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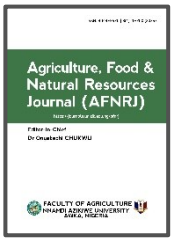


Original Article

# Gene action for yield and striga resistance traits in maize hybrids evaluated under striga-infested and striga-free conditions

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**ABSTRACT**

*Striga hermonthica (Del.) Benth. is a destructive parasitic weed limiting maize production in sub-Saharan Africa. This study evaluated combining ability and gene action for grain yield, agronomic traits and Striga resistance in maize hybrids. Thirty-six $F_1$ hybrids derived from nine white-kernel inbred lines through a diallel mating design without reciprocals were evaluated alongside four commercial checks under Striga-infested and Striga-free conditions at Samaru and Batsari, Nigeria. Entries were arranged in a 5 × 8 alpha-lattice design with three replications. Data were collected on grain yield, flowering and other agronomic traits, emerged Striga counts at 10 weeks after planting and Striga damage ratings. Data were subjected to combined analysis of variance, separately for the two infestation conditions, and combining ability was analysed using Griffing's Method IV, Model I. Significant differences occurred among hybrids for grain yield and most agronomic and Striga-related traits. General and specific combining ability effects were significant for most traits, with GCA/SCA mean-square ratios below unity (0.21–0.85), indicating larger SCA than GCA mean squares. Under Striga infestation, TZEEI 6 × TZEE-WPOP C5 yielded 4.91 t ha$^{-1}$, with seven emerged Striga plants and a damage rating of 1. Under Striga-free conditions, TZEI 108 × TZEE-WPOP C5 yielded 6.65 t ha$^{-1}$. These findings support further evaluation of promising crosses for hybrid development in Striga-endemic environments.*

**KEYWORDS:** *Action, Diallel analysis, General combining ability, Hybrid breeding, Specific combining ability*

## INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereal crops in sub-Saharan Africa (SSA), where it serves as an important food, feed, and industrial crop (Badu-Apraku & Fakorede, 2017). In Nigeria, the crop contributes substantially to national food security and provides raw materials for livestock feed and agro-industrial processing. Despite its economic and nutritional importance, average maize yields in SSA remain considerably lower than the global average because of a combination of biotic and abiotic constraints, low adoption of improved technologies, and suboptimal crop management practices (Badu-Apraku & Fakorede, 2017; FAO, 2022).

Among the biotic constraints, *Striga hermonthica* (Del.) Benth (Striga) is regarded as one of the most destructive parasitic weeds affecting maize production in the savannah ecologies of West and Central Africa. The parasite attaches to host roots and withdraws water, mineral nutrients, and photosynthates, resulting in chlorosis, severe stunting, poor ear development, and substantial grain yield losses. Under severe infestation, maize yield losses may reach 100% (Kim, 1991; Yacoubou *et*

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*al*., 2021; Dossa *et al*., 2023), while persistent and severe Striga infestation may ultimately lead farmers to abandon affected fields (Ejeta, 2007; Parker, 2012).

More than 50 million hectares of agricultural land under cereal cultivation in sub-Saharan Africa (SSA) are infested by Striga spp., resulting in substantial cereal yield losses and estimated annual economic losses of up to US$10 billion (Dossa *et al*., 2024).

Several control options, including hand weeding, crop rotation, fertilizer application, herbicide use, biological control and integrated Striga management, have been proposed for managing Striga (Yacoubou *et al*., 2021). However, individual control measures may be constrained by labour and resource requirements or may provide inadequate control under smallholder production systems. Consequently, host-plant resistance remains a practical and sustainable component of Striga management, particularly when incorporated into integrated management strategies (Badu-Apraku & Fakorede, 2017; Dossa *et al*., 2023).

Genetic improvement for Striga resistance in maize depends on the availability of resistant parental lines, knowledge of the inheritance of resistance traits, and the ability to identify cross combinations that combine high grain yield with low Striga emergence and damage. Previous studies have shown that resistance and tolerance to Striga in maize are complex traits influenced by the genetic background of the parents, the level of infestation, and the test environment (Menkir & Kling, 2007; Badu-Apraku *et al*., 2012; Ifie *et al*., 2015; Alabi *et al*., 2020). Therefore, understanding the type of gene action controlling grain yield and Striga-related traits is important for choosing the most appropriate breeding strategy.

