover, ER=ear rot,

Ear length: Concerning ear length out of all the hybrids evaluated only one cross (L1 × L7) showed significant positive sca effects for ear length. These hybrids are good specific combiner to enhance grain yield. On the contrary, L1 × L5, L3 × L5 and L6 × L7 showed significant negative sca effects indicating that these hybrids are poor specific combiner for ear length. These results agreed with the finding of [32, 33, 35] who reported significant positive and negative sca effect for ear length.

Days to anthesis: For days to anthesis, hybrids L1×L2, L2×L5, L3×L5, L5×L7, and L5×L8 revealed negative and highly significant sca effects while L1×L8, L2×L4, L3×L4, L3×L6, L4×L7 and L4×L8, showed negative and significant sca effects, towards the desired direction of earliness. Conversely, the cross L1×L4, L1×L5, L2×L8, L3×L8, and L4×L5 exhibited positive and highly significant sca effect, while L2×L3 and L6×L7 showed positive and significant sca effect towards undesirable direction of lateness. Consequently those crosses with negative sca for days to anthesis exhibit a tendency to enhance early maturity whereas crosses that had positive sca effects had a tendency to enhance late maturity towards undesirable direction (Table 5). The result is in agreement with the finding of [28, 32, 31, 36] who report highly significant positive and negative sca effect for days to anthesis in combining ability study of early maturing maize. Similar author Dagne *et al.* [40] found significant differences for SCA mean squares for days to anthesis in the study made with a factorial cross among six locally developed lines and seven CIMMYT inbred lines.

Days to silking; For days to silking, hybrids L1 × L2, L2 × L5, L4 × L8, and L5 × L7 revealed negative and highly significant sca effects followed by L1 × L7, L3 × L4, L3 × L5, L4 × L7 and L5 × L8 which showed negative and significant sca effects, which are considered desirable as those were observed to be associated with earliness. In contrast, the cross L1 × L4, L1 × L5, L2 × L8, L3 × L8 and L4 × L5 exhibited positive and highly significant sca effect towards undesirable direction of lateness. As a result, those crosses with high sca effects had a tendency to enhance late maturity, while crosses that had lower sca effect regarded as a tendency to enhance early maturity (Table 5). These results were comparable with the finding of [44, 29, 37, 27, 32, 30, 31, 36] who report highly significant positive and negative sca effect for days to silking.

Number of kernel per row: With respect to number of kernel per row, hybrids L4 × L6, L4 × L7, L5 × L6 and L5 × L7 showed positive and highly significant sca effects, whereas L1×L3 and L1× L7 depicted positive and significant sca effect for number of kernel per row, indicating the tendency of the hybrids to enhance grain yield. On the other hand L1 × L4, L2×L3, L3×L8, L4×L5, and L6×L7 showed negative and significant sca effects, indicating the tendency of the hybrids combinations to decrease the trait (Table 5). These results were comparable with the finding of [39, 37, 32, 35] who reported significantly positive and negative sca effect for number of kernel per row.

Days to maturity: Hybrids, L1 × L2, L1 × L4, L1 × L5, L3×L6, L3×L8, L4×L5, L4×L6, L4×L8, L5×L8, and L6×L7 showed negative and highly significant sca effects for days to maturity, which are considered desirable as those were observed to be associated with earliness; Hence, earliness is a desirable character as it is useful in multiple cropping system and increases water and land use efficiency. On the contrary the cross L1×L6, L1×L7, L1×L8, L2×L7, L3×L4, L3×L7, L4×L7, L5×L6, L5×L7 and L6×L8 showed positive and highly significant sca effect for days to maturity followed by L2×L3, L2×L5 and L2×L6 which revealed positive and significant sca effect to undesirable direction of lateness (Table 5). These results agreed with those reported by [29, 32, 36] who reported highly significant positive and negative sca effect for days to maturity.

