Evaluation of Diallel Crosses of Highland Adapted QPM Maize Hybrids under Optimum and Low Nitrogen Conditions

Tefera Kumsa1, Demissew Abakemal1, Dufera Tulu1, Zeleke Keimiso1, Habtamu Zeleke2 and Mekuanent Belay2
1Ambo Agricultural Research Center, Ethiopia
2Haramaya University, Ethiopia

Abstract: Eight inbred lines collected from Ambo Agricultural Research Center Highland maize sub-program and were evaluated under optimum and Low Nitrogen condition at Ambo and Haramaya University in 2018. Breeding programs have created inbred lines of maize introduced from CIMMYT; they were tested locally for their heterosis. The objective of this study was to generate information regarding the combining ability effect of selected highland adapted maize inbred lines and their crosses for further breeding and cultivar development in view of this limitation. P6 was the lines that exhibited positive and hence good combiner for gain yield in all locations and environmental condition and crosses found to be good yield potential in this study were (P1xP2), (P2xP7) and (P4xP6).

Keywords: Diallel, QPM, Breeding program, CIMMYT.

INTRODUCTION

Maize (Zea mays ssp. mays L) has key importance in assuring the world food security and a high yielding cereal crop as well [1]. In Ethiopia, maize crop has been considered as one of the most important food security assurance and expansion of its agricultural production. According to the Central Statistic Agency report of 2018, maize is an important staple crop, ranking first among cereals in total grain production (27.43%) and second in area coverage (16.79%). However, the national average yield of maize (3.9 t ha⁻¹) is still low [2] compared to the world average.

In Ethiopia QPM development program was launched in 1994 with the evaluation of open pollinated varieties (OPVs) and pools introduced from CIMMYT [3]. Higher content of lysine and tryptophan have been successfully increased in maize through conventional breeding.

The Ambo highland breeding program is one of the three maize breeding programs under National Maize Research Program of the Ethiopian Institute of Agricultural Research. Yearly, the breeding program handles several numbers of QPM and non QPM crosses generated at different stages of the breeding pipeline with the aim of identifying, superior genotypes for the target agroecolgy. This is because improved commercial maize varieties suited to highland areas of Ethiopia have been fewer and consequently access to maize seed has also been limited. Evaluation of the genetic potential or performances of maize genotypes within the breeding, pipeline will help identifying genotypes with good traits of interest for future use in breeding and cultivar development.

For target environment mating design such as diallel play an important role in the selection and advancement of breeding materials. Hayman [4] and Griffing [5] proposed the concept of diallel cross as the recombination of genetic variability available in the program, performing crosses among all lineages. The diallel scheme of analysis allows estimating useful genetic information to select parental lines and verify the combining ability effect, which are described as general and specific. The objective of this study was, therefore, to generate information regarding the combining ability effect of selected highland adapted maize inbred lines and their crosses for further breeding and cultivar development in view of this limitation.
**MATERIAL AND METHOD**

**Study Location**
The study was conducted at Ambo (optimum and Low-N conditions), Agricultural Research Center and Haramaya University in the main cropping season of 2019. The locations represent highland, sub-humid maize growing environments of Ethiopia [6].

**Experimental Design and Cultural Practices**
In each location alpha lattice experimental design (5x6) were used with two replications. Each plot consisted a single row of 5.25m long. The spacing was 75 cm between rows and 25 cm between plants. Planting was done in the rainy season of 2019 after reliable moisture level of soil attained to ensure good germination and seedling development using two seeds per hill and thinned out to one plant after 35 days of planting.

**Data Collection**
The data were recorded by field scorer and taken mostly from twenty-one maize plants for each plot. Traits such as Grain yield, days to anthesis, days to silking. Plant height, ear height, root and stalk lodging, husk cover, ear rot, disease (TLB and Rust), plant aspect, ear aspect, days to maturity, Ear per plant, number of ear and number of plant were recorded for the study.

