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# Genetic Analysis and Hybrid Performance for Yield and Yield Related Traits in Diallel Crosses of Mid-Altitude Maize (*Zea mays L.*) Inbred Lines

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**ABSTRACT**

**This study was initiated with the objectives of estimating combing ability and hybrid performance of selected conventional maize inbred lines. Ten elite inbred lines were selected based on over per se performances. The crosses were done in a 10 x 10 half-diallel mating design to produce 45 $f_1$ single crosses hybrids during 2016. The experiment was conducted at bako national maize research center in 2017 main season by using alpha lattice design. The traits which were studied showed highly significant genotypic differences in all traits, indicating the existence of genetic diversities among genotypes. Genetic analysis showed; significant mean squares due to gca for all traits under the study and sca for most traits was observed. The inbred lines l4 and l5 were good general combiners for grain yield. Crosses l1 x l4 and l7 x l9 for grain, l1 x l4, l1 x l5 and l7x l9 for 1000 kernel weight, l1 x l10 and l2x l8 for shelling percentage exhibited significant sca effects in desired direction.**

***Keywords-*** General combining ability, specific combining ability, diallel mating, grain yield.

## I. INTRODUCTION

Maize (*Zea mays* L, 2n = 20) is one of the three most important cereal crops widely grown throughout the world. The world maize production area was around 196.08 million hectares, and that of wheat and rice was 220.83 million and 163.00 million hectares, respectively [1]. In Ethiopia, among cereals, maize ranks second to teff in area coverage (20.89% maize: 29.53% teff) and first in total production (30.91%maize: 19.78% for Teff) [2]. Despite a remarkable increase in maize yield starting from late 1990s, maize yield is still low relative to that of the developed countries and world average. According to [1] for example, the national average grain yield for USA, Canada, Turkey, Argentina, Egypt, and world average was 10.21 ton ha$^{-1}$, 10.21 ton ha$^{-1}$, 11.42 ton ha$^{-1}$, 8.06 ton ha$^{-1}$, 8.00 ton ha$^{-1}$ and 5.93 ton ha$^{-1}$ respectively. In Ethiopia maize is becoming increasingly important in terms of production and area coverage. In 2019/20 main cropping season, maize was cultivated on 2.3 million hectares from which 8.5 million tons of maize grain was produced [1]. Maize has a significant importance in the food security and diets of rural Ethiopia and gradually penetrated into urban centers. This is particularly evidenced by green maize being sold at road sides throughout the country as a hunger-breaking food available during the months of February to May annually [3].

The demand for maize in Ethiopia is increasing from time to time due to the high food demand associated with increased human population. From [4]to [2], the population of Ethiopia increased from 90.08 million to 103.9 million people out of which maize growers increased from 7.49 million to 10.86 million at house hold level. On the other hand, maize production is in the country is highly constrained by the existing and emerging biotic and abiotic stresses aggravated by the prevailing climate change, soil degradation and loss of arable lands as well as fast growing human population. Thus, the development and release of a greater number of higher potential stress tolerant maize varieties is very important to help cope with these challenges. Development of commercial maize hybrids usually requires good knowledge of combining ability of the breeding materials to be used [5]. For this reason, inbred lines should be evaluated for general combining ability (GCA) and specific combining ability (SCA) [6]. Information on combing ability of maize germplasm is essential in maximizing the effectiveness of hybrid development. Diallel crossing is one of the mating schemes employed to study the combining ability of inbred lines Diallel crossing scheme have been applied to provide a systematic approach for the detection of suitable parents and crosses for different characters. In addition, diallel analysis gives plant breeders the opportunity to choose the efficient selection method by allowing them to estimate several genetic parameters [7].

In maize, heterosis and combining ability for grain yield were studied by several workers [5]; [8].Combining ability analysis and generation of genetic information in breeding materials is a necessary routine breeding activity at initial stage of hybrid variety development provide reliable estimates of genetic components, and gene action governing a complex trait [9] and thereby help in selecting inbred lines with good combining ability. Combining ability analysis is very useful and efficient procedure if properly conducted and the results are properly interpreted to be able to discard lines with poor combining abilities and promote only good lines for further use in subsequent cycles of selection [10]. Therefore, this study was initiated to support the maize hybrids breeding program of the mid-altitude maize breeding with the following objectives: -

- To estimate GCA and SCA effects a set newly developed mid-altitude maize inbred lines for grain yield and related traits
- To identify the best performing hybrid with excellent parental lines for possible release

***Combining Ability***

The concepts of general and specific combining ability were introduced by [11]. Combining ability is defined as the performance of parents in hybrid combination [12]. The combining ability of inbred lines is critical and determines their potential value in hybrid or synthetic variety development to enhance yield and stress tolerance. In maize hybrid programs the GCA and SCA effects are important indicators of the potential value of inbred lines and hybrids, respectively [13]. General combing ability of an inbred line is the average contribution that the inbred line makes to the hybrid performance in a series of hybrid combinations in comparison to that of other inbred lines in the same series of hybrid combinations. It indicates the additive gene action affecting a genetic trait in such a way that each enhances the expression of the trait. Whereas SCA shows the situations in which the performance of a hybrid is relatively better or worse than would be expected on the average performances (i.e., GCA) of the parents involved [14].

Estimates of the variances due to GCA and SCA provide an appropriate diagnosis of the main role of additive or non-additive gene action. Ratio of additive to non-additive gene action is considered in order to decide which kind of genetic variation predominates for a given character. If the ratio of additive to non- additive gene action is more than unity, it indicates the major role of additive variance in controlling the expression of a character, whereas less than unity indicates the importance of non-additive variance [15].

One of the concerns of plant breeders in the improvement of maize crop through hybridization is the choice of superior parents for yield and other desirable traits. The GCA helps to evaluate the contribution of an inbred line to the hybrid performance and population improvement whereas SCA is utilized to identify cross combination with superior performance [16]; [17]. Combining ability enhances cross breeding by enabling the preliminary selection of inbred lines that perform well in crosses ultimately an entire population of high performing hybrids can be generated [18].

Various studies were conducted and estimated combining ability in maize using commercial or newly developed inbred lines. [19] studied the combining ability in an 8 x 8 diallel crosses of early and drought tolerant maize populations, and observed significant mean square due to GCA in all traits measured. Mean square due to SCA was also significant for days to tasseling, days to silking, plant height, ear height and grain yield implying that both additive and non-additive types of gene actions govern these traits. [20] estimated the combing ability of tropical mid-altitude inbred lines, some of which are used in Ethiopia, under low and optimum Nitrogen conditions in mid-altitude areas of eastern and southern Africa. The authors reported that the contribution of GCA to total genetic variation was higher than SCA for secondary traits under both conditions. However, they noticed a higher contribution of SCA than GCA for grain yield under low nitrogen conditions.