Plant height: Hybrids, L1 × L6, L3×L4, L4 × L7, and L5×L7 exhibited positive and highly significant sca effects, while L1 × L7, L6 × L8, exhibited positive and significant sca effects for plant height towards undesirable direction of tallness as contributes to susceptibility to lodging. In contrast, hybrids L1 × L4, L2 × L8, L3×L8, L4×L5, L6×L7, L7×L8 and L3×L5 showed negative and highly significant sca effects for plant height towards the desirable direction of shortness, which indicated that this hybrid were good specific combiner for plant height. As a result, these short-statured hybrid plants are desirable to reduce stem lodging problems in maize and for ease of mechanized operations (Table 5). These results were comparable with the finding of [27, 28, 32, 31, 33] who report highly significant positive and negative sca effect for plant height. The same author (Dagne *et al.* [40] found significant differences for SCA mean squares for plant height in the study made with a factorial cross among six locally developed lines and seven CIMMYT inbred lines.

Ear diameter: Hybrid L1 × L7 showed positive and highly significant sca effect followed by L6 × L8 which showed positive and significant sca effect for ear diameter towards the desirable direction for larger ear diameter to improve grain yield; conversely, hybrid L3 × L5 depicted negative and significant sca effects towards undesirable direction (Table 5). These results agreed with the finding of [32] who reported highly significant positive and negative sca effect for ear diameter.

Number of kernel rows per ear: Number of kernel row per ears showed positive and highly significant sca effects for hybrids L1 × L7 and L6 × L8 indicating the tendency of the hybrids to enhance the trait as they are directly correlated with grain yield. Whereas, crosses L1 × L2 and L3×L5 showed negative and significant sca effects towards undesirable direction (Table 5). These results agreed with the finding of [32, 35] who reported significant positive and negative sca effect for number of kernel rows per ear.

Grain yield: In the present study, the highest sca effects for grain yield was recorded from L3 × L6, L3 × L8, and L2 × L5 that revealed positive and significant sca effect for grain yield indicated that these hybrids were good specific combiner for the development of high yielding hybrids to enhance grain yield. Therefore it could be better to convert single crosses identified to three-way crosses or double cross to enhance grain yield. On the other hand, negative and significant sca effects were exhibited by L1 × L4, L1 × L5 and L4 × L5, indicating they were poor specific combiner for grain yield (Table 5). Generally, the hybrids with positive and significant sca effect were selected for their desirable character to improve the productivity of maize grain yield by exploiting maximum heterosis. On the contrary, crosses with negative SCA values are undesirable for grain yield. However, good specific combiners were not necessarily found from the two good general combiner crosses. These results were comparable with the finding of [28, 29, 19, 32, 33] who reported highly significant positive and negative sca effect for grain yield. Similarly Dagne *et al*. [40] found significant differences for SCA mean squares for grain yield in the study made with a factorial cross among six locally developed lines and seven CIMMYT inbred lines.

4. Summery and Conclusion

Mean square due to specific combining ability and general combining ability was significant for grain yield, biomass yield, days to anthesis, days to silking, plant and ear height, husk cover, plant aspect, ear aspect, common rust *(Puccinia sorghi*), days to maturity, thousand kernel weight, kernels per row, harvest index, and *Turccicum* leaf blight (TLB), which indicated that this trait were governed by both additive and non-additive type of gen action. But additive type of gene action had preponderance to control grain yield, number of ear per plant, plant aspect, ear aspect, rust, harvest index, *turcicum* leaf blight, ear rot, thousand kernel weight, days to maturity, plant height, biomass yield, husk cover since GCA/SCA ratio was greater than unity.

General combining ability effects suggested that the parents L3 and L8 were good general combiners for grain yield, followed by L2 and L6. Inbred lines L6 and L7, and L1 and L6 were good general combiner for plant height and ear height, respectively. These lines could be selected for their good traits for further exploitation in the breeding program. Parental line L3, L6, and L8 were good general combiners for biomass yield indicating that these lines had the tendency to increase biomass yield. Inbred line L3 was the best general combiners for days to anthesis and silking, and resistance for rust and *Turccicum* leaf blight. Thus, it could be used to develop early maturing and disease resistance varieties. Inbred lines L3 and L8, L1 and L3, and L3 were the good general combiners for number of ears per plant, number of kernels per row and thousand kernel weight, respectively. This indicated that these lines had favorable allele to improve number of ear per plant, number of kernel per row and thousand kernel weight to enhance grain yield.