Days to 50% silking and 50% anthesis were calculated as number of days from sowing until 50% of plants in each row showing tassel and silks. Anthesis-silking interval (ASI; days) computed as the difference between days to 50% anthesis and silking. Plant height (PH; cm) was measured as the distance from the soil surface to the top of tassel. Ear height (EH; cm) was measured as the distance from the soil surface to the main ear bearing node. Plant aspect was recorded by observing overall phenotypic appearance of the ear in a plot at harvesting time by using 1 to 5 scoring scale; where 1 = excellent and 5 = poor. Kernel modification data measured by using 1 to 5 scoring scale of opaque’s of the kernel. 1=excellent and 5= choky type.

**RESULTS AND DISCUSSION**

**Analysis of Variance (ANOVA)**
Individual location analysis of variances were made on grain yield and yield related traits such as days to anthesis, days to silking, plant and ear height, ear per plant, bad husk cover, ear rot, ear aspect, plant aspect, ear texture, anthesis silking interval, root lodge, (Rust) diseases, stalk lodge and *E. turcicum* leaf blight (TLB) for each location.

Result in table 2 indicated that mean squares due to entries (genotypes) revealed significant highly (p<0.01) difference for grain yield and other related traits at Ambo (optimum and low-N condition) and Haramaya as well, indicating that there is variability

---

**Experimental Materials**
Eight QPM inbred lines were selected depending on their performance and diverse pedigree back grounds (Table 1). The experiment was composed of 28 F1 crosses formed using half diallel mating design at Ambo during the main cropping season of 2019 and Two (2) commercial hybrid checks: check-1 (Kolba) and check-2(Jibat).

---

| S/N | Lines Code | Pedigree | Source |
|-----|------------|----------|--------|
| 1   | L1         | [ECU/SNSYN[SC/ETO]]c1F1-##(GLS=1)-34-3-1-2/CML144(BC2)-34-8-2-1-1-1-1-1-B-##-B | AHMBP |
| 2   | L2         | [POOL9Ac7-SR(BC2)]FS67-1-2-3-1-##/CML144(BC2)-10-11-2-4-1-2-1-2-1-1-B-##B | AHMBP |
| 3   | L3         | [POOL9Ac7-SR(BC2)]FS68-1-1-2-1-1/CML144(BC2)-33-10-2-4-1-2-1-1-B-##B | AHMBP |
| 4   | L4         | (CML197/(CML197/[(CLQR CWQ50/CML312SR)-2-2-1-BB/CML197]-BB)F2)-B-B-9-1-B-## | AHMBP |
| 5   | L5         | (CML197/CML197/[(CLQR CWQ50/CML312SR)-2-2-1-BB/CML197]-BB)F2)-B-B-35-2-B-## | AHMBP |
| 6   | L6         | (CML197/CML197/[(CLQR CWQ50/CML312SR)-2-2-1-BB/CML197]-BB)F2)-B-B-44-2-B-## | AHMBP |
| 7   | L7         | (CML197/CML197/(CLQR CWQ50/CML312SR)-2-2-1-BBB)F2)-B-B-18-2-B-## | AHMBP |
| 8   | L8         | (CML395/CML395/CML511)F2)-B-B-37-1-B-## | AHMBP |

*AHMBP = Ambo Highland Maize Breeding Program*
between materials evaluated. As the study result showed that significant differences were observed among F1 hybrids for all traits in line with the report of Mohamed Ali, 2020 [16].

Results in Table 2 indicate that mean squares of genotypes and most character in all location and environmental condition were significantly different. Under managed low N stress F1 hybrids were significant for most traits. This finding is similar with the report of Susan et al., [9].

Table 2: Mean squares due to genotypes for grain yield and related traits at three locations under optimum and low –N conditions in 2019

| Traits  | Ambo (Opt.) | Ambo (Low-N) | Haramaya (Opt) |
|---------|-------------|--------------|----------------|
| GY      | DF=29       | DF=18        | DF=29          |
|        | **4.30**    | **0.80**     | **0.82**       |
| AD      | **26.41**   | **21.60**    | 3.41           |
| ASI     | 18.23       | 26.1         | 10.1           |
| EPP     | 0.8**       | 0.11**       | 0.08**         |
| HC      | 396.4**     | 5.91**       | 7.02**         |
| EA      | 0.3**       | 0.28**       | 0.1**          |
| PA      | 0.4**       | 0.41**       | 0.2**          |
| TXT     | 0.29**      | 0.42**       | 0.12**         |
| CV      | 18.7        | 41.9         | 15.9           |
| GY mean | 4.8         | 1.5          | 7.5            |