[21] studied ninety-six hybrids generated using 24 inbred lines through a design II mating scheme, and found that both GCA and SCA were significant ($P < 0.001$) with GCA accounting for more than 70% of the variation for GLS score, Days to silking, plant height, ear height, ear aspect, and ear rot; 68% for grain yield; and 60% for plant aspect (visual phenotypic appearance) score. [22] studied an 8 x 8 diallel crosses of selected maize inbred lines for grain yield and GLS reaction and he observed significant GCA and SCA effects for all traits. He found that both additive and non-additive gene actions were involved in the control of the traits he studied. However, the magnitudes of mean squares due to GCA were higher than that of SCA for all traits except grain yield showed that additive gene action contributed more to genetic variability of these traits than the non-additive one.

[23] studied combining ability of conventional (non QPM) highland maize inbred lines, crosses were made from five lines and three testers using line by tester mating scheme. In the combined analysis of variance, mean squares due to GCA of lines, testers and SCA of crosses were significant for ear height, ear length and grain yield. He concluded that the magnitude of mean squares due to GCA of lines was higher than that of the SCA in yield and other agronomic traits, indicating that additive gene actions were more important than non-additive gene action in controlling the inheritance of the traits studied.

[24] Also reported that mean squares due to GCA and SCA were also significant ($P < 0.01$ or $P < 0.05$) for all the traits studied except GCA of lines for days of maturity, TLB and grain yield, GCA of testers for HI and SCA of line by testers for days of maturity and CLR, which had insignificant mean squares. This indicated that both additive and non-additive gene effects were involved in the control of most of the traits. However, the proportion of GCA sum of squares was higher than that of SCA for all traits. [25] reported that mean squares of general (GCA) and specific (SCA) combining abilities and their interactions with locations for the studied traits. General (GCA) and specific (SCA) combining abilities were highly significant for all traits, indicating that, additive and non-additive gene actions

were important in controlling the studied traits. [13] studied eighteen selected inbred lines using factorial mating scheme and formed hybrids developed to determine combining ability effects, he conclude that the significance of the mean squares of the GCA effects of females and males and the SCA effects of F x M indicated the importance of both additive and non-additive gene effects, respectively.

[26] Studied the Performance and Combining Ability of twenty-five inbred lines and two tester using line by tester cross mating design. He indicated GCA of line was significant for grain yield, agronomic traits and disease severity index and the mean square due to SCA for line by tester combinations were also significant for grain yield, stalk lodging, root lodging, ear rot, husk cover, maturity date, days to 50% silking and Turcicum leaf blight. He concluded that significant GCA and SCA effects were indicative of the importance of additive and non- additive gene effects in the control of the traits. However, in all traits, the proportion of GCA sum of square was higher than SCA sum of squares indicating the preponderance of additive gene effects in the control of all traits.

[27] studied heterosis and Combining ability analysis for grain yield and yield component traits in 8×8 diallel cross and reported the mean squares due to GCA for days to maturity, ear diameter, member of kernels per row, 1000 kernel weight and grain yield were significant, indicating the importance of additive genetic variance in controlling these traits. The mean squares due to SCA were also significant for days to maturity, ear length, number of kernels per row and 1000 kernel weight indicating the importance of non-additive genetic variance in controlling these traits.

***Diallel Mating Design***

There are various mating designs depending on the objectives of breeders [28]. Gene action can be estimated using various mating designs. Mating designs are methods used to produce progenies in breeding programs [29]. They enable breeders to estimate genetic variances and combining abilities. Diallel mating design has utility as a method to analyze crosses or parents with crosses for general combining ability (GCA) due to additive type of gene action and specific combining ability (SCA) due to non-additive gene action [30]. The method of diallel crosses has been widely used in genetic research to investigate the inheritance of important traits among a set of genotypes. This design provides information about the components of genetic control, helps the breeder in the selection of desirable parents for crossing programs, and in deciding a suitable breeding procedure for genetic improvement of various quantitative traits. In addition, diallel mating designs are suitable for cross pollinated crops like maize for which GCA and SCA and their interaction with environment are taken care of [30]; [31].

The significant contribution of GCA and SCA is then interpreted for breeding purpose. If GCA is significant, it means additive gene effect is important and thus selection could improve the germplasm. If SCA is significant then, dominance gene effect is important and thus hybrid vigor could be achieved in crosses among inbred lines.

If GCA and SCA are both significant, GCA/SCA ratio is used for interpretation [32]. In this case, If the ratio = 1, then both equally important and if the ratio >1 then additive gene action is more important than dominance gene effects. A relatively larger GCA/SCA variance ratio demonstrates the importance of additive genetic effects and the lower ratio indicates predominance of dominance and/or epistatic gene effects [33]. Depending on the type of parents used for crosses, fixed or random models are used for analysis. If parents are selected based on a certain criterion, this is referred to as the fixed model (model I), whereas the random model (model II) is applied if the parents are random sample from the reference population [30].

## II. MATERIALS AND METHODS

***Experimental Location***

The experiment was conducted at Bako National Maize research center during 2017 main cropping season. Bako is located in East Wollega zone of the Oromia National Regional State, Western Ethiopia. The center lies between $9^0$6' North latitude and $37^0$09' east longitude in the sub-humid agro-ecology, at altitude of 1650 meters above sea level (m.a.s.l). It is 250 km far from Addis Ababa, the capital city of the country. The mean annual rain fall in the last half century is 1238 mm. The rainy season covers April to October and maximum rain is received in the months of July and August. The mean minimum, mean maximum and average air temperature is 12.8, 29.0, and $20.9^0$C, respectively; and relative humidity of 51.04%. The soil is reddish brown in color and clay and loam in texture [34]. According to USDA (2015) soil classification, the soil is Alfisols developed from basalt parent materials, and is deeply weathered and slightly acidic in reaction [34].

***Experimental Materials***

Ten inbred lines namely, L1, L2, L3, L4, L5, L6 and L7 from BNMRC (Bako National Maize Research Center), L8 and L9 from CIMMYT and L10 from IITA were used in this study. The inbred lines were cross pollinated in a half diallel fashion to develop 45 single cross hybrids. A total of 48 hybrids, 45 single cross hybrids and three commercial standard checks (BH546, BH547 and SPRH1) were evaluated during 2017 main cropping season for grain yield and related agronomic traits.

***Experimental Design***

Each 48hybridwas sown in 5.1 meter long rows with inter and intrarow spacing of 0.75 m and 0.30 m respectively. The experiment was laid out in alpha lattice (0, 1) with two replications.