Significant progress has been made in developing early- and extra-early maize inbred lines and hybrids with improved resistance to Striga and enhanced grain yield under infestation (Badu-Apraku *et al*., 2012; Ifie *et al*., 2015; Badu-Apraku *et al*., 2020). Recent studies have also emphasized the importance of combining ability analysis, heterotic grouping, and tester identification in developing maize hybrids adapted to Striga-infested and non-infested environments (Oyekale *et al*., 2020; Adu *et al*., 2022; Makinde *et al*., 2023; Okunlola *et al*., 2023). These studies indicate that the relative importance of additive and non-additive gene effects may differ across traits, populations, and environments.

Combining ability analysis is an important tool in hybrid breeding because it reveals the relative performance of inbred lines in hybrid combinations and provides insight into the nature of gene action controlling target traits (Griffing, 1956). General combining ability (GCA) measures the average performance of a parent in hybrid combinations and is mainly associated with additive gene effects, whereas specific combining ability (SCA) reflects the performance of particular cross combinations and is largely associated with non-additive gene effects, including dominance and epistasis. Knowledge of the relative importance of GCA and SCA is essential because traits governed mainly by additive effects can be improved through selection and recurrent improvement, while traits governed mainly by non-additive effects are better exploited through hybrid development (Griffing, 1956; Badu-Apraku *et al*., 2016).

Previous genetic studies on maize under Striga infestation have reported significant contributions of both additive and non-additive gene effects to grain yield and resistance-related traits. In some cases, additive effects were more important for grain yield and adaptive traits, suggesting the usefulness of recurrent selection and parental population improvement. In other cases, non-additive effects were more important for grain yield and Striga resistance, indicating the importance of dominance effects and heterosis breeding (Menkir & Kling, 2007; Badu-Apraku *et al*., 2012; Ifie *et al*., 2015; Alabi *et al*., 2020; Okunlola *et al*., 2023). These contrasting reports show that gene action for Striga resistance is not fixed but depends on the genetic materials and environments under investigation.

Although several studies have examined the inheritance of Striga resistance in tropical maize, information is still needed on the combining ability of hybrids derived from diverse white-kernel inbred lines representing different maturity groups under both Striga-infested and Striga-free conditions in the Nigerian savannahs. The evaluation of these specific parental lines and hybrid combinations provides additional breeding information for identifying superior parents and crosses and guiding the development of high-yielding, Striga-resistant maize hybrids adapted to target environments.

Therefore, this study was undertaken to evaluate the performance of maize hybrids under Striga-infested and Striga-free conditions and to determine the relative importance of additive and non-additive gene effects controlling grain yield, agronomic traits, and Striga resistance traits.

## MATERIALS AND METHODS

### Experimental Sites

Field trials were conducted during the 2017 cropping season at Samaru (11°11′N, 07°38′E, 686 m asl) in the Northern Guinea savannah and Batsari (12°45′N, 07°15′E, 551 m asl) in the Sudan savannah of Nigeria. Samaru receives an average annual rainfall of ~1,050 mm, while Batsari receives ~850 mm. Both sites are Striga-endemic and represent contrasting production environments.

### Genetic Materials and Population Development

The genetic materials consisted of nine white-kernel inbred lines representing different maturity groups. Two inbreds, TZEEI 6 and TZEE-WPOP C5, belonged to the extra-early maturity group, while TZEI 59, TZEI 60, TZEI 86, and TZEI 108 were classified as early-maturing lines. Two quality protein maize (QPM) inbreds, TZEQI 4 and TZEQI 24, also belonged to the early maturity group, and ENT 3 was an early-maturing

line with known resistance to Striga. A total of 36 $F_1$ hybrids were generated from these parents using a diallel mating design without reciprocals. Four commercial checks—SAMMAZ 42, SAMMAZ 46, SAMMAZ 33, and SAMMAZ 32—were included as controls.

