

# **Assessing Performance of White Endosperm Testers with Varying Resistance Reactions to *Striga* (*Striga hermonthica*) for Evaluating Resistant Maize (*Zea mays* L.) Inbred lines**

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## **Abstract**

Identification of testers is crucial for hybrid maize breeding programme. However, limited information is available about ideal testers for characterizing the combining ability of *Striga* resistant maize inbreds. This study was conducted to assess the relative value of three inbred testers with varying resistance reactions to *S. hermonthica* for determining the combining ability of *Striga* resistant inbreds. Ninety testcrosses involving 30 *Striga* resistant inbreds and three testers were evaluated under artificial and natural *Striga* infestation and non-infested conditions at two locations for two years. Lines x tester interaction was significant ( $p \leq 0.05$ ) for most traits, indicating differential ranking of lines by the testers. The GCA effects of testers for most traits were high, highlighting the predominance of additive gene action in controlling the overall performance of testcrosses. The resistant and tolerant testers exhibited desirable GCA effects, broader testcross performance, greater genetic variances and consistent ranking of testcrosses under both growing conditions than the susceptible tester. These testers can be successfully used for identifying superior *Striga* resistant inbreds to develop high yielding and resistant hybrids for commercialization.

**Keywords:** Hybrids; maize; inbreds; testers; testcrosses; *S. hermonthica*

## Introduction

In a relatively short period of time after introduction, maize (*Zea mays*) has become a major staple cereal crop across regions in sub-Saharan Africa currently occupying 40 percent of the total cereal production area in the continent (Ekpa et al., 2019). The demand for maize in African and other developing countries will double by 2050 (CIMMYT IITA, 2010). Increasing the productivity of maize in smallholder farmers' fields will contribute to meeting the increasing demand for food and other uses. This may be achieved by supporting resilience of smallholder farming communities through access to technologies to mitigate the adverse effects of climate change and prevalent pests and diseases including a parasitic weed known as *Striga hermonthica* (Del.) Benth that perpetuate low grain yields of most cereals (Cairns et al., 2012; Gichuru, 2013). *S. hermonthica* depletes nutrients and water from the host plants such as maize thereby affecting the productivity of the crop (Spallek et al., 2013; Kim, 1991) in millions hectares of infested land across Africa (Lagoke et al. 1991).

The development and deployment of maize varieties with polygenic resistance to *S. hermonthica* has thus been considered a critical component of an integrated control strategy to minimize yield losses in farmers' fields as most of the maize cultivars currently grown by farmers may suffer close to 100% yield loss under severe *Striga* infestation (Kling et al., 2000; Menkir et al., 2007). Maize breeders at the International Institute of Tropical Agricultural (IITA) made significant advances in identifying tolerant white maize germplasm that were used for developing diverse source populations (Kim et al. 1991; Kim and Winslow 1991). The resulting diverse populations have been sources of resistant maize inbred lines with desirable agronomic traits, supporting fewer emerged parasites and sustaining less *Striga* damage symptoms to develop resistant hybrids targeted to areas infested with the parasite (Menkir et al., 2016; Menkir and Meseka, 2019).

The success of resistance hybrid maize breeding program depends on the choice of the most appropriate tester that correctly determine the combining abilities of *Striga* resistant maize inbred lines to select potential parents of superior hybrids for commercialization (Hallauer and Lopez-Perez, 1979). As testers with high frequency of favorable alleles have been recommended to identify lines that form hybrids with superior specific combining ability (Hallauer and Carena, 2009), breeders in IITA have used *Striga* resistant white inbred testers to assess the performance

of new inbred lines in hybrid combinations under artificial *Striga* infestation. However, the potential usefulness of other testers with susceptible and tolerant reactions to the parasite in determining the combining ability of resistant inbred lines has rarely been reported.

Several studies have been conducted on the identification of suitable testers in maize breeding programs providing different recommendation. Many recommend use of testers that are simple to use and maximize the genetic difference expressed among testcrosses of inbred lines in hybrid breeding (Matzinger, 1953; Russell, 1961; Rawlings and Thompson, 1962; Allison and Curnow, 1966; Hallauer and Miranda, 1988; Hallauer et al., 2010; Miranda et al., 2012). Moreover, lines and populations with low frequency of favorable alleles have been regarded as desirable testers in most breeding programs because they permit easier identification of lines with high frequency of favorable allele for target traits (Hallauer & Miranda Filho, 1995; Hallauer et al., 2010). In contrast, Hallauer and Carena (2009) suggest use of elite inbred lines with high frequencies of favorable alleles as testers to identify superior hybrids for direct commercialization. The differing recommendations highlight the need for further studies to identify and use testers particularly in *Striga* resistance hybrid breeding programs.