***Trial Management***

Each plot was hand planted with two seeds per hill, which were later thinned to one plant per hill to get a total plant population of 44, 444 per hectare. Planting was done on the onset of the main rainy season when the soil retains sufficient moisture to promote optimum germination and seedling development. Weeds were controlled by applying pre-emergence herbicide at planting and followed by 2-3 hand weeding at different stages of plant growth. Di-ammonium phosphate and urea fertilizers were applied as per the package of the locations (150 kg ha$^{-1}$ and 200kg ha$^{-1}$ respectively). Di-ammonium phosphate fertilizer was applied once at planting time, while urea was applied in split, half at planting and the remaining half at knee height. Other agronomic practices were carried out as per the recommendation for the area.

***Collected Data***

***Days to anthesis (AD)****:* The number of days from planting date to when 50% of the plants in a plot start shedding pollens.

***Days to silking (SD):*** The number of days from plant planting date to when 50% of the plants in a plot have grown 2-3 cm silks.

***Plant height (PH):*** The height from the soil surface to the first tassel branch of ten randomly taken plants from each experimental unit was measured in centimetres. Like ear height, this was also measured two weeks after pollen shedding had ceased from the same plants that EH measured.

***Ear height (EH):*** The height from the ground level to the upper most ear-bearing node of ten randomly taken plants from each experimental unit was measured in centimetres. The measurement was made two weeks after pollen shedding ceased.

***Grain weight per plot (GY)****:* Ears were removed from all plants in each plot leaving other crop residues (husk, leaf, stem and tassel) intact. The total field weight from all the ears of each experimental unit was recorded and converted to ton ha$^{-1}$

***Ear diameter (ED):*** This was measured at the mid-section along the ear length, as the average diameter often randomly taken ears from each experimental plot in centimetres using digital calliper.

***Ear length (EL):*** Length of ears from the base to tip was measured in centimetres. Data recorded represents the average length of ten randomly taken ears from each experimental unit.

***Thousand Kernel weight (TKW)****:* After shelling each ten randomly selected ear, random kernels from the bulk of shelled grain in each experimental unit was taken and thousand kernels were counted using a seed counter and weighed in grams and then adjusted to 12.5% grain moisture.

***Harvest index (HI):*** Harvest Index (HI) (%): The ratio of grain yield to total above ground dry biomass yield times by100 was calculated by the formula

$$\boldsymbol{HI = \frac{GY}{AGB} x\ 100}$$

Where HI is harvesting index, GY is grain yield and AGB is above ground dry biomass yield including grain.

***Shelling percentage (SHP):*** The ratio of weight of ten sampled cob after shelling to the weight ten sampled cob before shelling multiplied by 100.

***Estimation of combing ability***

Combining ability analysis was conducted using [30]method IV (F$_1$'s) model I (fixed model) to obtain the estimates of GCA and SCA effects using the Proc GLM model of the SAS program [35]using Diallel-SAS procedure [36]. The mathematical model used for combining ability analysis was as follows:

$$X_{ij} = \mu + g_i + g_j + s_{ij} + \frac{1}{bc}\sum_k \sum_l e_{ijkl}$$

Where; $X_{ij}$ = the value of a character measured on cross of i$^{th}$ and j$^{th}$ parents.

$\mu$ = Population mean

$g_i$ $(g_j)$ = the general combing ability effect

$s_{ij}$ = the specific combing ability effect

$e_{ijkl}$ = the effect peculiar to the ijkl$^{th}$ observation

p, b and c = number of parents, blocks and sampled plants, respectively.

Once mean squares for general combining ability and specific combining ability were found to be significant, they justify the adequacy of calculating general combining ability or GCA ($g_i$) and specific combining ability or SCA ($s_{ij}$) effects for each parent and cross, respectively.

**Table 1: Analysis of variance table for combining ability for single location**

| Source of Variation | Df | Expectation of Mean Squares (Model I, Method IV) |
|---|---|---|
| GCA | n-1 | $\left(\frac{1-2}{n-1}\right)\sum_{gi} 2 + Me$ |
| SCA | n(n-3)/2 | $\left(\frac{2}{n-3}\right)\sum_i \sum_j S_{ij^2} + Me$ |
| Error | (r-1){[n(n-1)/2]-1} | Me |

n = number of parental lines

Estimation of general combining ability effects ($g_i$)

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$$\mathbf{gi} = \frac{\mathbf{1}}{\boldsymbol{n(n-1)}}\boldsymbol{(nxi.+2xj.)}$$

Where, $g_i$ = GCA effect for the $i^{th}$ parent
Estimation of specific combining ability effects ($s_{ij}$)

$$\mathbf{Sij = Xij - \frac{1}{n-2}(xi.+xj) + \frac{2}{(n-1)(n-2)}X.}$$

Where, $S_{ij}$ = SCA effect for ij cross

Tests of significance of the combining ability effects and their differences were made using t-test. Standard error of the estimates of GCA effects (SE ($g_i$)) and SCA effects (SE ($s_{ij}$)) were computed by formula suggested by [29].

Restriction of $\Sigma gi = 0$ and $\Sigma s_{ij} = 0$ were imposed on combing ability effects.

Estimation of standard error to test the significance of GCA effects of n parents and also standard error of difference of GCA effects were calculated using the following formula.

$$\mathbf{SE}\ (\boldsymbol{gi}) = \sqrt{\frac{\mathbf{n-1}}{\mathbf{n(n-2)}}\mathbf{Me'}} \qquad \mathbf{SE}\ (\mathbf{g_i{-}g_j}) = \sqrt{\frac{\mathbf{2}}{\mathbf{(n-2)}}\mathbf{Me'}}$$

Similarly, standard error required to test the significance of SCA effects (Sij) and difference between SCA effects were computed as:

$$\mathbf{SE\ (sij)} = \sqrt{\frac{\mathbf{n-3}}{\mathbf{(n-1)}}\mathbf{Me'}}$$

$$\mathbf{SE\ (sij)} - \boldsymbol{Sjk}) = \sqrt{\frac{\mathbf{2(n-3)}}{\mathbf{(n-1)}}\mathbf{Me'}}$$

$$\mathbf{SE\ (sij} - \boldsymbol{Skl}) = \sqrt{\frac{\mathbf{2(n-3)}}{\mathbf{(n-2)}}\mathbf{Me'}}$$

# III. RESULTS

The results of analysis of variance were presented in Table 2. Analysis of variance showed that the tested crosses had highly significant difference in grain yield and other agronomic traits such as days to antithesis, silking and maturity, plant height, ear height, ear diameter, ear length, thousand kernel weight, shelling percentage, harvest index ($P < 0.01$).

