***Original Research Article***

**Mean Performance and Heterotic Pattern of Maize (*Zea Mays L*.) Inbred Lines Adapted to Sub-Humid Central Highland of Ethiopia**

# ABSTRACT

 In spite of abiotic and biotic stresses and low availability of high-yielding cultivars restrict potential production of maize, it is a major food crop in Africa. To overcome this production barrier, promising germplasm must be chosen, combining ability must be understood, and heterotic groups must be formed in order to generate high-yielding maize varieties. The study set out to evaluate plant height, ear height, ear diameter, thousand seed weight, kernel per row, kernel row per ear, and number of ear per plant in order to assess the performance evaluation and heterotic pattern of inbred lines. In 2019, twenty-six inbred lines and two single cross testers were crossed using a line by tester mating design to create fifty-two three way cross F1 hybrids. The experiment, which used an alpha lattice design with two replications, was conducted at the Ambo and Kulumsa Agricultural Research Centers during the 2020 cropping season. Analyses of variance revealed that among the parameters with significant mean squares arising from crosses and lines both within and across locations were grain yield, anthesis date, silking date, plant height, ear height, kernel row per ear, and number of ears per plant. Because of the lines, testers, and crossings for grain yield, anthesis date, silking date, plant height, ear height, kernel row per ear, and number of ear per plant, the line x tester ANOVA results revealed significant mean squares. Due to line x site, line x tester, tester x site, and line x tester x site, there was a noticeable difference in plant height, ear height, and the number of ears per plant. This proved that different environment have different selection criteria for materials and different performance levels. This genetic study Categorized, L1, L22, and L24 under heterotic group A (CEL08008/CEL08047), while L8, L10, L14, L17, L20, and L26 were placed under heterotic group-B (CEL08024/CML561).

***Keywords:*** *Additive gene type, Conventional maize, Heterotic pattern, Inbred line.*

# INTRODUCTION

“Maize (*Zea mays L*., 2n=20) is an important cereal crop belonging to the tribe *Maydeae*, of the grassfamily, *Poaceae*, Genus *Zea*, Species *mays* (Piperno and Flannery, 2001)*.* Among cereal crops*,* it is the world’s most widely grown cereal and is the primary staple food in many developing countries” (Morrie et.al 1999). “In 2018/2019 cropping season, the total world production of maize was 1,124 MT, with the United States producing 366.287 MT, China 257.330 MT, Brazil 94.500 MT, European Union 83.185 MT” (FAOSTAT, 2018/19).

“In Africa, Egypt (5.45 t ha-1), South Africa (5.45 tha-1) and Ethiopia (3.74 t ha-1) are the top three maize producers in 2020/2021 cropping season” (USDA, 2021). However, CSA(2021) report revealed that, in Ethiopia, maize productivity is 4.18 that which is relatively higher than USDA, (2021) report, though both reports indicate that maize productivity is still lower than the world maize average (5.65 t ha-1) in Ethiopia (USDA,2021).

“In Ethiopia maize is the leading cereal crop in terms of production with 10.56 million tons followed by wheat (5.78 million tons) and tef (5.51 million tons)” (CSA, 2021). “Ethiopian farmers grow maize primarily for subsistence with 75% of all maize output consumed by farming households, making it a key crop for overall food security and economic development in the country” (CSA, 2013). “The per capita consumption of maize is 50 kg year-1 per annum in Ethiopia” (Abebe *et al.,* 2018). “In terms of calorie intake, maize is the most important staple crop for the rural Ethiopian population” (Berhane *et al.,* 2020). Based on area of production CSA reported that in Ethiopia by 2019/20 main cropping season out of the total grain crop area, 81.46% (10,478,218.03) hectares) was under cereals.

“Climate change poses significant risks to future crop productivity as temperatures rise, rainfall patterns become more variable, and pest and disease pressures increase” (Heisey and Rubenstein, 2015). “Maize production in Ethiopia has also been under the threat of drought and famine in the last four decades” (Abate *et al.*, 2015). “In Ethiopia, the national average maize productivity of the country is very low in comparison to the average yield per hectare of the world (5.2t/ha-1) and that of the developed countries (7.2 t/ha-1)” (FAO, 2017). “This is due to several biotic and abiotic stresses that limit maize productivity across countries in sub-Saharan Africa” (Badu-Apraku *et al.,* 2011). “Among abiotic stresses, drought and low soil fertility are the most important stresses that affect maize production” (Mosisa *et al*., 2007; Lobell *et al.,* 2011; Weber *et al.,* 2012).

“To reduce these significant challenges improving germplasm and sustainable intensification to raise and stabilizing yields to close yield gaps is strictly required” (Foley *et al*., 2011). Legesse *et al.,* (2012) “also revealed that incorporating genetically variable germplasm into maize breeding programs is necessary to cope with the ever-changing environmental factors and increasing population pressure”.