Parental lines L1, L2, L6 and L7 were good general combiners for days to maturity indicating these lines have favorable allele frequency for earliness and could be used to develop early maturing varieties. Inbred lines L3, and L8, L2, L3, and L8 were good general combiners for plant aspect and ear aspect, respectively. These lines contribute favorable allele to improve desirable characters such as uniform, clean, nonlodge and disease free; therefore, it could be promoted to the next stage of evaluation in accordance with yielding ability. For husk cover, L2, L3 and L4 were the top general combiners as such these lines had the tendency to develop good husk cover to protect the ear from bird, ear rot and field infestation by weevil before harvest.

Estimates of sca effects indicated that many cross combinations had significant sca effects for all trait studied except ear rot. Among all only three crosses (L2×L5, L3×L6 and L3×L8) exhibited significant positive sca effects for grain yield. The cross L1×L7, showed high sca effect for kernel yield, whereas the crosses L1×L3 L1×L8, L3×L6, L5×L8 showed high sca effect for thousand kernel weight and L5×L8 showed high sca effect for disease reaction such as rust and *Turccicum* leaf blight. Therefore, these potential hybrids identified through this investigation could be promoted to three-way crosses or double cross by selecting other good inbred lines as the third parent to improve the productivity the crop.

Generally, these crosses involved high x high, high x average, and average x low gca effects point out the role of interaction between additive x additive or additive x non additive gene interactions. The crosses with high sca effect for grain yield, L3 × L6 evolved from high x average general combiner parents were reveled additive x dominance type of gene action. For same trait, L3 × L8 involved high x high combiner's parents depicting additive x additive types of gene action. The hybrids L2× L5 evolved from average x low general combiner parent's revealed additive x dominance type of gene action.

References

[1] Piperno, D. R. and Flannery, K. V. 2001. The earliest archaeological maize (*Zea mays* L.) from highland Mexico: new accelerator mass spectrometry dates and their implications. *Proceedings of National Academy of Sciences*, 98: 2101-2103.

[2] Hallauer, A. R., and J. B. Miranda. 1988. *Quantitative genetics in maize breeding. 2nd ed*. Iowa State University Press, Iowa, Ames.

[3] Hallauer, A. R. 1990. Methods used in developing maize inbreds. *Maydica*, 35: 1–16.

[4] Allard R. W. 1960. *Principles of Plant Breeding 1st Edition*. John Wiley and Sons, Inc., New York.

[5] Kempthorne, O. 1957. An Introduction to Genetic Statistics. New York: John Wiley & Sons, Inc. London: Chapman & Hall Ltd. pp. 458-471.

[6] Chukwu, S. C., E. O. Okporie, G. C. Onyishi, L. G. Ekwu, A. C. Nwogbaga and N. V. Ede. 2016. Application of diallel analyses in crop improvement. *Agric. Biol. J. N. Am*., 7 (2): 95-106.

[7] Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing system. *Australian Journal of Biological Science*, 9: 463-493.

[8] Moneam, M. A. A., M. S. Sultan, S. E. Sadek and M. S. Shalof. 2015. Combining abilities for yield and yield components in diallel crosses of six new yellow maize inbred lines. *International Journal of Plant Breeding and Genetics*, 9 (2): 86-94.

[9] Sprague G, Tatum L. 1942. General versus specific combining ability in single crosses of corn. *Journal of the American Society of Agronomy*, 34: 923-932.

[10] Vacaro, E., Fernandex, J., Neto, B., Pegoraro, D. G., Nuss, C. N and Conceicao, L. H. 2002. Combining ability of twelve maize populations. *Pesuisa Gropecuria Brasilerira*, 37: 67-72.

[11] Donald, C. M. 1962. In search of yield. *Journal of Australian Institute of Agricultural Sciences*, 28: 171-178.

[12] Gudeta Napir. 2007. Heterosis and combining abilities in QPM versions of early generation highland maize (*Zea mays* L.) inbred lines. MSc. Thesis, Haramaya University, Haramaya, Ethiopia.

[13] Demissew. A. 2014. Genetic diversity and combining ability of selected quality protein maize (QPM) inbred lines adapted to the highland agro-ecology of Ethiopia. A thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy (PhD) in Plant Breeding, School of Agricultural, Earth and Environmental Sciences College of Agriculture, Engineering and Science University of KwaZulu-Natal Republic of South Africa Pp. 45-47.

[14] Mandefro Nigussie. 1998. Heterosis, combining ability and correlation in 8 x 8 diallel crosses of drought tolerant Maize (*Zea mays* L.) populations. M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.