** = highly significant at (p<0.01), * = significant at (p<0.05), GY = grain yield, AD = number of days to anthesis, ASI=anthesis - silking interval, EPP = number of ears per plant, HC=husk cover, EA= ear aspect, PA= plant aspect, TXT = seed texture

Combining ability analysis

Analysis of variances for combining ability revealed that variances for general combining ability (GCA) and specific combining ability (SCA) were significant for some traits while non-significant for most traits under the three environmental conditions and its similar with the finding of [10].

Table 3: Diallel analysis of variance for yield and yield related traits of highland maize hybrids grown at Ambo (optimum and Low -N) and Haramaya

| Source | Df | Mean squares |
|--------|----|--------------|
|        |    | DA | DS | ASI | HC | PA | Kmod | EA | Yield (t ha-1) |
| Ambo (opt) | 27 | 21.4 | 1.4 | 11.8 | 110.3 | 0.28 | 0.3* | 0.31* | 3.3 |
| Cosses  | 7  | 35.3* | 2.1* | 12.6 | 150.8 | 0.3* | 0.2 | 0.1 | 0.8 |
| GCA     | 20 | 22.4 | 1.5 | 12.1 | 96.9* | 0.4 | 0.3* | 0.2 | 4.5 |
| SCA     | 22 | 13.1 | 25.2 | 16.11 | 106.3 | 0.2 | 0.2 | 0.2 | 2.9 |
| Ambo (Low-N) | SEN | |
| Ambo (Low-N) | 27 | 1.1 | 15 | 0.6 | 0.2 | 0.3* | 0.3* | 0.22 | 0.6 |
| Cosses  | 7  | 1.2 | 18.4 | 0.8 | 0.3* | 0.2 | 0.2 | 0.3* | 0.9 |
| GCA     | 20 | 0.9 | 13.8 | 0.5 | 0.2 | 0.3* | 3.3 | 0.23 | 0.6 |
| SCA     | 22 | 15.0 | 15 | 27.7 | 0.3 | 0.29 | 2.7 | 0.19 | 0.5 |
| Haramaya | ER | |
| GCA     | 27 | 68.8 | 69.5 | 0.31* | 187.5* | 0.19 | 172.1* | 0.29* | 2.5 |
| SCA     | 7  | 130.2 | 127.1 | 0.16 | 162.3 | 0.18 | 216.3* | 0.19 | 0.8 |
| Error   | 22 | 190.1 | 184.9 | 0.4 | 699.4 | 0.19 | 83.5 | 0.14 | 3.2 |

*Significant at P < 0.05. ** Significant at P < 0.01. GCA, general combining ability; SCA, specific combining ability; DT, days to tasseling; DS, days to silking; ASI, anthesis silking interval; PA, plant aspect; Kmod,kernel modification; EA, ear aspect; HC, husk cover and GY, grain yield, SEN , senesces , ER , ear rot
General Combining Ability (GCA) Effects

Estimates of general combining ability effects are presented in Table (4). Some inbred parents showed positive and significant GCA effects for some traits at Ambo (optimum and Low- N conditions) site. Parents with significantly desirable GCA effects were considered as high combiners, Low or poor combiners had significant but negative (undesirable) GCA effect for grain yield [11]. At Ambo (opt.) the good general combiner parent is characterized by its better breeding value when crossed with other parents as stated in the report of Kumar et al., [12].