**Experimental Design and Striga Infestation**

The 36 hybrids and 4 checks (40 entries) were evaluated under Striga-infested and Striga-free conditions at both sites. A 5 × 8 α-lattice design with three replications was used. Each plot consisted of a single 5 m row, with 0.75 m spacing between rows and 0.25 m between plants, corresponding to ~53,333 plants $ha^{-1}$. For artificial infestation, *Striga hermonthica* seeds collected from naturally infested fields, particularly from plants parasitizing sorghum, were bulked and mixed with sand to facilitate uniform application. The seed–sand inoculum was placed in each planting hole before sowing the maize seeds, following Kim (1991). Non-infested plots were established on Striga-free fields and managed to prevent infestation.

**Agronomic Practices**

Three seeds were sown per hill and thinned to two seedlings two weeks after emergence. Fertilizer was applied at 60 kg N, 60 kg $P_2O_5$, and 60 kg $K_2O$ $ha^{-1}$ at planting, followed by top-dressing with 60 kg N $ha^{-1}$ four weeks after planting. Weeds were controlled manually in Striga-free plots, while no weeding was done in infested plots after Striga emergence to allow full parasite expression.

**Data Collection**

Data were recorded on agronomic and Striga-related traits using standard protocols (Kim, 1991; Badu-Apraku *et al*., 2012). Agronomic traits: days to 50% anthesis, days to 50% silking, anthesis–silking interval, plant height (cm), ears per plant, plant aspect, ear aspect, grain moisture content (%), and grain yield (kg $ha^{-1}$, adjusted to 15% moisture and 80% shelling percentage). Striga traits: emerged Striga plants counted at 10 weeks after planting (WAP) and Striga damage rating scored on a 1–9 scale (1 = no visible damage, 9 = complete plant death).

**Base Index**

A base index was used to rank hybrids under Striga-infested conditions by combining grain yield, ears per plant, Striga damage rating and emerged Striga counts. The index was computed as $I = [(2 \times YLI) + EPP - SDR - 0.5(STRCO)]$, where YLI = grain yield under infestation, EPP = ears per plant, SDR = Striga damage rating, and STRCO = emerged Striga counts at 10 WAP. Higher positive values indicated better tolerance to Striga infestation.

**Statistical Analysis**

Data were subjected to analysis of variance (ANOVA) using PROC GLM in SAS. Combined analyses across the two locations (Samaru and Batsari) were performed separately for the Striga-infested and Striga-free conditions, with genotypes considered fixed and locations considered random. Combining ability analysis was conducted using Griffing's (1956) Method IV, Model I, partitioning variation among crosses into general combining ability (GCA) and specific combining ability (SCA). The relative importance of GCA and SCA was further assessed using the ratio of GCA to SCA mean squares (GCA/SCA), following Yallou *et al*. (2009). Ratios greater than unity indicate relatively larger GCA mean squares, whereas ratios below unity indicate relatively larger SCA mean squares.

## RESULTS AND DISCUSSION

The combined analysis of variance across the two locations (Samaru and Batsari), conducted separately under Striga-infested and Striga-free conditions, revealed significant differences among the hybrids for grain yield, agronomic traits, and Striga-related parameters, indicating substantial genetic variability among the test materials (Table 1). Location effects were significant for some traits, indicating that the expression of these traits differed between Samaru and Batsari (Table 1). Significant GCA × location interactions were observed for days to anthesis, days to silking, and plant height under the same conditions, while the SCA × location interaction was significant for plant height under the Striga-free condition (Table 1). These interactions indicate that the combining ability effects for these traits varied between locations.

Partitioning of the genetic variation into general combining ability (GCA) and specific combining ability (SCA) components showed that both effects were significant for most of the measured traits under both Striga-infested and Striga-free conditions (Table 1). The GCA/SCA mean-square ratios were below unity for all traits, ranging from 0.21 to 0.85, indicating consistently larger SCA than GCA mean squares. For grain yield, the ratios were 0.49 and 0.62 under Striga-infested and Striga-free conditions, respectively, while ratios of 0.25 and 0.77 were obtained for Striga emergence and damage rating under infestation, respectively (Table 1). This pattern indicates the greater relative importance of non-additive gene effects for these traits. These findings suggest that non-additive gene effects played an important role in the expression of hybrid performance under Striga infestation. Similar predominance of non-additive gene action for grain yield and Striga resistance has been reported in tropical maize by Menkir & Kling (2007), Ifie *et al*. (2015), and Alabi *et al*. (2020).