**Table 2: Analysis of variance for grain yield and yield related traits in diallel crosses**

| Traits | Mean squares | | | | |
|---|---|---|---|---|---|
| | Entry (DE = 47) | Cross (Df = 44) | Replication (DF=1) | Block(Rep) (DF=14) | Error (DF=33) |
| GY | 2.79** | 2.70** | 1.05 | 2.35** | 0.81 |
| AD | 5.89** | 6.21** | 58.59** | 3.59 | 2.94 |
| SD | 6.38** | 6.82** | 54.00** | 6.52** | 1.96 |
| PH | 756.65** | 796.68** | 3264.33** | 65.34 | 60.39 |
| EH | 357.32** | 375.40** | 1885.94** | 84.24* | 53.47 |
| ED | 0.10** | 0.08** | 0.05* | 0.01 | 0.01 |
| EL | 2.47** | 2.46** | 6.00* | 0.83 | 0.96 |
| TKW | 4003.32** | 3884.84** | 266.67 | 1456.37** | 428.61 |
| SHP | 11.43** | 11.25** | 1.37 | 1.96 | 2.71 |
| HI | 19.56** | 20.43** | 888.11** | 126.84** | 7.40 |

* = 0.05 and ** = 0.01 significant probability level; DF = degree of freedom;GY = Grain Yield; AD = 50% Days to Anthesis; SD = 50% Days to silking; PH = Plant Height (cm); EH = Ear Height (cm); ED = Ear Diameter (cm); EL = Ear Length (cm); TKW = Thousand Kernel Weight (gm); SHP = Shelling Percentage; HI = Harvest Index (%)

***Means Performance of Genotypes***

The range of mean values of crosses for grain yield and other agronomic traits studied were given in Table 3. For all the traits, there was wide range of values, from low to high among the entries evaluated Table 3. Top five performing crosses at 10% selection intensity for grain yield with best check were presented in Table 4. The higher grain yield records were obtained from the crosses of L1 x L4 (11.79 ton ha$^{-1}$), L2 x L4 (10.67 ton ha$^{-1}$), L1 x L5 (10.42 ton ha$^{-1}$), L7 x L8 (10.20 ton ha$^{-1}$) and L4 x L6 (10.1 ton ha$^{-1}$). Contrarily, the lowest grain yield (5.84 ton ha$^{-1}$) was recorded from the crosses of L8 x L10 (Table 3).The three check hybrids used in this study BH546, BH547 and SPRH1 had mean grain yield of 9.93, 9.91 and 7.72 ton ha$^{-1}$, respectively.

Maximum number of days to tasseling (82.50) was obtained from the cross of L8 x L10 while relatively lower number of days (73.5) to tasseling was obtained from cross of L3 x L4. Whereas, number of days to silking was ranging from 73.5 days in cross of L3 x L4 to 82.5 days in the cross of L8 x L10. Plant height varied from 249.75 cm to 351.00 cm in crosses of L1 x L3 and L2 x L5 respectively. The ear height ranged from 122.50 cm to 185.25 cm in crosses of L5 x L10 and L1xL3 respectively.

Ear diameter and length was found in the range of 4.24cm for cross L3 x L8, 15.58cm for cross L9 x L10 to 5.65 for BH547 and 20.6 cm for cross L3 x L7 respectively. In the case of ear diameter all crosses showed lower diameter than best standard check BH547 (Table 3). Number of rows per ear ranged from 8.43 to 16.20 with an overall mean of 14.32. Mean thousand-kernel weight varied from 300.00 gm (L8 x L10) to 495.00 gm (L7 x L9 and best check BH546). All crosses except L7 x L9 which showed equal kernel weight with highest standard check BH546) exhibited low thousand kernel weights (Table 3).

Maximum shelling percentage was observed in the cross L3 x L8 (85.01%) and the lowest was recorded with cross L2 x L5 (73.18%). Thirty-one genotypes were exhibited shelling percentage ranged from 80.14 to 85.01 %.Harvest index ranged from 21.65% to 44.36% with the mean of 33.72%. The minimum and maximum harvest index values were recorded from the crosses L4 x L9 and L6 x L7, respectively, Among all the crosses, L3 x L5, L3 x L8, L4 x L7, L5 x L7 and L6 x L7 had more that 40% harvest index, Above 15 crosses showed higher harvest index values than the best standard checks (BH 546), which had a harvest index value of 36.43%. Thirty-three crosses showed above 30% harvest index.

**Table 3: Range of mean performance of genotypes**

| Traits | G. mean | Minimum | Genotypes | Maximum | Genotypes | CV (%) | $R^2$ (%) | LSD $_{5\%}$ | SE(m) |
|---|---|---|---|---|---|---|---|---|---|
| GY | 8.65 | 5.84 | L8 x L10 | 11.79 | L1 x L4 | 10.40 | 87.69 | 2.26 | 1.06 |
| AD | 77.47 | 73.50 | L3 x L4 | 82.50 | L8 x L10 | 2.21 | 88.66 | 3.15 | 1.25 |
| SD | 78.06 | 73.50 | L3 x L4 | 82.50 | L8 x L10 | 1.79 | 87.46 | 3.79 | 1.38 |
| PH | 300.58 | 249.75 | L1 x L3 | 351.00 | L2 x L5 | 2.59 | 95.94 | 15.82 | 2.81 |
| EH | 151.14 | 122.50 | L1 x L3 | 185.25 | L5 x L10 | 4.84 | 94.51 | 14.41 | 2.68 |
| ED | 5.03 | 4.24 | L3 x L8 | 5.65 | BH547 | 1.92 | 96.29 | 0.20 | 0.32 |
| EL | 18.17 | 15.58 | L9 x L10 | 20.60 | L3 x L7 | 5.40 | 82.92 | 1.93 | 0.98 |
| TKW | 397.08 | 300.00 | L8 x L10 | 495.00 | L7 x L9 | 5.21 | 94.85 | 54.53 | 5.22 |
| SHP | 80.44 | 73.18 | L2 x L5 | 85.01 | L3 x L8 | 2.05 | 88.54 | 3.17 | 1.26 |

GY = Grain Yield; AD = 50% Days to Anthesis; SD = 50% Days to silking; PH = Plant Height (cm); EH = Ear Height (cm); ED = Ear Diameter (cm); EL = Ear Length (cm); TKW = Thousand Kernel Weight (gm); SHP = Shelling Percentage; HI = Harvest Index (%); G. mean = Grand mean; CV = Coefficient of Variation; $R^2$ =R-Square; LSD = Least Significant Difference; SE (m) = Standard Error of mean