Table-4: Estimates for general combining ability effects of inbred parents

| Parents | DA | DS | ASI | PA | Kmod | HC | EA | GY |
|---------|----|----|-----|----|------|----|----|----|
| Ambo (opt) | SE(gi) | 0.69 | 0.9 | 0.7 | 0.08 | 0.07 | 1.9 | 0.09 | 0.32 |
| Ambo (Low N) | | | | | | | | |
| P1 | -0.75 | -2.23 | 1.48 | -0.10 | 0.00 | -0.16 | 0.06 | 0.32* |
| P2 | -1.00 | -2.81* | 1.81 | 0.10 | -0.33 | -0.16 | 0.10 | 0.01 |
| P3 | 0.50 | 1.69 | -1.19 | -0.23* | -0.42 | 0.79 | 0.23* | -0.38* |
| P4 | -0.92 | 0.10 | -1.02 | 0.02 | -0.17 | -0.60 | -0.06 | 0.14 |
| P5 | -1.25 | -2.73* | 1.48 | 0.01 | 0.50 | -0.60 | 0.10 | -0.36* |
| P6 | 1.58* | 2.77* | -1.19 | 0.06 | 0.58 | -0.04 | 0.15 | 0.02 |
| P7 | 2.00* | 2.02 | -0.02 | -0.06 | 0.00 | 0.79 | -0.16 | -0.08 |
| P8 | -0.17 | 1.19 | -1.35 | 0.06 | -0.17 | -0.04 | -0.23* | 0.35* |
| SE(gi) | 0.74 | 1.17 | 1.00 | 0.10 | 0.31 | 0.47 | 0.08 | 0.14 |

Ambo (Low N)

| Parents | DA | DS | ASI | PA | SEN | HC | EA | GY |
|---------|----|----|-----|----|-----|----|----|----|
| P1 | -0.75 | -2.23 | 1.48 | -0.10 | 0.00 | -0.16 | 0.06 | 0.32* |
| P2 | -1.00 | -2.81* | 1.81 | 0.10 | -0.33 | -0.16 | 0.10 | 0.01 |
| P3 | 0.50 | 1.69 | -1.19 | -0.23* | -0.42 | 0.79 | 0.23* | -0.38* |
| P4 | -0.92 | 0.10 | -1.02 | 0.02 | -0.17 | -0.60 | -0.06 | 0.14 |
| P5 | -1.25 | -2.73* | 1.48 | 0.01 | 0.50 | -0.60 | 0.10 | -0.36* |
| P6 | 1.58* | 2.77* | -1.19 | 0.06 | 0.58 | -0.04 | 0.15 | 0.02 |
| P7 | 2.00* | 2.02 | -0.02 | -0.06 | 0.00 | 0.79 | -0.16 | -0.08 |
| P8 | -0.17 | 1.19 | -1.35 | 0.06 | -0.17 | -0.04 | -0.23* | 0.35* |
| SE(gi) | 0.74 | 1.17 | 1.00 | 0.10 | 0.31 | 0.47 | 0.08 | 0.14 |

Haramaya (Opt)

| Parent | DA | DS | ASI | PA | ER | HC | EA | Gy |
|--------|----|----|-----|----|----|----|----|----|
| P1 | 0.35 | 0.38 | -0.02 | -0.17 | -6.55* | -14.29* | -0.10 | -0.16 |
| P2 | -2.31 | -2.21 | -0.10 | 0.08 | -4.56* | -11.49* | -0.19* | -0.15 |
| P3 | 2.02 | 1.96 | 0.06 | 0.13 | -1.17 | 1.25 | 0.06 | 0.58 |
| P4 | 1.44 | 1.46 | -0.02 | 0.08 | 2.46 | 12.24* | 0.10 | -0.31 |
| P5 | 2.60 | 2.71 | -0.10 | 0.00 | 0.19 | 11.99* | 0.06 | -0.09 |
| P6 | -5.65* | -5.71* | 0.06 | 0.08 | 7.20* | 14.27* | 0.19* | 0.08 |
| P7 | -2.73 | -2.63 | -0.10 | 0.00 | 1.58 | -4.10 | -0.10 | 0.01 |
| P8 | 4.27 | 4.04 | 0.23 | -0.21* | 0.84 | -9.87 | -0.02 | 0.04 |
| SE(gi) | 2.63 | 2.59 | 0.12 | 0.08 | 1.74 | 5.04 | 0.07 | 0.34 |