The predominance of SCA mean squares was also evident for the agronomic traits. The GCA/SCA ratios for days to anthesis ranged from 0.48 to 0.85, while those for days to silking ranged from 0.25 to 0.50. Plant height showed particularly low ratios of 0.23 and 0.21 under Striga-infested and Striga-free conditions, respectively (Table 1). These results further indicate the importance of non-additive gene effects in the inheritance of agronomic traits among the hybrids evaluated.

**Table 1a: Combined ANOVA mean squares for grain yield and flowering traits of maize hybrids**

| Source of Variation | df | Grain yield (t ha-1) | | Days to Anthesis | | Days to silking | | Anthesis silking interval | |
|---|---|---|---|---|---|---|---|---|---|
| | | I | NI | I | NI | I | NI | I | NI |
| Location | 1 | 0.74** | 0.51 | 0.01 | 0.44 | 0.44 | 0.01 | 1.36 | 1.36 |
| GCA | 8 | 3.56** | 5.58** | 7.36** | 6.24* | 6.44* | 58.87** | 3.78** | 3.78* |
| SCA | 27 | 7.25** | 8.97** | 8.62** | 12.97** | 12.97** | 232.61** | 5.59** | 5.59 |
| GCA × Location | 8 | 0.05 | 0.25 | 6.03* | 5.26* | 5.26* | 48.21* | 0.61 | 0.61 |
| SCA × Location | 27 | 0.09 | 0.12 | 2.64 | 2.3 | 2.3 | 71.29 | 0.51 | 0.51 |
| Error | 70 | 0.09 | 0.19 | 2.35 | 2.39 | 2.39 | 2.35 | 0.79 | 0.79 |

**, ** Significant at 5% and 1% levels of probability, respectively. I = Striga-Infested; NI = Striga non-Infested, WAP= weeks after planting*

**Table 1b: Combined ANOVA mean squares for agronomic and Striga resistance traits of maize hybrids**

| Source of Variation | df | Plant aspect | | Ear aspect | | Ears per plant | | Plant height (cm) | | Striga counts 10WAP | Striga damage rating 10 WAP |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | I | NI | I | NI | I | NI | I | NI | I | I |
| Location | 1 | 1.46 | 1.46 | 1 | 0 | 0 | 0 | 10833.34** | 10848.96** | 3.77 | 1.85 |
| GCA | 8 | 1.87** | 1.87 | 1.36** | 0.05 | 0.05 | 0.05 | 541.21 | 521.82 | 14.79 | 19.54** |
| SCA | 27 | 2.25** | 2.25 | 1.94** | 0.10* | 0.10* | 0.10* | 2384.78** | 2436.29** | 58.18** | 25.39** |
| GCA × Location | 8 | 0.35 | 0.35 | 0.07 | 0.16 | 0.16 | 0.16 | 0.03 | 1044.55** | 3.53 | 1.36 |
| SCA × Location | 27 | 0.29 | 0.29 | 0.53 | 0.12 | 0.12 | 0.12 | 0.05 | 561.40** | 10.6 | 1.07 |
| Error | 70 | 0.41 | 0.41 | 0.46 | 0.02 | 0.02 | 0.02 | 147.06 | 422.03 | 10.93 | 1.35 |

**, ** Significant at 5% and 1% levels of probability, respectively. I = Striga-Infested; NI = Striga non-Infested, WAP= weeks after planting*

The GCA effects of the parental inbred lines revealed considerable variation in their breeding values for grain yield and Striga-related traits (Table 2). TZEEI 6, TZEI 108, and TZEE-WPOP C5 exhibited positive and significant GCA effects for grain yield under both Striga-infested and Striga-free conditions, indicating that these inbreds contributed favourable alleles for enhanced productivity. ENT 3 showed desirable GCA effects for reduced Striga emergence, indicating its potential value as a parent in breeding for Striga resistance. In addition, TZEI 108 and TZEE-WPOP C5 showed negative GCA effects for Striga damage rating, indicating their usefulness for improving tolerance to Striga damage. The superior combining ability of these inbred lines indicates their potential usefulness in hybrid development and population improvement programmes. Similar results involving extra-early and early maize inbreds under Striga infestation have been reported by Ifie *et al*. (2015) and Badu-Apraku *et al*. (2020).