**Table 4: Means performances of top five performing hybrids for grain yield at 10 % selection intensity**

| | Traits | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Crosses | GY | AD | SD | PH | EH | ED | EL | TKW | SHP | HI |
| L1 x L4 | 11.79 | 76.00 | 77.00 | 299.25 | 144.75 | 5.46 | 18.98 | 460.00 | 75.38 | 34.06 |
| L2 x L4 | 10.67 | 77.50 | 77.50 | 299.75 | 140.75 | 5.52 | 19.28 | 430.00 | 75.33 | 35.41 |
| L1 x L5 | 10.42 | 75.50 | 74.50 | 300.75 | 143.00 | 5.31 | 19.18 | 480.00 | 79.71 | 29.05 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| L7 x L8 | 10.20 | 75.50 | 76.00 | 311.15 | 162.50 | 4.52 | 18.38 | 365.00 | 83.22 | 31.83 |
| L4 x L6 | 10.10 | 78.50 | 78.50 | 319.50 | 164.00 | 5.32 | 19.23 | 435.00 | 80.19 | 25.55 |
| BH546 | 9.93 | 78.50 | 79.00 | 307.50 | 146.00 | 4.97 | 19.08 | 395.00 | 82.38 | 36.43 |
| G. mean | 8.65 | 77.47 | 78.06 | 300.58 | 151.14 | 5.03 | 18.17 | 397.08 | 80.44 | 33.72 |
| CV (%) | 10.40 | 2.21 | 1.79 | 2.03 | 2.59 | 1.92 | 5.40 | 5.21 | 2.05 | 8.07 |
| LSD $_{(0.05)}$ | 2.26 | 3.15 | 3.79 | 15.82 | 14.41 | 0.20 | 1.93 | 54.53 | 3.17 | 13.19 |

GY = Grain Yield (tonha$^{-1}$); AD = 50% Days to Anthesis; SD = 50% Days to silking; PH = Plant Height (cm); EH = Ear Height (cm); ED = Ear Diameter (cm); EL = Ear Length (cm); TKW = Thousand Kernel Weight (gm); SHP = Shelling Percentage; HI = Harvest Index (%); G. mean = Grand mean; CV = Coefficient of Variation; LSD = Least Significant Difference

### *Combining Ability Analysis*

Mean squares due to general combining ability (GCA), specific combining ability (SCA) and error are presented in Table 5. Mean squares due to GCA were highly significant ($P < 0.01$) for all the traits except for harvest index which showed significant ($P < 0.05$). Mean squares due to SCA effects were highly significant ($P < 0.01$) for plant and ear height, ear diameter, thousand kernel weight and shelling percentage and significant ($P < 0.05$) for grain yield, days to anthesis and maturity. The ratio of sum squares due to GCA to sum squares due to SCA was greater than unit for all traits except for grain yield, days to silking and harvest index.

**Table 5: Mean squares of general combining ability, specific combining ability and error for yield and related traits in half diallel crosses**

| Traits | Mean squares | | | Sum squares | | Ratio |
|---|---|---|---|---|---|---|
| | GCA (Df = 9) | SCA (Df = 35) | Error (Df = 44) | $SS_{GCA}$ | $SS_{SCA}$ | $SS_{GCA}/SS_{SCA}$ |
| GY | 6.47** | 2.54* | 1.29 | 58.25 | 89.07 | 0.65 |
| AD | 26.11** | 4.43* | 2.4 | 235 | 155.22 | 1.51 |
| SD | 20.50** | 5.43 | 3.42 | 184.53 | 189.88 | 0.97 |
| PH | 3788.39** | 250.20** | 54.26 | 34095.51 | 8756.83 | 3.89 |
| EH | 1384.62** | 151.26** | 53.13 | 12461.6 | 5294.25 | 2.35 |
| ED | 0.61** | 0.03** | 0.01 | 5.49 | 0.91 | 6.03 |
| EL | 10.17** | 1.06 | 0.91 | 91.57 | 37.24 | 2.46 |
| TKW | 21181.94** | 1133.21** | 751.36 | 190637.5 | 39662.5 | 4.81 |
| SHP | 50.93** | 5.14** | 2.42 | 458.4 | 179.8 | 2.55 |
| HI | 115.87* | 44.22 | 45.24 | 1042.84 | 1547.53 | 0.67 |

* = 0.05 and ** = 0.01 significant probability level; DF = Degree of Freedom; GY = Grain yield; AD = Days to Anthesis; SD = Days to Silking; PH = Plant Height; EH = Ear Height; ED = Ear Diameter; EL = Ear Length; TKW = Thousand Kernel Weight; SHP = Shelling Percentage; HI = Harvest Index; GCA = General Combining Ability; SCA = Specific Combining Ability; $SS_{GCA}$ = Sum Squares due to General Combining Ability; $SS_{SCA}$= Sum Squares due to Specific Combining Ability

### *Estimation of GCA effects*

Estimation of GCA effects of the inbred lines was presented in Table 6. Significant differences in GCA effects were detected among lines for various traits. Forgrain yield, six of the inbred lines showed positive GCA effect while the remaining four inbred lines expressed negative GCA effects.For days to anthesis, seven of the inbred lines expressed negative GCA effects of which L1, L2 and L7 showed significant GCA effects. The inbred lines L5, L8 and L10 showed significant ($P < 0.01$) and positive GCA effects for this trait.

In the case of days to silking, seven of the inbred lines showed negative GCA effects of which only L1 depicted significant ($P < 0.01$) GCA effects. On the other hand, three of the inbreed lines (L5, L8, L10) manifested significant and positive GCA effects. For plant height five inbred lines expressed negative GCA effects and the remaining five inbred lines showed positive GCA effects. No inbred lines manifested significant positive and negative GCA effects for this trait. For ear height, four inbred lines (L5, L6, L7 and L10) showed positive highly significant ($P < 0.01$) GCA effects while among the remaining six showed negative GCA effects, four of them (L1, L2, L3 and L9) depicted highly significant.

In the case of ear diameter, six inbred lines (L1, L2, L4, L5, L6 and L9) were showed positive and highly significant ($P < 0.01$) GCA effects. The remaining four inbred lines were showed negative and significant GCA effects except for L10 which showed non- significant GCA effect for this trait. Lines L1 and L10 showed negative and significant GCA effects for ear length whereas Lines L4, L5 and L7 showed positive and significant GCA effects of the same trait. For thousand kernel weight, four inbred lines (L4, L5, L6 and L7) expressed positive and highly significant ($P < 0.01$) GCA effects while L6 showed significant ($P < 0.05$) GCA effects. Contrarily, six lines showed negative and significant GCA effects.

For shelling percentage, L6 and L8 showed positive significant GCA effects out of six lines showed positive GCA effects whereas, four inbred lines had negative and significant GCA effects. On the other hand, only L7 had positive and significant GCA effects for harvest index while the six remained showed negatively non-significant GCA effects.