The line x tester method of analysis has been extensively used by breeders to evaluate the combining abilities of lines to select suitable parents for hybrid formation (Menkir *et al.*, 2004; Legesse et al., 2009; Rahma et al., 2013; Izar and Chakraborty, 2013; Kamara et al., 2014; Ruswandi et al., 2015). This method has proven useful to identify appropriate testers for use in breeding programs (Gutierrez-Gaitan et al., 1986; Vasal et al., 1992a; Li et al., 2007). The fact that identification of desirable testers and their discriminating capacity is still an unsolved issue in crop breeding (Hallauer et al., 2010), evaluating the relative importance of using different types of testers will be useful to select those that are suitable for resistance breeding programs (Gutierrez-Gaitan et al., 1986; Vasal et al., 1992b; Li et al., 2007). Also, conducting continual studies to identify new testers will be important for improving the efficiency of discriminating among new maize inbred lines emanating from a resistance breeding program (Guimaraes et al., 2012). Zebire et al. (2020) found that *Striga* resistant followed by *Striga* tolerant yellow maize inbred lines were suitable testers under artificial *Striga* infested and non-infested conditions. However, the relative superiority of these testers has not been confirmed under natural field infestation. The present study was, therefore, conducted to determine the usefulness of white inbred lines with varying resistance reactions to *S. hermonthica* to select new *Striga* resistant

maize inbred lines with superior hybrid combinations under artificial, natural *Striga* infestation and non-infested conditions.

## **2.0 Material and Methods**

### **2.1 Genetic Materials**

A total of 30 *Striga* resistant white maize inbred lines and three testers with varying levels of resistance to *S. hermonthica* developed at IITA were used for this study (Supplementary Table S1). The 30 inbred lines were extracted from bi-parental crosses of pairs of *Striga* resistant lines as well as synthetics, broad-based populations and a backcross containing *Zea diploperennis* (*Z. diplo*) as a donor of favorable resistance alleles (Kling et al., 2000). Repeated screening of selected lines from each of the synthetics, broad-based populations and a backcross containing *Zea diploperennis* under artificial *Striga* infestation, both in the screen house and in the field led to the development of the 30 *Striga*-resistant maize inbred lines (Menkir, 2006). The three testers representing three heterotic groups were also selected from diverse source populations with different genetic backgrounds (Supplementary Table S1). The first tester (T1) is a *Striga* resistant tester derived from the backcross population containing *Zea diploperennis* as a donor of resistance to the parasite, while the second tester (T2) is a *Striga* tolerant tester derived from a cross of a tropical population with a temperate inbred line (N28/TZSR). The third tester is a *Striga* susceptible tester (T3) derived from a cross of two tropical populations (TLATT7844/TLR). The genetic backgrounds of the sources of the resistant maize inbred lines and testers have been fully described by Kling et al. (2000) and Kim et al. (1998).

### **2.2 Generation and Evaluation of Testcrosses**

The 30 maize inbred lines each were crossed to the three testers to generate 90 testcrosses under irrigation during the 2015/16 dry season at IITA in Ibadan Nigeria. The 90 testcrosses along with known tolerant and susceptible benchmark hybrids were evaluated under artificial *Striga* infestation and non-infested conditions in Abuja and Mokwa in 2017 and 2018 as well as under natural field infestation at Agwanmalamai and Samaru in 2017 and 2018. In each location, the 92 hybrids were arranged in a  $4 \times 23$  alpha lattice design with two replications. In Abuja and Mokwa, the hybrids were planted in a criss-cross arrangement (Pearce, 1976) that allowed planting of each hybrid in adjacent infested and non-infested strips, which were located directly opposite to each other and separated by a 1.5m alley. This arrangement provides precise

estimates of yield loss attributable to *S. hermonthica* damage (Kling et al., 2000). In the current study, the procedure described by Menkir and Meseka (2019) was followed to inoculate the infested strip and keep the non-infested strip free from *Striga* seeds. Within each strip, a hybrid was planted in a 4 m-long row with an inter-row spacing of 0.75 m and an intra-row spacing of 0.25m. In addition, the trials at Agwanmalamai and Samaru were planted under natural field infestation using the hot spots for *Striga* infestation. In all the trials, two maize seeds were placed in the same hole with the *Striga* seeds and later thinned to one maize plant per hill at two weeks after planting (WAP). Fertilizer was applied at the rate of 30 kg/ha each of N, P, and K at 30 days after planting. An additional 20 kg N ha<sup>-1</sup> was applied as urea at 6 WAP. This delay in application and reduced rate of fertilizer was necessary to enhance the germination of *Striga* seeds and subsequent attachment of *Striga* plants to the roots of the host plants in *Striga*-infested plots (Kim, 1991). Weeds other than *Striga* were controlled by hand weeding in both infested and non-infested fields.