**Table 2: General combining ability effects for grain yield and agronomic traits of maize inbred lines**

| S/n | Inbreds | Grain yield (t $ha^{-1}$) | | Days to anthesis | | Days to silking | | Anthesis silking Interval | | Plant aspect | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | I | NI | I | NI | I | NI | I | NI | I | NI |
| 1. | TZEI 86 | -0.08 | -0.10 | 0.01 | 0.01 | -0.16 | -0.16 | -0.01 | -0.01 | -0.27* | -0.34** |
| 2. | TZEI 60 | -0.45** | -0.66** | 0.33 | 0.33 | 0.12 | 0.12 | -0.26 | -0.26 | 0.18 | -0.27* |
| 3. | TZEI 59 | -0.11 | -0.02 | 0.80* | 0.80** | 0.59* | 0.59* | -0.26 | -0.26 | 0.08 | 0.18 |
| 4. | TZEI 108 | 0.16** | 0.20** | 0.01 | 0.01 | 0.23 | 0.23 | 0.38* | 0.38* | 0.15 | 0.08 |
| 5. | ENT 3 | -0.43** | -0.53** | 0.55 | 0.55 | 0.56 | 0.55 | -0.04 | -0.04 | -0.19 | 0.15 |
| 6. | TZEEI 6 | 0.31** | 0.33** | -0.45 | -0.45 | -0.98** | -0.98** | -0.58** | -0.58** | -0.24* | -0.19 |
| 7. | TZEE-WPOP $C_5$ | 1.16** | 1.23** | -0.35 | -0.35 | 0.05 | 0.05 | 0.35* | 0.35* | 0.54** | -0.24* |
| 8. | TZEQI 4 | -0.14** | -0.40** | -0.42 | -0.42 | 0.19 | 0.19 | 0.56** | 0.56** | 0.09 | 0.54** |
| 9. | TZEQI 24 | -0.42** | -0.04 | -0.49 | -0.49 | -0.59* | -0.59* | -0.15 | -0.15 | 0.01 | 0.09 |

**, ** Significant at 5% and 1% levels of probability, respectively. I = Striga-Infested; NI = Striga non-Infested, WAP= weeks after planting*

Specific combining ability effects varied substantially among the hybrid combinations (Table 3), indicating the importance of specific parental interactions in the expression of grain yield and resistance traits. TZEEI 6 × TZEE-WPOP C5 recorded high positive SCA effects for grain yield under both Striga-infested and Striga-free conditions, while TZEE-WPOP C5 × TZEQI 4 had a high positive SCA effect under Striga-infested conditions. These results suggest strong non-additive genetic interactions between the parental lines of the superior hybrids, especially under Striga stress. Conversely, some hybrid combinations exhibited low or negative SCA effects for grain yield, emphasizing the importance of selecting appropriate parental combinations for hybrid development.

**Table 3: Specific combining ability effects for grain yield under Striga-infested and Striga-free conditions**

| Parents | TZEI 86 | TZEI 60 | TZEI 59 | TZEI 108 | ENT 3 | TZEEI 6 | TZEE-WPOP $C_5$ | TZEQI 4 | TZEQI 24 |
|---|---|---|---|---|---|---|---|---|---|
| TZEI 86 | | -0.17 | 0.06 | 0.00 | -0.13 | 0.05 | 0.61** | -0.71** | 0.30* |
| TZEI 60 | -0.51** | | -0.40** | 0.07 | 0.45** | -0.50** | -1.25** | 1.21** | 0.60** |
| TZEI 59 | 0.73** | -0.06 | | 2.10** | -0.43** | -0.21 | -1.25** | -0.06 | 0.19 |
| TZEI 108 | -0.51** | 0.25 | 1.03** | | -0.07 | -1.42** | -0.09 | -0.50** | -0.10 |
| ENT 3 | -0.78** | 1.31** | -0.06 | -1.48** | | 0.12 | -0.31* | -1.46** | 0.83** |
| TZEEI 6 | 1.62** | -1.40** | -1.69** | -0.07 | 0.25 | | 2.33** | -0.39** | 0.00 |
| TZEE-WPOP $C_5$ | -0.61** | -1.16** | -1.22** | 2.23** | -0.52** | 1.92** | | 1.34** | -1.39** |
| TZEQI 4 | -0.94** | 1.12** | 1.23** | -1.25** | -0.16 | 0.37* | 0.35 | | -0.43** |
| TZEQI 24 | 1.00** | 0.45* | 0.04 | -0.21 | 1.44** | -1.01** | -0.99** | -0.73** | |