Specific Combining Ability (SCA) Effects

Results of the SCA effects of the crosses for yield and different yield related characters are presented in Table 5. Positive SCA effect for grain yield was observed in 14 crosses but significant positive effects were observed on three crosses for gain yield as well. For traits such as days to silking and plant aspect, the cross (P1xP7) showed significant negative SCA effect, but positive and significant effect for the trait kernel modification from the same crosses at this location.
At Ambo Low-N condition, 12 F1 crosses revealed positive SCA effect for grain yield of these crosses (P1xP3) and (P3xP8) showed significant positive SCA effect for gain yield. From (P2xP5) positive and significant SCA effect observed for the traits Senescence, husk cover, ear rot and ear aspect indicating tolerant to open tip and rotting. This finding is in line with the report of in line with the report of Francis et al., 13. At all testing and environments crosses that exhibited positive SCA effect for gain yield indicating the prevalence of non-additive gene effects for the inheritance of these traits as the report of Motiar et al., 14. Significant SCA effects indicated that the crosses performed better or poorer than what would be expected based on GCA effects of the respective parent as the report of Bitew et al., 15.

Table-5: Estimates of specific combining ability (SCA) effects on yield and its components in diallel cross of maize

| Crosses | DA | DS | ASI | PA | Knod | HC | EA | GY |
|---------|----|----|-----|----|------|----|----|----|
| P1xP2  | 1.40 | 0.26 | 1.14 | 0.71** | -0.54* | -4.84 | 0.35 | -2.06* |
| P1xP3  | 1.32 | 1.76 | -0.44 | 0.01 | -0.12 | -1.00 | -0.40 | 0.66 |
| P1xP4  | 2.82 | 5.10 | -2.27 | 0.34 | 0.05 | 1.71 | 0.05 | -0.29 |
| P1xP5  | 5.15* | 7.51* | -2.36 | 0.38 | -0.29 | -0.59 | 0.43 | 0.22 |
| P1xP6  | -3.26 | -2.90 | -0.36 | -0.37 | 0.21 | 5.59 | -0.20 | 1.00 |
| P1xP7  | -2.85 | -6.74* | 3.89 | -0.54* | 0.84** | -4.63 | -0.07 | -0.35 |
| P1xP8  | -4.60 | -4.99 | 0.39 | -0.54* | -0.16 | 3.77 | -0.15 | 0.83 |
| P2xP3  | -0.35 | -1.57 | 1.23 | -0.24 | 0.55* | -4.79 | 0.01 | -0.19 |
| P2xP4  | -2.35 | -6.74* | 4.39* | -0.41 | 0.46 | -2.84 | -0.03 | 0.52 |
| P2xP5  | -1.01 | 0.18 | -1.19 | 0.13 | -0.37 | -7.04 | 0.10 | -1.53 |
| P2xP6  | -1.93 | 1.26 | -3.19 | -0.37 | -0.37 | 8.15 | -0.03 | 2.15* |
| P2xP7  | -0.01 | 2.93 | -2.94 | -0.04 | 0.01 | 11.58* | -0.15 | 0.11 |
| P2xP8  | -4.24* | 3.68 | 0.56 | 0.21 | 0.26 | -0.22 | -0.24 | 1.01 |
| P3xP4  | -3.43 | -5.74 | 2.31 | -0.37 | 0.13 | -0.74 | -0.03 | -0.27 |
| P3xP5  | 0.90 | 2.68 | -1.77 | 0.42 | -0.20 | 6.81 | 0.35 | -1.27 |
| P3xP6  | 3.49 | 2.26 | 1.23 | 0.42 | -0.45* | -6.86 | 0.22 | -1.74 |
| P3xP7  | -4.10* | -0.57 | -3.52 | -0.24 | 0.17 | 4.52 | -0.15 | 2.68* |
| P3xP8  | 2.15 | 1.18 | 0.98 | 0.01 | -0.08 | 2.07 | 0.01 | 0.14 |
| P4xP5  | 0.40 | 0.01 | 0.39 | 0.01 | -0.29 | -4.04 | -0.20 | -0.22 |
| P4xP6  | -2.51 | -0.90 | -1.61 | -0.24 | 0.21** | 11.25* | -0.07 | 1.31 |
| P4xP7  | 5.40* | 6.76* | -1.36 | 0.59* | -0.41 | -6.87* | 0.55 | -1.80 |
| P4xP8  | -0.35 | 1.51 | -1.86 | 0.09 | -0.16 | 1.53 | -0.28* | 0.76 |
| P5xP6  | 1.32 | -0.99 | 2.31 | -0.20 | 0.38** | -5.55 | -0.20 | -0.28 |
| P5xP7  | -2.76 | -6.32* | 3.56 | -0.37 | 0.01 | 10.68* | -0.32 | 2.09* |
| P5xP8  | -4.01* | -3.07 | -0.94 | -0.37 | 0.76 | -0.27 | -0.15 | 1.00 |
| P6xP7  | 2.32 | 1.76 | 0.56 | 0.38 | 0.01 | -10.49* | -0.20 | -0.71 |
| P6xP8  | 0.57 | -0.49 | 1.06 | 0.38 | 0.01 | -2.09 | 0.47 | -1.72 |
| P7xP8  | 1.99 | 2.18 | -0.19 | 0.21 | -0.62 | -4.80 | 0.35 | -2.01* |