Inbred line performance evaluation and heterotic pattern studies provide useful information regarding the selection of suitable parents for effective hybridization programs and indicate the nature and magnitude of various types of gene action. The information on the nature and magnitude of gene action is important in understanding the genetic potential of a population and deciding the breeding procedure to be adopted in a given population. Therefore, this study aims in to evaluate the performance and heterotic grouping of sub-humid central highland maize inbred lines of Ethiopia**.**

**Material and Methods**

## Description of Experimental Site

The main cropping season of 2020 was used to perform this study at the Kulumsa and Ambo Agriculture Research Centers in Ethiopia's central highland agro ecology. The Ambo Agriculture Research Centre is situated at an altitude of 2225 masl at 8 57 N latitude and 38 07 E longitude. The majority of the topsoil (0–30 cm) has a pH of 7.8 and is a heavy clay vertisoils type (Demissew, 2014). The average minimum and maximum temperatures are 11.7 °C and 25.5 °C, respectively, with an average value of 18.6 °C. The long-term total annual rainfall is 1115 mm. At a height of 2200 masl, Kulumsa is situated at 8° 5' N latitude and 39° 10' E longitude. Luvisol/eutric nitosols, with good drainage and pH, are the most common form of soil. The total long-term annual rainfall is 830 mm. The mean minimum and maximum temperatures are 10 oC and 23.2 oC, respectively with an average value of 16.6 oC [30].

##  Experimental Materials

Twenty-six maize inbred lines and two single cross testers (**Table.1**) were used in this study. The materials were developed at Ambo highland maize breeding program. The inbred lines were test crossed to two single cross testers following line × tester mating design as described by (Kempthorne, 1957) during the main season of 2019 at Ambo Agricultural research center to generate 52 F1 hybrids [30].

**Table 1.List of lines and testers used in the experiment. [30]**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| S/N | Coded parent Lines | Type of materials | Generation | Source |
| 1 | CEL17289 | Inbred lines | S5 | CIMMYT |
| 2 | CEL17295 | Inbred lines | S5 | CIMMYT |
| 3 | CEL17298 | Inbred lines | S5 | CIMMYT |
| 4 | CEL17301 | Inbred lines | S5 | CIMMYT |
| 5 | CEL17310 | Inbred lines | S5 | CIMMYT |
| 6 | CEL17312 | Inbred lines | S5 | CIMMYT |
| 7 | CEL17314 | Inbred lines | S5 | CIMMYT |
| 8 | CEL17315 | Inbred lines | S5 | CIMMYT |
| 9 | CEL17316 | Inbred lines | S5 | CIMMYT |
| 10 | CEL17329 | Inbred lines | S5 | CIMMYT |
| 11 | CEL17330 | Inbred lines | S5 | CIMMYT |
| 12 | CEL17331 | Inbred lines | S5 | CIMMYT |
| 13 | CEL17333 | Inbred lines | S5 | CIMMYT |
| 14 | CEL17334 | Inbred lines | S5 | CIMMYT |
| 15 | CEL17335 | Inbred lines | S5 | CIMMYT |
| 16 | CEL17336 | Inbred lines | S5 | CIMMYT |
| 17 | CEL17351 | Inbred lines | S5 | CIMMYT |
| 18 | CEL17353 | Inbred lines | S5 | CIMMYT |
| 19 | CEL17357 | Inbred lines | S5 | CIMMYT |
| 20 | CEL17371 | Inbred lines | S5 | CIMMYT |
| 21 | CEL17372 | Inbred lines | S5 | CIMMYT |
| 22 | CEL17377 | Inbred lines | S5 | CIMMYT |
| 23 | CEL17378 | Inbred lines | S5 | CIMMYT |
| 24 | CEL17379 | Inbred lines | S5 | CIMMYT |
| 25 | CEL17380 | Inbred lines | S5 | CIMMYT |
| 26 | CEL17404 | Inbred lines | S5 | CIMMYT |
|  | **Testers** |  |  |  |
| 1 | CEL08008/CEL08047 | Single cross tester | S5 | CIMMYT |
| 2 | CEL08024/CML561 | Single cross tester | S5 | CIMMYT |

## Experimental Design and Agronomic Practices

“In an Alpha Lattice design, 52 F1 hybrids created through line-by-tester mating were repeated twice. The trial was carried out at the Agricultural Research Station in Ambo and Kulumsa. Each entry was planted in a single row plot of 4 metres long, with 0.75 metres between rows and 0.25 metres between plants. To achieve a density of 53,333 maize plants per hectare, the experimental materials were manually planted with two seeds per hill, which were then thinned out to one plant/hill. DAP and UREA were used at the prescribed rates of 150 and 200 kg/ha, respectively. At planting time, a band application of diammonium phosphate (DAP), a phosphorous fertiliser, was made. At 40 days and 70 days following planting, urea was administered in two splits. Other agronomic management procedures were carried out in accordance with local recommendations” [30].

##  Data Collection and Data Analysis

Data were collected on days to silking, number of ear per plant, days to anthesis, grain weight, anthesis silking interval, moisture index, thousand seed weight, ear height, ear length, ear diameter, plant height, number of kernel per row and number of row per ear. The collected data were subjected for analysis of variance using SAS 9.2 software. The mean squares of GCA and SCA generated from line x tester mating design, was calculated according to the procedures suggested by Kempthorne (1957). The significance of GCA and SCA effects was tested using t test.