**, ** Significant at 5% and 1% level of probability, respectively. Note: Upper diagonal = Striga-infested; lower diagonal = Striga-free.*

Considerable variation was also observed in the mean performance of the hybrids and checks under both Striga-infested and Striga-free conditions (Table 4). Under Striga infestation, TZEEI 6 × TZEE-WPOP C5 recorded the highest grain yield (4.91 t ha$^{-1}$), followed by TZEE-WPOP C5 × TZEQI 4 (3.46 t ha$^{-1}$) and TZEI 59 × TZEI 108 (3.26 t ha$^{-1}$). The best-performing commercial check under infestation was SAMMAZ 46, which produced 2.27 t ha$^{-1}$. Hybrid TZEEI 6 × TZEE-WPOP C5 out-yielded SAMMAZ 46 by approximately 116.3% under Striga-infested conditions, while TZEE-WPOP C5 × TZEQI 4 exceeded the same check by about 52.4%. These results demonstrate the substantial hybrid advantage and improved adaptation of the superior experimental hybrids under Striga stress conditions.

Under Striga-free conditions, TZEI 108 × TZEE-WPOP C5 recorded the highest grain yield (6.65 t ha$^{-1}$), followed closely by TZEEI 6 × TZEE-WPOP C5 (6.47 t ha$^{-1}$). The high yield of TZEEI 6 × TZEE-WPOP C5 under both Striga-infested and Striga-free conditions indicates broad adaptation and strong yield potential. This hybrid also recorded low Striga emergence (7 plants at 10 WAP), the lowest Striga damage rating (1), and the highest base index (3.71), confirming its superiority for both productivity and Striga resistance. Similarly, TZEE-WPOP C5 × TZEQI 4 combined high grain yield under infestation (3.46 t ha$^{-1}$) with low Striga damage rating (2) and a high base index (2.29), making it another promising hybrid for further evaluation.

The superior performance of TZEEI 6 × TZEE-WPOP C5 and TZEE-WPOP C5 × TZEQI 4 may be attributed to favourable non-additive genetic interactions, as reflected by their positive SCA effects for grain yield and good mean performance under Striga infestation. Similar superiority of specific hybrid combinations over commercial checks under Striga infestation has been reported in tropical maize breeding programmes in West and Central Africa (Badu-Apraku *et al*., 2012; Oyekunle *et al*., 2017).

Overall, the consistently lower GCA/SCA mean-square ratios across grain yield, agronomic, and Striga-related traits indicate the greater relative importance of non-additive gene effects in the genetic materials evaluated. This highlights the potential of heterosis breeding for exploiting favourable specific cross combinations for improved grain yield and Striga resistance. The outstanding hybrids identified in this study, particularly TZEEI 6 × TZEE-WPOP C5 and TZEE-WPOP C5 × TZEQI 4, should be advanced to further multi-environment evaluation to confirm their yield stability and adaptation across Striga-endemic ecologies.

**Table 4. Mean performance of maize hybrids for grain yield, agronomic traits and Striga-related parameters under Striga-infested and Striga-free conditions**