| SE(ij)  | 2.16 | 2.99 | 2.39 | 0.27 | 0.23 | 6.16 | 0.29 | 1.02 |

© East African Scholars Publisher, Kenya 43
Tefera Kumsa, *EAS J Biotechnol Genet;* Vol-3, Iss-2 (Mar-Apr, 2021); 30-37

### Table 6: Mean square due to combined analyses of genetic variance for grain yield and agronomic traits of maize

| Source | df | Yield | KPE | EL | ED | HC | ER | GC |
|--------|----|-------|-----|----|----|----|----|----|
| ENV    | 2  | 134.02** | 0.09 | 4.66 | 2.54** | 14.06 | 57.26** |
| REP (ENV) | 6  | 5.64 | 13.88* | 3.68 | 0.57** | 17.96 | 64.02** |
| Crosses | 65 | 5.52 | 32.64** | 16.22** | 0.2** | 204.91** | 197.12** |
| Crosses*Env | 130 | 5.63 | 9.95 | 6.22* | 0.12* | 73.55** | 69.53** |
| GCA     | 11 | 9.81* | 22.38** | 10.31** | 0.27** | 157.96** | 114.73** |
| GCA * ENV | 54 | 4.65 | 34.74** | 17.42** | 0.18** | 214.48** | 213.90** |
| SCA * ENV | 22 | 8.31* | 1.72 | 2.67 | 0.17** | 9.07 | 20.30* |
| Error   | 528 | 5.26 | 6.29 | 4.2 | 0.1 | 33.32 | 33.74 |
| Mean    | 7.34 | 31.25 | 14.66 | 4.49 | 9.48 | 9.11 |
| CV      | 18.63 | 8.03 | 7.20 | 45.88 | 43.69 |
CONCLUSION

In conclusion, inbred lines such as P2, P4, P5, P6 and P7 had positive but non-significant GCA effect for grain yield at Ambo optimum condition. P2, P4 and P6 were significant positive GCA effect while, P1 and P8 showed significant positive GCA for gain yield at Ambo low N condition. At Haramaya P3, P6. P7 and P8 had positive but insignificant GCA effect for gain yield. Therefore, P6 was the lines that exhibited positive and hence good combiner for gain yield in all locations and environmental condition. For SCA effects the crosses of those line were selected for further breeding purpose. Positive SCA effects observed from cross such as (P2xP4), (P2xP6), (P2xP7), (P3xP8), (P4xP) 8 and (P5xP8) both at Ambo (opt.) and Haramya. At Ambo (optimum and Low –N) condition cross that revealed positive SCA effects were (P1xP8), (P2xP7), (P3xP7), (P4xP6) and (P5xP7). In the same pattern the cross that exhibited positive SCA effect in both Ambo low-N and Haramaya were (P1xP2), (P2xP7) and (P4xP6). The overall study indicated cross that showed positive SCA effects in all testing and environment are (P2xP7) and (P4x P6). Therefore those crosses with per se performance could be more rewarding in a hybrid breeding program in the future career.