# RESULTS AND DISCUSSION

##  Analysis of Variance

“Overall ANOVA result of the current investigation displayed in (**Table. 1**). Analysis of variance was made on yield and yield-related traits of grain yield (GY), anthesis of date (AD),1000-kernel weight (TW), anthesis silking interval (ASI), silking date (SD), plant height (PH), and ear height (EH), number of ears per plant (EPP), number of kernel rows per ear (KRPE), number of kernels per row (KPR), ear length (EL) and ear diameter(ED) for each locations and across the locations” [30].

**Table 2. Analysis of variance for yield and yield related traits for testcross across location. [30]**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Traits** | **L****df=1** | **Re(L)df=1** | **B(L\*R)df=12** | **Entdf=51** | **Ent\*Ldf=51** | **Errordf=90** | **Mean±SE(m)** | **CV%** | **R2** |
| **GY** | 73.8\*\* | 36.64\*\* | 2.72\*\* | 5.28\*\* | 2.85\*\* | 0.948 | 7.44±0.97 | 13.08 | 0.88 |
| **AD** | 68.08\*\* | 15.64\* | 5.36 | 11.77\*\* | 4.14 | 5.02 | 97.02±2.24 | 2.31 | 0.7 |
| **SD** | 10.17 | 5.7 | 6.29 | 12.65\*\* | 5.07 | 5.37 | 98.79±2.32 | 2.35 | 0.69 |
| **ASI** | 12.62\*\* | 4.64 | 1.13 | 1.96 | 1.28 | 1.73 | 1.76±1.32 | 74.55 | 0.63 |
| **PH** | 510.9 | 1707\*\* | 442\*\* | 397.7\*\* | 212.5 | 156.78 | 225.4±12.52 | 5.56 | 0.76 |
| **EH** | 3894\*\* | 1611\*\* | 302\* | 406.2\*\* | 229.8\*\* | 130.08 | 125.73±11.41 | 9.07 | 0.79 |
| **EPP** | 0.93\*\* | 0.2\* | 0.03 | 0.11\*\* | 0.08\* | 0.05 | 1.39±0.22 | 15.51 | 0.73 |
| **EL** | 0.81 | 19.16\*\* | 4.24 | 3.24 | 3.18 | 3.1 | 17.38±1.76 | 10.14 | 0.59 |
| **ED** | 2.77 | 19.16 | 3.2\* | 7.13 | 6.41 | 5.13 | 46.68±2.26 | 4.86 | 0.63 |
| **KRPE** | 1.56 | 2.4 | 1.77 | 1.18 | 1 | 0.99 | 12.61±0.99 | 7.3 | 0.6 |
| **KPR** | 218.12\*\* | 27.98 | 12.16 | 21.11\* | 10.49 | 14.35 | 36.66±3.8 | 10.33 | 0.62 |
| **TSW** | 22.89 | 4429.93 | 3286.43 | 1707.25 | 1547.88 | 1862.03 | 350.51±43.15 | 12.31 | 0.53 |

\*\*highly significant (p<0.01), \*significant (p<0.05) L=location, Re=replication, Ent=entry, SE= standard error, CV= coefficient of variation, R2=coefficient of determination.

“This suggests that there is enough variation present to choose among the tested genotypes. Different authors” (Dagne et al., 2010; Amiruzzaman et al., 2010; Amare et al., 2016 and Ziggiju et al., 2017); Tulu et al., 2018) “revealed significant genotype differences for grain yield and yield-related parameters of various sets of maize genotypes. For grain yield, ear height, and ear per plant, the interaction between location and entrance (Location x entry) was highly significant (P<0.01) and significant (p<0.05)”. For features including anthesis date, silking date, anthesis silking interval, plant height, ear length, ear diameter, kernel row per ear, kernel per row, and thousand seed weight, however, non-significant interaction effects of (Location x entry) were noted. (Bayisa *et al*. (2008), and Dagne (2008) found consistent performance of this attribute across studies, which is consistent with the findings of the current investigation. While the rest of the traits were non-significant, traits like grain yield, anthesis date, silking date, plant height, ear height, and ear per plant are highly significant at (p<0.01 and kernel row per ear significant at (p<0.05) for genotype.

## Mean Performances of test cross for Yield and Yield-related traits across location.

Performances of the 52 testcrosses are presented in (***Appendix. I*).** The highest grain yield (10.13 t/ha-1) was recorded for (L14xT1). The cross L14 x T1 had high yield performance at both sites and across both sites. Most high yielding crosses were the test cross of T1 while the lowest GY (3.60 t/ha-1) was recorded from L2xT2. Across location overall mean of grain yield was 7.38 t ha-1 ranging from 3.60 (L2xT2) to 10.14 t ha-1 (L14xT1). The genotypes L14xT1 (10.13 t/ha), L26xT1 (9.51 t/ha), L10xT1 (9.25 t/ha), L7xT1 (8.83 t/ha) and L7xT2 (8.8 t/ha) were high yielder whereas genotypes L14xT2 (5.93 t/ha), L1xT1 (5.73t/ha), L24xT1 (5.25t/ha), L17xT2 (4.46t/ha), L2xT2 (3.6 t/ha) were low yielder as compared to the other genotypes. Among the 52 tested genotypes, 29 genotypes gave higher than the average yield (7.38 t /ha-1) whereas 23 genotypes gave lower than average yield. The following graph shows the yield performance of cross across the testing sites.