| S/n | Hybrids/checks | Grain yield (t ha$^{-1}$) | | Days to 50% Anthesis | | Plant height (cm) | | Striga counts 10WAP | Striga damage Rating 10 WAP | Base index |
|---|---|---|---|---|---|---|---|---|---|---|
| | | I | NI | I | NI | I | NI | I | I | I |
| 1 | TZEI 86 × TZEI 60 | 0.4 | 1.7 | 59 | 59 | 95 | 110 | 10 | 8 | -0.72 |
| 2 | TZEI 86 × TZEI 59 | 0.98 | 3.59 | 60 | 60 | 100 | 165 | 13 | 6 | -0.15 |
| 3 | TZEI 86 × TZEI 108 | 1.18 | 2.57 | 62 | 58 | 98 | 163 | 13 | 6 | 0.05 |
| 4 | TZEI 86 × ENT 3 | 0.46 | 1.57 | 62 | 60 | 130 | 168 | 15 | 7 | -0.66 |
| 5 | TZEI 86 × TZEEI 6 | 1.39 | 4.83 | 59 | 58 | 115 | 164 | 18 | 7 | 0.26 |
| 6 | TZEI 86 × TZEE-WPOP $C_5$ | 2.79 | 3.5 | 61 | 59 | 152 | 169 | 12 | 2 | 1.63 |
| 7 | TZEI 86 × TZEQI 4 | 0.17 | 1.54 | 61 | 57 | 95 | 165 | 11 | 8 | -0.94 |
| 8 | TZEI 86 × TZEQI 24 | 0.9 | 3.85 | 61 | 60 | 110 | 156 | 11 | 6 | -0.22 |
| 9 | TZEI 60 × TZEI 59 | 0.15 | 2.24 | 60 | 59 | 79 | 94 | 5 | 8 | -0.96 |
| 10 | TZEI 60 × TZEI 108 | 0.89 | 2.77 | 61 | 61 | 109 | 154 | 11 | 8 | -0.23 |
| 11 | TZEI 60 × ENT 3 | 0.67 | 3.1 | 62 | 60 | 105 | 160 | 12 | 5 | -0.45 |
| 12 | TZEI 60 × TZEEI 6 | 0.48 | 1.25 | 61 | 58 | 107 | 162 | 15 | 8 | -0.64 |
| 13 | TZEI 60 × TZEE-WPOP $C_5$ | 0.57 | 2.4 | 63 | 60 | 81 | 115 | 9 | 8 | -0.54 |
| 14 | TZEI 60 × TZEQI 4 | 1.72 | 3.04 | 60 | 58 | 116 | 129 | 17 | 6 | 0.58 |
| 15 | TZEI 60 × TZEQI 24 | 0.83 | 2.74 | 61 | 61 | 125 | 135 | 13 | 3 | -0.3 |
| 16 | TZEI 59 × TZEI 108 | 3.26 | 4.2 | 63 | 60 | 127 | 174 | 13 | 3 | 2.09 |
| 17 | TZEI 59 × ENT 3 | 0.14 | 2.37 | 62 | 60 | 94 | 164 | 7 | 9 | -0.97 |
| 18 | TZEI 59 × TZEEI 6 | 1.11 | 1.61 | 61 | 57 | 140 | 149 | 13 | 4 | -0.02 |
| 19 | TZEI 59 × TZEE-WPOP-$C_5$ | 0.91 | 2.98 | 62 | 61 | 102 | 169 | 15 | 6 | -0.21 |
| 20 | TZEI 59× TZEQI 4 | 0.8 | 3.79 | 62 | 59 | 163 | 165 | 17 | 7 | -0.33 |
| 21 | TZEI 59 × TZEQI 24 | 0.77 | 2.97 | 59 | 60 | 105 | 165 | 19 | 6 | -0.35 |
| 22 | TZEI 108 × ENT 3 | 0.77 | 1.17 | 56 | 57 | 120 | 136 | 13 | 8 | -0.35 |
| 23 | TZEI 108 × TZEEI 6 | 0.17 | 3.45 | 60 | 60 | 82 | 179 | 9 | 8 | -0.94 |
| 24 | TZEI 108 × TZEE-WPOP-$C_5$ | 2.34 | 6.65 | 60 | 57 | 101 | 169 | 15 | 2 | 1.19 |
| 25 | TZEI 108 × TZEQI 4 | 0.63 | 1.53 | 60 | 56 | 147 | 159 | 15 | 4 | -0.49 |
| 26 | TZEI 108 × TZEQI 24 | 0.74 | 2.94 | 62 | 60 | 117 | 152 | 12 | 5 | -0.38 |
| 27 | ENT 3 × TZEEI 6 | 1.11 | 3.03 | 62 | 62 | 85 | 181 | 11 | 5 | -0.02 |
| 28 | ENT 3 × TZEE-WPOP $C_5$ | 1.53 | 3.16 | 62 | 58 | 105 | 170 | 15 | 4 | 0.39 |
| 29 | ENT 3 × TZEQI 4 | 0.08 | 1.89 | 61 | 64 | 86 | 105 | 3 | 9 | -1.03 |
| 30 | ENT 3 × TZEQI 24 | 1.08 | 3.85 | 62 | 62 | 133 | 187 | 11 | 8 | -0.04 |
| 31 | TZEEI 6 × TZEE-WPOP $C_5$ | 4.91 | 6.47 | 59 | 59 | 146 | 167 | 7 | 1 | 3.71 |
| 32 | TZEEI 6 × TZEQI 4 | 0.89 | 3.29 | 61 | 61 | 84 | 158 | 10 | 8 | -0.24 |
| 33 | TZEEI 6 × TZEQI 24 | 1 | 2.27 | 58 | 61 | 88 | 165 | 12 | 9 | -0.13 |
| 34 | TZEE-WPOP $C_5$ × TZEQI 4 | 3.46 | 4.16 | 56 | 54 | 105 | 142 | 14 | 2 | 2.29 |
| 35 | TZEE-WPOP $C_5$ × TZEQI 24 | 0.45 | 3.18 | 59 | 61 | 111 | 192 | 13 | 7 | -0.66 |
| 36 | TZEQI 4 × TZEQI 24 | 0.11 | 1.82 | 60 | 62 | 72 | 95 | 8 | 9 | -1 |
| 37 | SAMMAZ 42 | 1.57 | 4.13 | 58 | 58 | 128 | 165 | 14 | 6 | 0.43 |
| 38 | SAMMAZ 46 | 2.27 | 3.67 | 61 | 62 | 128 | 161 | 10 | 4 | 1.12 |
| 39 | SAMMAZ 33 | 0.97 | 2.61 | 62 | 62 | 103 | 165 | 12 | 7 | -0.16 |
| 40 | SAMMAZ 32 | 0.48 | 2.27 | 63 | 61 | 116 | 137 | 16 | 7 | -0.63 |
| | Mean | 1.13 | 3 | 61 | 59 | 110 | 154 | 12 | 6 | |
| | S.E ± | 0.2 | 0.31 | 1.06 | 1.04 | 12.36 | 12 | 26.98 | 20.63 | |
| | CV (%) | 25.63 | 14.8 | 2.46 | 2.49 | 9.22 | 12 | 2.33 | 0.87 | |