**Table 6: Estimation of general combining ability effect for grain yield and other agronomic traits**

| Lines | GY (tha$^{-1}$) | AD (days) | SD (days) | PH (cm) | EH (cm) | ED (cm) | EL (cm) | TKW (gm) | SHP (%) | HI (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| L1 | 0.21 | -1.81** | -1.79** | -20.74 | -12.99** | 0.16** | -0.73** | -11.25 | -1.32** | -1.46 |
| L2 | 0.22 | -0.81* | -0.41 | 0.88 | -4.96** | 0.17** | -0.23 | -2.5 | -3.35** | 1.6 |
| L3 | -0.4 | -0.69 | -0.79 | -12.99 | -10.08** | -0.29** | 0.4 | -9.38 | 0.03 | -0.74 |
| L4 | 0.87** | -0.06 | -0.35 | 4.23 | -3.24 | 0.24** | 0.89** | 36.88** | -1.47** | -2.43 |
| L5 | 0.67* | 1.31** | 0.90* | 32.35 | 12.83** | 0.07** | 1.12** | 45.63** | 0.03 | 1.65 |
| L6 | 0.14 | -0.69 | -0.6 | 13.48 | 12.54** | 0.09** | -0.15 | 15.63* | 0.91* | 1.52 |
| L7 | 0.42 | -0.88* | -0.41 | 3.62 | 5.83** | -0.05* | 0.88** | 46.25** | 1.24 | 5.95* |
| L8 | -0.18 | 1.88** | 1.78** | -1.63 | -1.11 | -0.33** | -0.11 | -53.13** | 3.28** | -1.41 |
| L9 | -1.04** | -0.19 | -0.04 | -16.12 | -7.02** | 0.07** | -1.01 | -15.00* | -0.02** | -2.92 |
| L10 | -0.92** | 1.94** | 1.71** | -3.09 | 8.20** | -0.13 | -1.06** | -53.13** | 0.67 | -1.75 |
| SE ($g_i$) | 0.3 | 0.58 | 0.46 | 2.61 | 2.45 | 0.03 | 0.19 | 6.24 | 0.47 | 2.51 |
| SE ($g_i$-$g_j$) | 0.45 | 0.86 | 0.7 | 3.88 | 3.65 | 0.11 | 0.63 | 20.82 | 1.56 | 8.36 |

* = 0.05 and ** = 0.01 significant probability level; GY= Grain Yield; AD = Days to Anthesis; SD = Days to Silking; PH = Plant Height; EH = Ear Height; ED = Ear Diameter; EL= Ear Length; TKW = Thousand Kernel Weight; SHP = Shelling Percentage; HI = Harvest Index;SE (gi) = Standard Error of general combining ability effects; SE (gi-gj) = Standard Error of the difference of general combining ability effect

### *Estimation of SCA effects*

Estimation of SCA effects for eight traits was presented in Table **7**. For grain yield, 23 crosses showed positive SCA effects out of which L1 x L4 and L7 x L9 crosses were showed positive highly significant ($P < 0.01$) while the remaining 22 crosses showed negative SCA effects out of which L1 x L3, L4 x L9, and L5 x L7 crosses were showed negative significant ($P < 0.01$) SCA effects for this trait. For days to anthesis, 25 crosses showed negative SCA effects out of which L3 x L4 and L7 x L8 showed negative highly significant ($P < 0.01$) SCA effects whereas L5 x L7 showed positive and significant SCA effects out of the remained 20 crosses those showed positive SCA effects.

For plant and ear height each six crosses (L1 x L4, L2 x L3, L2 x L5, L3 x L9, L5 x L8, L6 x L7, L7 x L10) and (L1 x L4, L1 x L10, L2 x L3, L2 x L8, L5 x L10, L7 x L9, L7 x L10) showed positive and significant SCA effects respectively while the seven crosses (L1 x L3 , L1 x L5 , L2 x L6 , L3 x L5 , L5 x L7, L5 x L9 , L9 x L10) and five crosses (L2 x L7, L3 x L10, L4 x L10, L5 x L7, L8 x L10) depicted negatively significant SCA effects respectively. Regarding to ear diameter, 21 cross combinations exhibited positive SCA effects out of which L3 x L7, L5 x L8 and L7 x L9 showed highly significant ($P < 0.01$) whereas L2 x L6, L3 x L8 and L5 x L7 exhibited negative and significant SCA effect out of the remaining 24 crosses those showed negative SCA effects.

Twenty out of 45 crosses showed positive SCA effects for 1000-kernel weight. Among these crosses L1 x L4, L1 x L5 and L7 x L9 showed positive and significant SCA effects. On the other hand, out of the remaining twenty-five crosses expressed negative SCA effect, L2 x L5 showed negative significant ($P < 0.05$). For shelling percentage, 22 crosses showed positive SCA effects out of which L1 x L10 and L2 x L8 had positive and significant SCA effects whereas L2 x L5 and L4 x L8 showed negative highly significant ($P < 0.01$) SCA effects.