Fig 1. The graph shows the relationship of cross and mean grain yield.

The overall mean for the number of kernels per row (KPR) was 36.66 ranging from L22xT1 (28.00) to L1xT1 (40.50). Crosses L1xT1 (40.50), L12xT2 (40.00), L14xT2 (40.00), and L20xT2 (39.75) displayed a higher number of kernels per row. Crosses L22xT1 (28.00), L16xT1 (31.75), L14xT1 (32.75), and L13xT1 (33.50) displayed a lower number of kernels per row. From of 52 tested genotypes, more than half (30) genotypes gave higher than average kernel per row (36.66). Thousand kernels weight (TKW) ranged from L10xT2 (305.50 gm) to L4xT2 (388.00gm) and with an overall mean of 350.51gm. Crosses L4xT2 (388 gm), L5xT1 (384.75 gm), L22xT2 (376.75gm) and L1xT1 (375.00gm) expressed higher TKW, while crosses L10xT2 (305.50gm), L22xT1 (312.75 gm) and L25xT2 (317.50gm) and L21xT1 (318.25gm displayed lower TKW. The overall mean values of number rows per ear (NRPE) were 12.61 ranging from L19xT2 (11.25) to L2xT1 (13.50), Crosses L2xT1 (13.50), L10xT2 (13.50), L11xT2 (13.50), and L13xT2 (13.50) had a higher number of row per ear, while crosses L19xT2 (11.25), L17xT2 (11.50), L22xT1 (11.75) and L4xT1 (11.75) showed lower of NRPE. Ear diameter ranged from L19xT2 (43.75mm) crosses to L20xT1 (49.75mm) with an overall mean of 46.57 mm. Crosses L20xT1 (49.75mm), L2xT1 (5.12 mm), L10xT1 (49.00mm) and L10xT2 (48.50mm) displayed higher ear diameter (ED), while crosses L19xT2 (43.75mm), L18xT2 (44.25mm), L2xT2 (44.25mm) and L22xT1(44.50mm) expressed lower ED. The mean value for ear length (EL) was 17.38 cm and ranged from 15cm (L22xT2) to 19.25 cm (L1xT1). Crosses L26xT1 (249.50cm), L17xT1 (247.00cm), L24xT1 (245.75cm) and L9xT1 (243.25) showed higher plant height while crosses L21xT2 (207.50cm), L10xT2 (207.50cm) and L18xT2 (208.50cm) L16xT2 (210.00cm) expressed lower PH. The overall mean of plant height is 230.01cm. Ear height (EH) ranged from 111.00cm (L22xT2) to 145cm (L26xT1) with a mean ear height of 130.67cm. Crosses 145cm (L26xT1), L9xT1 (142.75cm), L2xT1 (141.50cm) and L17xT1 (140.75cm) expressed higher ear height, while crosses 111.00cm (L22xT2), L26xT2 (106.50cm), L18xT2 (106.00) and L21xT2 (103.50cm) expressed lower ear height. The following graph s the plant and ear height performance of cross across the testing sites.

Fig 2. Plant height Mean of genotype

Fig 3.Ear height Mean of genotype

Days to anthesis ranged from 91.50 (L18xT2) to (L12xT2) 100.00 with an overall mean is 97.79. Crosses L12xT2, L3xT1, L22xT1, and L7xT1 show 100.00, 99.50, 99.50and 99.25 highest days to anthesis respectively while crosses L18xT2, L4xT1, L18xT1, and L5xT2 show 91.50, 92.00, 92.75, and 93.25 lowest days to anthesis respectively. 102.00, 101.75, 101.25, and 101.00 were the highest days to silking scored by L3xT1, L12xT2, L10xT2, and L17xT1 cross while 93.75, 94.25, 95.00 and 95.50 was the lowest days to silking scored by L18xT2, L4xT1, L18xT1, and L5xT2 cross respectively with an overall mean of 98.79. Anthesis silking interval (ASI) ranged from 0.25 days for L16xT1, to 3.75 days for L22xT2, and the overall mean was 1.76. L22xT2 (3.75), L2xT2 (2.75), L6xT1 (2.75) and L20xT1 (2.75) crosses showed the highest ASI while L16xT1 (0.25), L23xT1 (0.5) L21xT1 (0.75) and L17xT2 (0.75) crosses scored the lowest ASI. The number of ears per plant (EPP) ranged from L21xT1 (1.08) to T1xL1 (1.63) with an overall mean of 1.44. Crosses T1xL1 (1.63), L9xT1 (1.83), L14xT1 (1.75), and L6xT1 (1.68) expressed the highest ear per plant record while L21xT1 (1.08), L3xT29 (1.08), L11xT2 (1.13), and L14xT2 (1.15) showed the lowest ear per plant.