[15] Habtamu Zelleke, 2000. Combining ability for yield and other agronomic characters in inbred lines of maize (*Zea mays* L.). 60 (1): 63-70.

[16] Dagne Wegary, Habtamu Zelleke, Temam Hussien, M. T. Labuschagne and H. Singh. 2007. Heterosis and combining ability for grain yield and its components in selected maize inbred lines. *South African Journal of Plant and Soil*, 24 (3): 133-137.

[17] Bello, O. B and Olaoye, G. 2009. Combining ability for maize grain yield and other agronomic characters in a typical southern guinea savanna ecology of Nigeria. *Afri. Journal Biotechnol*. 8: 2518-2522.

[18] Gudeta Napir, Dagne Wogari and Habtamu Zeleke. 2015. Heterosis and combining ability of highland quality protein maize inbred lines. *Maydica Electron Publication* 60.

[19] Hailegebrial, K., Getachew, A., Legesse, W. and Yemane, T. 2015. Correlation and Path Coefficient Analysis of Grain Yield and Yield Related Traits in Maize (*Zea mays* L.) Hybrids, at Bako, Ethiopia. *Journal of Biology, Agriculture and Healthcare*, 5 (15): 3195-3208.

[20] Wende, A. 2013. Heterosis and combining ability of elite maize inbred lines for grain yield potential and reaction to Northern Corn Leaf Blight in the mid-altitude sub-humid agro ecologies. A thesis of Doctor of Philosophy (PhD) in Plant Breeding. University of Kwa Zulu- Natal Republic of South Africa. pp. 123-152.

[21] Tamirat Tessema, SentayehuAlamerew, DagneWegary and TemesgenMenamo. 2014. 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.

[22] Mostafa, M. A. N.; Abd-Elaziz, A. A.; Mahgoub, G. H. A. and El-Sherbiney, H. Y. S. 1996. Diallel analysis of grain yield and natural resistance to late wilt disease in newly developed inbred lines of maize. Bull. Fac. Agric., Cairo University, 47: 393-404.

[23] Singh, P. K. and J. P. Shahi. 2010. Genetic analysis in maize (Zea mays L.). *International Journal of Plant Sciences* 5 (1): 302-305.

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

[25] Sugiharto, A. N., Nugraha, A. A., Waluyo, A., Ardiarini, N. R. 2018. 'Assessment of combining ability and performance in corn For grain yield and yield components', *Journal by Innovative Scientific Information & Services Network*, 15 (2): 1225–1236.

[26] Lilian Gichuru, Kiarie Njoroge, Jane Ininda, and Lorroki Peter. 2011 combining ability of grain yield and agronomic traits in diverse maize lines with maize streak virus resistance for Eastern Africa region.

[27] Mhike X, Lungu, D M and Vivek B. 2011. Combining ability studies amongst AREX and CIMMYT maize (Zea mays L.) inbred lines under stress and non stress conditions. *African Journal of Agricultural Research*, 6 (8): 1952–1957.

[28] Amiruzzaman M., Islam M. A., Hasan L., Kadir M., Rohman M. M. 2013. Heterosis and combining ability in a diallel among elite inbred lines of maize (*Zea mays* L.). *Emirates Journal of Food and Agriculture*, 25 (2): 132-137.

[29] Girma, C. Hosana, Sentayehu Alamerew, B. T. & T. M. 2015. Test Cross Performance and Combining Ability, 15 (4).

[30] Yazachew Genet, Pangirayi Tongoona and Beatrice Ifie. 2017. General and Specific Combining Ability Studies of Selected Tropical White Maize Inbred Lines for Yield and Yield Related Traits. *International Journal of Agricultural Science and Research*, 7 (2): 381-396.

[31] Tolera Keno, Mosisa Worku and Habtamu Zeleke. 2017. 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.

[32] Mieso Keweti Shengu, Dagne Wegary Gissa, Habtamu Zelleke and Lealem Tilahun. 2016. Combining ability analysis of early maturing maize (Zea *mays. L*) inbred lines in central rift valley of Ethiopia. *International Journal of Scientific and Research Publications*, 6 (8): 551-563.

[33] Matin, M. Q. I., Rasul, M. G., Islam, A., Mian, M. K., Ivy, N. A., & Ahmed, J. U. 2017. Combining Ability and Heterosis in Maize (*Zea mays* L.). *American Journal of Biological Science, 4* (6): 84-90.