## CONCLUSION AND RECOMMENDATION

Significant genetic variability observed among the maize hybrids under both Striga-infested and Striga-free conditions indicated considerable potential for genetic improvement. Significant general combining ability (GCA) and specific combining ability (SCA) effects observed for most traits demonstrated the importance of both additive and non-additive gene action in the inheritance of grain yield, agronomic, and Striga resistance traits. However, GCA/SCA mean-square ratios were below unity for all evaluated traits, indicating consistently larger SCA than GCA mean squares and the greater relative importance of non-additive gene effects in the genetic materials evaluated.

Among the parental inbred lines, TZEEI 6, TZEI 108, and TZEE-WPOP C5 were identified as good general combiners for grain yield under both management conditions, while ENT 3 showed desirable GCA effects for reduced Striga emergence. Hybrids TZEEI 6 × TZEE-WPOP C5 and TZEE-WPOP C5 × TZEQI 4 combined high grain yield with low Striga damage and reduced Striga emergence, and substantially out-performed the commercial checks under infestation. In particular, TZEEI 6 × TZEE-WPOP C5 exceeded the best commercial check by more than 100% under Striga-infested conditions, indicating its strong potential for deployment in Striga-prone environments.

Therefore, TZEEI 6 × TZEE-WPOP C5 and TZEE-WPOP C5 × TZEQI 4 should be advanced for further multi-location and multi-season evaluation to confirm their yield stability and adaptation in Striga-endemic environments. The promising parental lines should also be used in hybrid development and recurrent selection programmes to improve grain yield, Striga resistance, and adaptive traits in tropical maize.

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### Authors' Contributions

IAZ conducted the data analysis, interpreted the results, and prepared the first draft of the manuscript. MO conceptualized and supervised the study and critically reviewed the manuscript. Ahmad Abubakar contributed to data interpretation and manuscript review. YMA contributed to manuscript review and technical input. All authors read and approved the final manuscript.

### Ethical Statement

Not applicable.

### AI Declaration Statement

The authors declare that ChatGPT (OpenAI) was used to assist with language editing, grammatical corrections, and improvement of manuscript clarity and presentation. All scientific analyses, results, interpretations and conclusions remain the responsibility of the authors. The authors reviewed and verified the final manuscript and take full responsibility for its content.

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