## Heterotic Grouping of Inbred Lines

“Heterotic grouping designates broad classes in maize with a diverse genetic base which are complementary and result in the expression of heterosis after crossing” (Melchinger and Gumber, 1998). “The hybrid breeding program needs to organize germplasm into heterotic groups to ease its operation and increase the genetic gain” ((Hallauer *et al.,* 1998; Reif *et al.,* 2007)). “In heterotic grouping, lines expressed negative SCA effect to a certain tester implies that both the line and the tester belong to the same heterotic group, while the reverse is true when the SCA effect is positive” (Vasal *et al.,* 1992).

In this study 26 newly generated inbred lines (with unknown heterotic grouping) were crossed to two testers of known heterotic group: tester-A (CEL08008/CEL0847, Heterotic Group A (HGA)) and tester B (CEL08024/CML561, Heterotic Group B (HGB).

Some inbred lines of the present study showed significant negative SCA effects when crossed with the testers. Such lines can confidently be assigned into heterotic groups and be instantly used in the hybrid development program. These lines were L1, L22 and L24 showed negative significant SCA value with TA (CEL08008/CEL0847) and grouped under heterotic group A while L8, L10, L14, L17, L20 and L26 showed negative significant SCA value with TB (CEL08024/CML561) and grouped under heterotic group B. Conversely inbred lines that gave positive and SCA effect with tester-A were grouped under heterotic group B and those which give positive and Significant SCA effects, when crossed to tester-B, were grouped under heterotic group-A. However, seventeen most inbred lines viz L2, L3, L4, L5, L6, L7, L9, L1, L12, L13, L15, L16, L18, L19, L21, L23 and L25 were neither revealed significant SCA in their cross combinations with the testers nor significantly higher GCA effects for grain yield, indicating that neither of the two testers used for the study was genetically divergent to provide the best discrimination among the inbred lines nor the inbred lines were good general combiners for grain yield. Similar to the present findings, Bayisa (2008), Gudeta (2007) and Gudeta *et al*. (2015) reported high and positive specific combining ability estimates for inbred lines and grouped the inbred lines under different heterotic groups.

In most inbred lines of present study, the SCA and GCA effects lines and cross were not significant. This indicates that the testers did not have appropriate power to distinctively discriminate the inbred lines into different heterotic groups. For example, L4, L6, L7, L11, L13, L15, L16, L18, L21, L23, and L25 had non-significant negative SCA effects when crossed to tester-A. This implies a resemblance of the lines to heterotic group-A but it does not exactly confirm it. Therefore, we suggest repeated testing of this trial for one more year to give conclusive justification. Similarly, inbred lines like L8, L10,L14, L17, L20, and L26 had a non-significant negative SCA effect when the test crossed with tester-B (Table. 3) showing their genetic closeness to this tester even though it needs further testing for conclusive grouping.

**Table 3. Heterotic Grouping of inbred lines corresponding to testers**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Tester  | TA(HGA)  |  | TB(HGB) |  |  |  |
| Line  | SCA  | GY(t/ha-1)  | SCA  | GY (t/ha-1)  | Line GCA  | Heterotic group |
| 1 | -1.37\*\*\* | 5.73 | 1.37\*\*\* | 8 | -0.63\*\* | A |
| 2 | 0.13 | 8.48 | -0.12 | 3.6 | 0.69\*\* | - |
| 3 | 0.19 | 7.78 | -0.17 | 6.98 | 0.02 | - |
| 4 | -0.21 | 8.55 | 0.22 | 8.48 | 0.98\*\*\* | - |
| 5 | 0.02 | 8.63 | -0.01 | 8.08 | 0.85\*\*\* | - |
| 6 | -0.24 | 6.63 | 0.25 | 6.63 | -0.82 | - |
| 7 | -0.50 | 8.83 | 0.51 | 8.8 | 1.08 | - |
| 8 | 0.74\*\* | 8.73 | -0.74\*\* | 6.8 | 0.31 | B |
| 9 | 0.12 | 8.08 | -0.11 | 7.3 | 0.30 | - |
| 10 | 0.76 | 9.25 | -0.76\*\* | 7.03 | 0.69\*\* | B |
| 11 | -0.28 | 7.3 | 0.29 | 7.53 | -0.06 | - |
| 12 | 0.45 | 7.55 | -0.44 | 6.18 | -0.55\* | - |
| 13 | -0.54 | 7.98 | 0.55 | 8.58 | 0.88\*\* | - |
| 14 | 1.90\*\*\* | 10.13 | -1.90\*\*\* | 5.93 | 0.41 | B |
| 15 | -0.35 | 7.03 | 0.36 | 7.38 | -0.15 | - |
| 16 | -0.02 | 7.65 | 0.03 | 7.33 | 0.07 | - |
| 17 | 1.46\*\*\* | 7.95 | -1.46\*\*\* | 4.46 | -1.26\*\*\* | B |
| 18 | -0.22 | 7.83 | 0.24 | 7.65 | 0.26 | - |
| 19 | 0.10 | 7.7 | -0.09 | 7.05 | 0.10 | - |
| 20 | 0.76\*\* | 8.78 | -0.75\*\* | 6.98 | 0.37 | B |
| 21 | -0.45 | 6.48 | 0.46 | 6.8 | -0.68\*\* | - |
| 22 | -1.50\*\*\* | 3.6 | 1.50\*\*\* | 6.13 | -2.69\*\*\* | A |
| 23 | -0.30 | 7.55 | 0.31 | 7.4 | 0.01 | - |
| 24 | -1.36\*\*\* | 5.25 | 1.36\*\*\* | 7.5 | -0.94\*\*\* | A |
| 25 | -0.28 | 7.73 | 0.29 | 7.8 | 0.24 | - |
| 26 | 1.12\*\*\* | 9.51 | -1.12\*\*\* | 6.4 | 0.37 | B |