[34] Munkvold GP, Osweiler G and Hartwig N. 1997. Corn Ear Rots, Storage Molds, Mycotoxins, and Animal Health Corn EarRots, Storage Molds, Extension and Outreach Publications, 24: 4–1997.

[35] Sandesh, G. M. Karthikeyan, A. Kavithamani, D. Thangaraj, K. Ganesan, K. N. Ravikesavan and Senthil N. 2018. Heterosis and combining ability studies for yield and its component traits in Maize (*Zea mays* L.). *Electronic Journal of Plant Breeding*, 9 (3): 1012-1023.

[36] Gemechu Nedi, Leta Tulu, Sentayehu Alamerew and Dagne Wakgery. 2018. 'Combining ability of selected maize (*Zea mays* L.) inbred lines for major diseases, grain yield and selected agronomic traits evaluated at Melko, South West Oromia region, Ethiopia'. *African Journal of Agricultural Research*, 13 (38): 1998–2005.

[37] Hosana GC, Alamerew S, Tadesse B. and Menamo T. 2015. Test cross performance and combining ability of maize (*Zea mays* L.) inbred lines at Bako, Western Ethiopia. Global Journal INC. (USA), 15 (4).

[38] Al-falahy MAH. 2015. Estimation combining ability, Heterosis and some genetic parameters across four environments using full diallel cross method. *International Journal of Pure and Applied Seciences and Technology*, 26 (1): 34–44.

[39] Divan R, Khorasani SK, Ebrahimi A and Bakhtiari S. 2013. Study on Combining Ability and Gene Effects in inbred lines and single Cross hybrids of Forage maize (*Zea mays* L.). *International Journal of Agronomy and Plant Production*, 4 (6): 1290–1297.

[40] Dagne Wegary, B. S. Vivek, Birhanu Tadesse, Koste Abdissa, Mosisa Worku and Legesse Wolde, 2010. Combining abilitiy and Heterotic Relationship between CIMMYT and Ethiopian Maize Inbred lines. *Ethiopian Journal of Agricultural Science.* 20, 82-93.

[41] Pavan R., Prakash G and Mallikarjuna NM. 2016. General and specific combining ability studies in single cross hybrids of maize (*Zea mays* L.). *Current Biotica*, 5: 196–208.

[42] Aminu, D., Mohammed, S. G., Kabir, B. G. 2014. Estimates of combining ability and heterosis for yield and yield traits in maize population (*Zea mays* L.): under drought conditions in the Northern Guinea and Sudan Savanna zones of Bornostate, *Nigeria. IJAIR*, 2 (5): 824-830.

[43] Amare Seyoum, Dagne Wegary and Sentayehu Alamerew. 2016. Combining ability of elite highland maize (*Zea mays* L.) inbred lines at Jimma Dedo, South West Ethiopia. *Advances in Crop Science and Technology,* 4: 212.

[44] Shushay Wolderufael, Habtamu Zeleke and Dagne Wagary. 2013. Line x tester analysis of maize inbred lines for grain yield and yield related traits. *Asian Journal of Plant Science and Research*, 3 (5): 12–19.

[45] Legesse Wolde., K. V. Pixely and A. M. Botha. 2009. Combining and heterotic grouping of highland transition maize inbred lines. *Maydica*, 54 (2009): 1–9.

[46] Berhanu T. 2009. Heterosis and Combining Ability for Yield, Yield Related Parameters and Stover Quality Traits for Food-Feed in maize (*Zea Mays* L.) adapted to the mid-altitude agro-ecology of Ethiopia. MSc Thesis, Haramaya University, Haramaya, Ethiopia, pp 89-152.

[47] Ali Abdikadir Hassan, Abubakar Ali Jama, Omar Hassan Mohamed, Bhabendra Kumar Biswas. 2019. Study on Combining Ability and Heterosis in Maize (*Zea mays* L.) Using Partial Diallel Analysis. *International Journal of plant breeding and crop science*, 6 (2): 520-526.

[48] Gomez, A. K. and A. A. Gomez. 1984. *Statistical Procedures for Agricultural Research*, 2nd edition. John and Sons Inc., Institute of Science publication, New York.