**Table 7: Estimation of specific combining ability effects for grain yield and other agronomic traits**

| Crosses | Traits | | | | | | |
|---|---|---|---|---|---|---|---|
| | GY | AD | PH | EH | ED | TKW | SHP |
| L1 x L2 | 0.06 | 0.18 | -2.63 | -7.82 | 0.03 | 10.42 | -0.56 |
| L1 x L3 | -1.95** | 0.06 | -17.01** | -5.45 | -0.08 | -27.71 | -1.64 |
| L1 x L4 | 2.08** | 0.43 | 15.27** | 9.96* | 0.03 | 36.04** | -2.17 |
| L1 x L5 | 0.91 | -1.44 | -11.35* | -7.85 | 0.05 | 47.29** | 0.67 |
| L1 x L6 | 0.02 | -0.94 | 0.27 | 2.68 | 0.09 | -7.71 | 0.41 |
| L1 x L7 | 0.37 | 1.24 | 7.38 | -4.35 | 0.02 | -3.33 | 0.93 |
| L1 x L8 | -0.83 | -0.01 | -3.37 | -0.67 | -0.02 | 1.04 | 0.31 |
| L1 x L9 | -0.22 | 0.56 | 4.62 | 3.99 | -0.07 | -27.08 | -0.21 |
| L1 x L10 | -0.44 | -0.07 | 6.83 | 9.52* | -0.04 | -28.96 | 2.26* |
| L2 x L3 | 0.31 | 0.06 | 23.62** | 12.52** | 0.20 | 13.54 | -1.90 |
| L2 x L4 | 0.95 | 0.93 | -5.85 | -2.07 | 0.08 | -2.71 | -0.19 |
| L2 x L5 | -0.24 | 0.06 | 17.27** | 6.11 | 0.00 | -36.46* | -3.84** |
| L2 x L6 | -0.94 | -1.94 | -13.10** | -3.10 | -0.20* | 13.54 | 1.72 |
| L2 x L7 | -1.37 | -0.76 | -15.50 | -13.39** | -0.07 | 12.92 | 1.41 |
| L2 x L8 | 1.11 | -1.01 | 1.75 | 15.05** | -0.10 | 12.29 | 4.19** |
| L2 x L9 | -0.65 | 0.56 | -8.26 | -8.79 | 0.10 | -20.83 | -0.81 |
| L2 x L10 | 0.78 | 1.93 | 2.71 | 1.49 | -0.04 | -2.71 | -0.02 |
| L3 x L4 | 0.42 | -3.19** | -1.48 | 2.55 | -0.11 | -5.83 | 1.42 |
| L3 x L5 | 1.01 | -0.07 | -10.35* | -5.01 | 0.01 | 15.42 | 0.43 |
| L3 x L6 | -0.58 | 0.93 | 2.52 | 2.77 | -0.01 | -9.58 | -0.11 |
| L3 x L7 | 0.75 | -1.38 | -7.87 | -4.01 | 0.17** | 9.79 | -0.35 |
| L3 x L8 | 0.36 | 1.37 | 4.88 | -0.32 | -0.17** | -15.83 | 1.37 |
| L3 x L9 | -0.24 | 0.93 | 9.87* | 6.33 | -0.05 | 6.04 | -0.21 |
| L3 x L10 | -0.09 | 1.31 | -4.17 | -9.39* | 0.04 | 14.17 | 0.99 |
| L4 x L5 | -0.69 | -1.19 | 3.43 | 1.15 | -0.01 | -25.83 | 1.77 |
| L4 x L6 | 0.46 | 1.81 | 1.30 | 3.68 | -0.05 | -15.83 | 0.41 |
| L4 x L7 | -0.54 | 0.49 | -11.59 | -6.10 | -0.02 | -11.46 | 0.51 |
| L4 x L8 | -0.19 | 0.74 | -3.34 | -0.17 | 0.11 | -2.08 | -2.91** |
| L4 x L9 | -1.96** | 1.31 | 5.90 | 1.24 | -0.12 | 19.79 | 1.09 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| L5 x L9 | 0.81 | -0.07 | -10.98* | -2.07 | -0.11 | -33.96 | 1.81 |
| L4 x L10 | -0.53 | -1.32 | -3.63 | -10.23* | 0.09 | 7.92 | 0.08 |
| L5 x L6 | -0.06 | 1.43 | -1.32 | 0.86 | 0.04 | 15.42 | -0.05 |
| L5 x L7 | -2.42** | 3.12** | -13.22** | -11.92* | -0.15* | -25.21 | 0.45 |
| L5 x L8 | 0.79 | -1.13 | 17.03** | 5.52 | 0.25** | 14.17 | 0.25 |
| L5 x L10 | -0.10 | -0.69 | 9.49 | 13.21** | -0.08 | 29.17 | -1.48 |
| L6 x L7 | -1.04 | 1.12 | 10.16* | 3.86 | -0.08 | -0.21 | -1.05 |
| L6 x L8 | 0.00 | 0.37 | -5.84 | -8.95 | 0.07 | 14.17 | -0.12 |
| L6 x L9 | 1.02 | -1.57 | 8.15 | -0.04 | 0.03 | -3.96 | -1.72 |
| L6 x L10 | 1.12 | -1.19 | -2.13 | -1.76 | 0.11 | -5.83 | 0.51 |
| L7 x L8 | 1.34 | -2.94** | 8.67 | 6.77 | -0.13 | -26.46 | -1.64 |
| L7 x L9 | 2.07** | -1.38 | 4.25 | 10.18* | 0.23** | 65.42** | 0.59 |
| L7 x L10 | 0.85 | 0.49 | 17.72** | 18.96** | 0.04 | -21.46 | -0.85 |
| L8 x L9 | -0.91 | 1.37 | -3.25 | -3.14 | 0.04 | -5.21 | -0.25 |
| L8 x L10 | -1.68 | 1.24 | -16.53 | -14.10** | -0.05 | 7.92 | -1.20 |
| L9 x L10 | 0.09 | -1.69 | -10.29* | -7.70 | -0.05 | -0.21 | -0.29 |
| SE(sij) | 1.00 | 1.37 | 6.50 | 6.43 | 0.09 | 24.17 | 1.37 |
| SE(Sij-Sjk) | 1.42 | 1.93 | 9.19 | 9.09 | 0.13 | 34.19 | 1.94 |
| SE(Sij-Skl) | 1.50 | 2.05 | 9.74 | 9.64 | 0.13 | 36.26 | 2.06 |

* = 0.05 and ** = 0.01 significant probability level; GY=Grain yield; AD = Days to Anthesis; PH = Plant Height; EH = Ear Height; ED = Ear Diameter; TKW = Thousand Kernel Weight; SHP = Shelling Percentage; SE ($S_{ij}$) = Standard Error of specific combining ability effect; SE ($S_{ij}$-$S_{ik}$) = standard error of the difference of specific combining ability having one parent in common; SE ($S_{ij}$-$S_{kl}$) = standard error of the difference of specific combining ability effects of the crosses having no parents in common.

## IV. DISCUSSION

Analysis of variance showed that the tested crosses had highly significant difference in grain yield and most other agronomic traits. Thus, it revealed that there were genetic variations among the tested entries. The current results are in line with the findings [37];[38];[39];[25];[40];[13];[26] and [41].The higher grain yield records were obtained from the crosses of L1 x L4 (11.79 ton $ha^{-1}$), L2 x L4 (10.67 ton $ha^{-1}$), L1 x L5 (10.42 ton $ha^{-1}$), L7 x L8 (10.20 ton $ha^{-1}$) L4 x L6 (10.1 ton $ha^{-1}$) as compared to best performing check BH546 (9.93 ton $ha^{-1}$) (Table 3) indicating that the two combined inbred lines in each crosses might be genetically diverse or belong to different heterotic groups. [42]and[43] reported that the performance of maize hybrids for grain yield greatly depends on the level of heterosis expressed in their hybrids and can be maximized by crossing inbred lines belonging to different heterotic groups. Contrarily, the lowest grain yield was recorded from the crosses of L8 x L10 (5.84 ton $ha^{-1}$) indicating that the two inbred lines are genetically similar or belonging to same heterotic groups.

Lower days to anthesis and silking was recorded in crosses L3 x L4 (73.5 days) and L3 x L4 (73.5 days) respectively (Table 3) indicating that relatively earlier maturing as compared to the remaining crosses and three standard checks (BH546, BH547 and SPRH1). Nowadays, earliness is a desirable attribute for maize production in view of recurrent droughts as early varieties can escape moisture stresses. In addition, such variety can be harvested early and the land could be used for growing other crop species within the same season; i.e., double cropping system. Conversely, late maturing crosses are important in the breeding programs to development high yielding hybrids in areas which receive sufficient rain fall [26].Most Crosses had shorter pant and ear height than best commercial check (SPRH1) in desirable for lodging tolerance and to apply necessary practices, whereas taller crosses are important as biomass could be used as animal feed and source of fuel [24];[26].