HGA=Heterotic group A, HGB=Heterotic group B, GY=Grain yield, SCA=Specific combining ability, GCA=General combining ability.

**Conclusion and Recommendation**

The current study was conducted to estimate the test cross performance and heterotic pattern of conventional highland maize inbred lines and classify them into heterotic groups. Twenty-six inbred lines were crossed during 2019/2020 with two single cross testers following the LxT mating design. Thus, 52 maize single cross hybrids were evaluated in alpha lattice design with two replications at Ambo and Kulumsa. Analysis of variance indicated the presence of significant variation among the genotypes for most studied traits. Mean square of hybrid x location showed highly significant difference for traits such as GY, AD, SD, PH, EH, EPP and significant interaction for KPR indicating that hybrid performance was not consistent across locations for the traits. Based on two sites grain yield performance, the present study identified crosses viz L14x T1 (10.13 t/ha), L26 x T1), L10xT1), L7x T1), (L7 xT2) and L20 x T1) for further multi-location evaluation. Based on significant negative SCA effects of crosses, L8, L10, L14, L17, L20, and L26 were suggested under heterotic group-B while L1, L22, and L24 were classified under heterotic group-A. From inbred lines assigned into the different heterotic groups, it is recommended to develop hybrid varieties. On the other hand, synthetic variety could be developed from inbred lines assigned into the same heterotic group by using it as a source of germ plasm. Use of different heterotic grouping is better to explore the possibility of separating these and other inbred lines into distinct heterotic groups using the currently used and other more divergent testers.

**Data availability:** The manuscript contains the data supporting the study's conclusions, and the corresponding author can be contacted with any additional questions.

**Declarations:** The authors declare they have no conflict of interest.

Disclaimer (Artificial intelligence)

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Details of the AI usage are given below:

1.

2.

3.