REFERENCES

1. Rohman, M. M., Islam, M. R., Naznin, T., Omy, S. H., Begum, S., Alam, S. S., ... & Hasanuzzaman, M. (2019). Maize production under salinity and drought conditions: Oxidative stress regulation by antioxidant defense and glyoxalase systems. In Plant Abiotic Stress Tolerance (pp. 1-34). Springer, Cham.
2. CSA (Central Statistics Agency). (2018). Agricultural Sample Survey 2017/2018: Report on Area and Production of Major Crops ((Private Peasant Holdings, Meher Season).
3. Teklewold, A., Gissa, D. W., Tadesse, A., Tadesse, B., Bantte, K., Friesen, D., & Prasanna, B. M. (2015). Quality Protein Maize (QPM): A guide to the technology and its promotion in Ethiopia.
4. Hayman, B. I. (1954). The theory and analysis of diallel crosses. Genetics, 39, 789-809.
5. Griffing, B. R. U. C. E. (1956). Concept of general and specific combining ability in relation to diallel crossing systems. Australian journal of biological sciences, 9(4), 463-493.
6. Worku, M., Bänziger, M., Friesen, D., Horst, W. J., & Vivek, B. (2008). Relative importance of general combining ability and specific combining ability among tropical maize (Zea mays L.) inbreds under contrasting nitrogen environments.
7. Bullo, N., & Dagne, W. (2016). Combining ability of inbred lines in quality protein maize (QPM) for varietal improvement. International Journal of plant breeding and crop Science, 3(1), 079-089.
8. Bullo, N., & Dagne, W. (2016). Combining ability of inbred lines in quality protein maize (QPM) for varietal improvement. International Journal of plant breeding and crop Science, 3(1), 079-089.
9. Njeri, S. G., Makumbi, D., Warburton, M. L., Jumbo, M. B., & Chemining’wa, G. (2017). Genetic analysis of tropical quality protein maize (Zea mays L.) germplasm. Euphytica, 213(11), 1-19.
10. Fayad, E. A., Lelah, A. A. A., Mostafa, E. S. E., & Morgan, S. F. (2019). Morphological identification and evaluate the combining ability and heterosis of some inbred lines of maize and its crosses. Zagazig Journal of Agricultural Research, 46(6), 2145-2157.
11. Amiruzzaman, M., Islam, M. A., Hassan, L., & Rohman, M. M. (2010). Combining ability and heterosis for yield and component characters in maize. Academic Journal of Plant Sciences, 3(2), 79-84.
12. Njeri, S. G., Makumbi, D., Warburton, M. L., Jumbo, M. B., & Chemining’wa, G. (2017). Genetic analysis of tropical quality protein maize (Zea mays L.) germplasm. Euphytica, 213(11), 1-19.
13. Onejeme, F. C., Okporie, E. O., & Eze, C. E. (2020). Combining Ability and Heterosis in Diallel Analysis of Maize (Zea mays L.) Lines. International Annals of Science, 9(1), 188-200.
14. Rohman, M. M., Hossain, M. G., Omy, S. H., Methela, N. J., & Molla, M. R. (2019). Evaluation of diallel crosses of maize at multilocation (Zea mays L.) for saline tolerance. Journal of Cereals and Oilseeds, 10(2), 29-42.
15. Tilahun, B., Dida, M., Deresa, T., Garoma, B., Demissie, G., Kebede, D., ... & Chere, A. T. (2017). Combining ability analysis of quality protein maize (QPM) inbred lines for grain yield, agronomic traits and reaction to grey leaf spot in mid-altitude areas of Ethiopia.
16. Ali, M. (2020). Diallel analysis of maize inbreds for grain yield, protein and tryptophan content. Egyptian Journal of Agronomy, 42(1), 1-17.

Cite This Article: Tefera Kumsa et al (2021). Evaluation of Diallel Crosses of Highland Adapted QPM Maize Hybrids Under Optimum and Low Nitrogen Conditions. EAS J Biotechnol Genet, 3(2), 30-37.

© East African Scholars Publisher, Kenya