Above fifteen crosses showed higher harvest index values than the best standard checks (BH 546), which had a harvest index value of 36.43%. Most crosses showed above 30% harvest index. The current result in line with the findings of [44]who evaluated harvest index of improved maize varieties released for commercial production from the 1970s to the 1990s. The authors reported that mean harvest index among 20 varieties varied from 31.1% to 45.0%. [24]also reported that mean harvest index across three locations among 63 hybrids ranged from 43.6% to 53.1%.

Genetic analysis for grain yield and other agronomic traits revealed significant ($P < 0.01$) for all traits except for harvest index which showed significant ($P < 0.05$) due to mean squares of GCA indicate that the inheritance of the traits was governed by additive genes while mean squares due to SCA showed significant for most traits indicate that contribution of non-additive gene action in controlling the expression of traits. Significant GCA and SCA mean squares indicate the contribution of both additive and non-additive gene action in controlling the expression of traits. Similar finding was reported by different investigators. For example,[19]observed significant mean square due to GCA and SCA for various traits; and concluded the importance of both additive and non-additive gene effects that govern the traits.[23];[26]and[27]noticed general and specific combining ability effects were significant for most traits they studied in conventional maize. All of the authors reported the importance of both additive and non-additive gene actions in controlling most of the traits in maize.

The ratio of $SS_{GCA}$ to $SS_{SCA}$ was greater than a unit for most quantitative traits indicating that the preponderance of additive gene in controlling the in heritance of the traits under the study. In agreement, [37]and [40]reported the predominance of additive gene effects in the inheritance of most traits in maize. [23]had also reported higher magnitude of mean squares due to GCA of lines than that of the SCA in yield and other agronomic traits indicating that additive gene actions were more important than non-additive gene action in controlling the inheritance of the traits studied. Similarly,[45];[24] and [26]also reported higher proportion of GCA sum of squares than that of SCA for all traits they studied. These findings confirm the greater contribution of additive gene effects for genetic variability of traits in maize than the non-additive gene effects. Thus, systematic recurrent selection could be used in maize improvement to exploit the additive gene effects. In contrary to this, the ratio of $SS_{GCA}$ to $SS_{SCA}$ was less than unit for some quantitative traits indicating that the role additive gene action is less as compared to non-additive gene action in controlling the inheritance of the traits under the study.

In the case of estimation of GCA effects, significant differences in GCA effects were detected among inbred lines for various traits.Similar findings were reported by [39];[40];[26]and[27]. Grain yield showed positive GCA effects among most inbred lines out of which (L1, L4) showed positive significant GCA effects in desired direction contributing to the increment of grain yield and considered as good combiners. For 50% days to anthesis, most inbred lines manifested negative GCA effects out of which L1, L2, and L7showed significant GCA effects in desired direction contributing to earliness while L1 and L7showed negative significant GCA effects. The contribution of negative GCA effects of inbred lines had gene combinations that enhance early anthesis and silking while Positive GCA value of the lines contributes undesirable traits as they showed a tendency to increase late anthesis and silking. [46];[47]revealed the importance of negative GCA effect for days to 50% tasseling and days to 50% silking to develop early maturing varieties.

Most inbred lines manifested negative and positive GCA effects for plant and ear height indicate the contribution of inbred lines to plant and ear height shortness and tallness respectively. No inbred line showed negative and positive significant GCA effect for plant height contributing to neither for increment nor decrement of plant height while for ear height out of the most inbred lines showed negative GCA effects, L1, L2, L3 and L9 depicted highly significant ($P < 0.01$) effects and considered as best combiners for this trait. Negatively significant GCA effects were contributing desirable genes that increase shortness of ear height while positively significant GCA effects were contributes undesirable genes that enhancing ear height [45];[48];[49];[50]and [23]. L2, L3, L4 showed negative significant GCA effects contributing to decrement of ear position.

For ear diameter and length, (L1, L2, L4, L5, L6, and L9) and (L4, L5, L7) manifested positive significant GCA effects respectively contributing to the increment of these traits. (L4, L5, L6), (L6, L8) and (L7) showed positive significant GCA effects to an increment of thousand kernel weight, shelling percentage and harvest index respectively. Positively significant GCA effects for these traits contributes desirable genes that increase 1000-kernel weight, shelling percentage and harvest index while negatively significant GCA effects were contributes undesirable genes that decrease these traits.

Estimation of SCA effects for grain yield indicated L1 x L4 and L7 x L9 crosses were the best specific combiners with highly significant ($P < 0.01$) and positive SCA effects while L1 x L3, L4 x L9, and L5 x L7 crosses were the worst parental combinations which showed negatively significant SCA effect for the trait (Table 7). Crosses with the higher positive value of SCA effect also showed higher values of mean grain yield performance, indicating good correspondence between SCA effects and mean grain yield. Hence, such cross combinations could effectively be exploited in hybrid breeding program. The result is in line with [49];[24];[40] and [26]. For day to an thesis, crosses L3 x L4 and L7 x L8 showed significant negative SCA effects for this trait in desired direction contributing to earliness whereas, L5 x L7 showed positive and significant SCA effects. Similarly, L3 x L4 and L7 x L8 crosses showed negative and significant SCA effects for day to maturity and L5 x L7 manifested positive significant SCA effects, indicating that the combination of parents gave undesirable genes that increase lateness of maturity (Table 7).

The cross combinations that exhibited positive and significantly high SCA effects were L3 x L7, L5 x L8 and L7 x L9 for ear diameter indicating the parents enhanced the ear diameter of their crosses whereas L2 x L6, L3 x L8 and L5 x L7 exhibited negative and significant SCA effects implying that the parents contribute to reduce the ear diameter of these specific crosses. Most crosses showed positive SCA effects for 1000-kernel weight out of which crosses L1 x L4, L1 x L5 and L7 x L9 showed positive and significant SCA effect for an increase of thousand kernel weight. On the other hand, out of the remaining twenty-five crosses expressed negative SCA effect L2 x L5 was the poorest for this trait **(Table 7**). For shelling percentage, L1 x L10 and L2 x L8 had positive and significant SCA effects in desired direction whereas, L2 x L5 and L4 x L8 showed negative highly significant SCA effects in undesired direction **(Table 7)**

In general, the best performing single crosses with desirable SCA effects and inbred lines with desirable GCA effects for grain yield were successfully performed. The best performed crosses and inbred lines could be used as genetic source to develop high yielder hybrids. Hence, the results lead to suggest the following points;

- Inbred lines L4 and L5 could be used for synthetic variety development
- Inbred lines L1, L2, L7 and L9 could be used to develop early maturing variety
- Single crosses L1 x L4 and L7 x L9 could be used for commercial utilization
- Ear diameter and length, thousand kernel weight, plant and ear height could be used for simultaneous improvement in maize breeding program.

However, further evaluation of these breeding materials at more locations and year is advisable to confirm the results observed in the study.

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