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**Appendix. I. Performance evaluation of cross across location**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **SN** |  | **GY** | **AD** | **SD** | **ASI** | **PH** | **EH** | **EPP** | **EL** | **ED** | **KRPE** | **KPR** | **TSW** |
| **Genotype** |
| **1** | **L1XT1** | 5.7 | 97.5 | 99.3 | 1.8 | 223.3 | 124.5 | 1.6 | 19.3 | 47.0 | 12.5 | 40.5 | 375.0 |
| **2** | **L1XT2** | 8.0 | 96.0 | 97.3 | 1.3 | 210.8 | 114.5 | 1.4 | 17.0 | 45.5 | 12.5 | 37.3 | 327.5 |
| **3** | **L2XT1** | 8.5 | 98.0 | 100.3 | 2.3 | 228.0 | 141.5 | 1.5 | 17.8 | 49.3 | 13.5 | 35.8 | 367.3 |
| **4** | **L2XT2** | 3.6 | 98.0 | 100.8 | 2.8 | 222.5 | 117.3 | 1.3 | 17.3 | 44.3 | 12.0 | 35.0 | 354.0 |
| **5** | **L3XT1** | 7.8 | 99.5 | 102.0 | 2.5 | 219.8 | 126.8 | 1.3 | 16.3 | 46.3 | 12.8 | 33.8 | 324.5 |
| **6** | **L3XT2** | 7.0 | 98.8 | 100.0 | 1.3 | 230.3 | 120.3 | 1.1 | 18.8 | 45.3 | 12.0 | 35.3 | 348.0 |
| **7** | **L4XT1** | 8.6 | 92.0 | 94.3 | 2.3 | 228.0 | 135.0 | 1.4 | 17.3 | 46.5 | 11.8 | 34.8 | 374.8 |
| **8** | **L4XT2** | 8.5 | 93.8 | 95.5 | 1.8 | 224.3 | 125.5 | 1.3 | 18.3 | 46.5 | 12.8 | 38.8 | 388.0 |
| **9** | **L5XT1** | 8.6 | 95.3 | 96.5 | 1.3 | 226.5 | 128.5 | 1.5 | 17.0 | 47.0 | 12.5 | 38.5 | 384.8 |
| **10** | **L5XT2** | 8.1 | 93.3 | 95.5 | 2.3 | 213.0 | 115.3 | 1.5 | 17.5 | 45.0 | 12.3 | 36.3 | 342.3 |
| **11** | **L6XT1** | 6.6 | 97.3 | 100.0 | 2.8 | 223.8 | 132.8 | 1.7 | 17.8 | 46.8 | 13.0 | 37.5 | 325.8 |
| **12** | **L6XT2** | 6.6 | 97.5 | 99.8 | 2.3 | 229.8 | 129.3 | 1.4 | 17.5 | 47.0 | 12.8 | 37.5 | 353.8 |
| **13** | **L7XT1** | 8.8 | 99.3 | 100.8 | 1.5 | 232.3 | 135.5 | 1.6 | 17.0 | 47.0 | 12.8 | 38.3 | 329.5 |
| **14** | **L7XT2** | 8.8 | 97.8 | 100.0 | 2.3 | 220.0 | 129.5 | 1.5 | 18.0 | 47.3 | 12.5 | 37.5 | 346.3 |
| **15** | **L8XT1** | 8.7 | 97.8 | 99.3 | 1.5 | 230.0 | 124.8 | 1.4 | 17.5 | 45.5 | 13.0 | 39.3 | 344.3 |
| **16** | **L8XT2** | 6.8 | 98.3 | 100.8 | 2.5 | 211.3 | 112.8 | 1.3 | 17.5 | 46.3 | 12.8 | 38.5 | 364.3 |
| **17** | **L9XT1** | 8.1 | 97.5 | 99.5 | 2.0 | 243.3 | 142.8 | 1.8 | 16.8 | 47.5 | 12.5 | 36.3 | 369.3 |
| **18** | **L9XT2** | 7.3 | 98.3 | 100.0 | 1.8 | 224.8 | 122.8 | 1.4 | 18.5 | 47.8 | 12.5 | 37.5 | 367.3 |
| **19** | **L10XT1** | 9.3 | 95.8 | 97.5 | 1.8 | 233.3 | 139.5 | 1.4 | 18.0 | 49.0 | 13.0 | 39.0 | 367.0 |
| **20** | **L10XT2** | 7.0 | 98.8 | 101.3 | 2.5 | 207.5 | 112.5 | 1.2 | 17.0 | 48.5 | 13.5 | 37.8 | 305.5 |
| **21** | **L11XT1** | 7.3 | 96.5 | 97.8 | 1.3 | 213.0 | 116.5 | 1.2 | 18.8 | 46.5 | 13.0 | 37.8 | 351.0 |
| **22** | **L11XT2** | 7.5 | 96.5 | 98.8 | 2.3 | 234.0 | 126.3 | 1.1 | 18.3 | 48.3 | 13.5 | 37.3 | 336.0 |
| **23** | **L12XT1** | 7.6 | 97.3 | 99.5 | 2.3 | 215.3 | 136.0 | 1.4 | 17.3 | 45.8 | 12.8 | 36.3 | 374.8 |
| **24** | **L12XT2** | 6.2 | 100.0 | 101.8 | 1.8 | 220.3 | 139.3 | 1.2 | 18.8 | 44.8 | 13.0 | 40.0 | 343.3 |
| **25** | **L13XT1** | 8.0 | 97.8 | 99.0 | 1.3 | 238.0 | 136.3 | 1.5 | 16.3 | 46.3 | 12.0 | 33.5 | 332.8 |
| **26** | **L13XT2** | 8.6 | 97.0 | 98.0 | 1.0 | 225.3 | 120.3 | 1.6 | 17.3 | 46.5 | 13.5 | 37.0 | 368.0 |
| **27** | **L14XT1** | 10.1 | 96.5 | 97.5 | 1.0 | 230.3 | 139.3 | 1.8 | 17.0 | 48.5 | 12.8 | 32.8 | 348.8 |
| **28** | **L14XT2** | 5.9 | 97.8 | 98.5 | 0.8 | 218.8 | 119.3 | 1.2 | 17.0 | 45.8 | 13.0 | 40.0 | 371.0 |
| **29** | **L15XT1** | 7.0 | 97.0 | 97.8 | 0.8 | 224.8 | 130.5 | 1.3 | 16.8 | 46.8 | 12.5 | 38.8 | 333.5 |
| **30** | **L15XT2** | 7.4 | 97.5 | 100.0 | 2.5 | 223.0 | 121.8 | 1.3 | 17.5 | 47.3 | 12.3 | 38.3 | 362.5 |
| **31** | **L16XT1** | 7.7 | 98.5 | 98.8 | 0.3 | 215.0 | 121.3 | 1.5 | 17.0 | 45.8 | 12.0 | 31.8 | 360.0 |
| **32** | **L16XT2** | 7.3 | 96.8 | 97.8 | 1.0 | 210.0 | 125.0 | 1.5 | 16.3 | 45.8 | 12.5 | 37.8 | 357.0 |
| **33** | **L17XT1** | 8.0 | 99.0 | 101.0 | 2.0 | 247.0 | 140.8 | 1.5 | 17.3 | 48.0 | 12.3 | 35.5 | 364.0 |
| **34** | **L17XT2** | 4.5 | 97.8 | 98.5 | 0.8 | 217.0 | 113.5 | 1.3 | 17.3 | 44.8 | 11.5 | 33.8 | 332.5 |
| **35** | **L18XT1** | 7.8 | 92.8 | 95.0 | 2.3 | 228.8 | 126.5 | 1.6 | 17.3 | 46.0 | 12.5 | 37.0 | 335.8 |
| **36** | **L18XT2** | 7.7 | 91.5 | 93.8 | 2.3 | 208.5 | 106.0 | 1.5 | 17.0 | 44.3 | 13.0 | 37.5 | 372.0 |
| **37** | **L19XT1** | 7.7 | 94.3 | 96.0 | 1.8 | 227.8 | 123.5 | 1.4 | 16.3 | 46.8 | 12.8 | 35.0 | 342.0 |
| **38** | **L19XT2** | 7.1 | 97.3 | 98.3 | 1.0 | 231.8 | 123.8 | 1.3 | 17.0 | 43.8 | 11.3 | 35.5 | 363.0 |
| **39** | **L20XT1** | 8.8 | 96.8 | 99.5 | 2.8 | 237.3 | 140.5 | 1.4 | 16.5 | 49.8 | 13.3 | 34.8 | 325.3 |
| **40** | **L20XT2** | 7.0 | 96.5 | 98.0 | 1.5 | 225.0 | 121.3 | 1.3 | 18.3 | 47.5 | 12.5 | 39.8 | 349.8 |
| **41** | **L21XT1** | 6.5 | 97.0 | 97.8 | 0.8 | 224.3 | 124.0 | 1.7 | 15.5 | 44.8 | 12.5 | 38.0 | 318.3 |
| **42** | **L21XT2** | 6.8 | 98.3 | 100.3 | 2.0 | 207.5 | 103.5 | 1.1 | 18.5 | 48.5 | 12.8 | 35.5 | 371.5 |
| **43** | **L22XT1** | 3.6 | 99.5 | 101.0 | 1.5 | 221.0 | 123.0 | 1.2 | 15.0 | 44.5 | 11.8 | 28.0 | 312.8 |
| **44** | **L22XT2** | 6.1 | 97.0 | 100.8 | 3.8 | 213.3 | 111.0 | 1.4 | 16.5 | 48.3 | 13.3 | 34.5 | 376.8 |
| **45** | **L23XT1** | 7.6 | 97.3 | 97.8 | 0.5 | 238.8 | 134.3 | 1.5 | 18.3 | 45.5 | 12.3 | 37.5 | 373.3 |
| **46** | **L23XT2** | 7.4 | 96.0 | 97.3 | 1.3 | 242.8 | 130.8 | 1.2 | 18.0 | 46.0 | 13.5 | 34.8 | 344.0 |
| **47** | **L24XT1** | 5.3 | 98.0 | 99.0 | 1.0 | 245.8 | 138.8 | 1.4 | 16.5 | 45.0 | 12.3 | 35.3 | 361.8 |
| **48** | **L24XT2** | 7.5 | 98.5 | 100.5 | 2.0 | 235.0 | 119.8 | 1.6 | 18.8 | 46.5 | 12.5 | 37.5 | 323.0 |
| **49** | **L25XT1** | 7.7 | 97.5 | 100.3 | 2.8 | 224.8 | 128.5 | 1.3 | 17.0 | 47.3 | 12.5 | 36.3 | 348.3 |
| **50** | **L25XT2** | 7.8 | 97.0 | 99.8 | 2.8 | 217.5 | 114.8 | 1.3 | 18.5 | 46.8 | 13.0 | 38.3 | 317.5 |
| **51** | **L26XT1** | 9.5 | 96.8 | 98.3 | 1.5 | 249.5 | 145.0 | 1.6 | 16.8 | 47.3 | 12.8 | 38.3 | 344.5 |
| **52** | **L26XT2** | 6.4 | 97.8 | 99.5 | 1.8 | 226.0 | 106.5 | 1.6 | 18.0 | 47.8 | 12.0 | 38.0 | 353.8 |
|  | **Mean** | **7.4** | **97.0** | **98.8** | **1.8** | **225.4** | **125.7** | **1.4** | **17.4** | **46.6** | **12.6** | **36.7** | **350.5** |
|  | **Max** | **10.1** | **100.0** | **102.0** | **3.8** | **249.5** | **145.0** | **1.8** | **19.3** | **49.4** | **13.5** | **40.5** | **388.0** |
|  | **Min** | **3.6** | **91.5** | **93.8** | **0.3** | **207.5** | **103.5** | **1.1** | **15.0** | **43.8** | **11.3** | **28.0** | **305.5** |
|  | **CV** | **8.7** | **2.2** | **2.3** | **72.6** | **4.5** | **7.9** | **15.4** | **9.3** | **4.6** | **7.9** | **10.1** | **12.5** |
|   | **LSD (5%)** | **1.4** | **3.2** | **3.3** | **1.9** | **17.6** | **16.0** | **0.3** | **2.5** | **3.2** | **1.4** | **5.3** | **60.6** |