### **2.3 Trait Measurements**

Data recorded in each plot under all research conditions included plant stand which was counted as the total number of plants per plot obtained immediately after thinning. Days to anthesis and silking were recorded as the number of days from planting to when 50% of the plants in a plot had anthers shedding pollen and showing emerged silks, respectively. Anthesis-silking interval was calculated as interval in days between dates of silking and anthesis. Plant height was measured in cm as the distance from the base of the plant to the height of the first tassel branch. Ear aspect was scored on a 1 to 9 scale, where 1 = clean, uniform, and large ears, and 9 = rotten, variable, and small ears. All ears harvested from each plot were shelled to determine percent moisture, which was used to determine grain yield adjusted to 15% moisture under both infested and non-infested conditions. Host plant damage symptoms were visually rated in each infested row at 8 and 10 weeks after planting using a scale of 1 to 9, where 1 = no visible host plant damage symptom and 9 = all leaves completely scorched, resulting in premature death (Kim, 1994). Also, the total numbers of emerged *S. hermonthica* plants were counted in each infested row at 8 and 10 weeks and were divided by the corresponding plant stand to obtain the number of emerged parasites per plant in each row. The total number of plants and ears were counted in each *Striga*-infested plot at the time of harvest and used to calculate the number of ears per plant. Ear height was measured in cm as the distance from the base of the plant to the height of the

node bearing the upper ear. Husk cover was rated on a 1 to 5 scale under non-infested condition, where 1= husks tightly arranged and extended beyond the ear tip and 5 = ear tips exposed. Plant aspect was rated on a scale of 1 to 9 in non-infested plots, where 1 = excellent plant type with large and similar ears, low ear placement, shorter plants, resistance to foliar diseases and little stalk and root lodging, and 9 = plants with small and variable ears, high ear placement, tall plants, susceptible to foliar diseases as well as stalk and root lodging. Also, ear rot was rated on a scale of 1 to 5, where 1 = little or no visible rotting of the ears and 5 = extensive visible rotting of the ears.

## ***2.4 Statistical Analysis***

Each location-year combination in the current study was regarded as test environment to conduct analyses of variance for all traits measured under infested and non-infested conditions using PROC MIXED procedure in SAS (SAS, 2013). In these analyses, environments, replication (environments), block (replication × environments), were considered as random effects, whereas testcrosses were regarded as fixed effects. Further line x tester analysis was conducted to partition the testcross mean square into lines, testers, line x tester, environment x line, environment x tester and environment x line x tester effects using a SAS program following the procedure of Singh and Chaudhary (1977). The efficiency of testers was determined based on the genetic variance estimates derived from combined analysis of variance of testcrosses means of each tester obtained from the four environments (Castellanos et al., 1998). Least significance test (LSD = 0.05) was computed to compare mean differences between testers for each trait. Second, the testcross means obtained in each of the four test environments were ranked using PROC RANK in SAS (SAS, 2013). The resulting ranks were then used to calculate Kendall's coefficient of concordance (W) to assess the similarity of the rank order of the 30 testcrosses across the four test environments (Kendall and Smith, 1939). The significance of GCA and SCA effects were tested by dividing the corresponding GCA and SCA values by their respective standard error and comparing the resulting observed t-value with tabular t-value using SAS. Baker's (1978) ratio of GCA: SCA mean square was computed to determine whether additive or non-additive gene effect determine the inheritance of each trait.

### 3.0 RESULTS

#### 3.1 Variations among testcrosses under *Striga*-infested and non-infested conditions

Environment and testcrosses effects were significant ( $p < 0.05$ ) for all the traits recorded under *Striga* infestation. Testcross  $\times$  environment interaction was significant ( $p < 0.01$ ) for all traits except for days to anthesis, plant height, and number of ears per plant and *Striga* damage rating at 8 and 10 WAP (Table 1). The GCA effects due to lines and testers were significant ( $p < 0.01$ ) for most of the traits. Line  $\times$  tester interactions (SCA) were also significant ( $p < 0.01$ ) for grain yield, anthesis-silking interval, ears aspect, plant height and number of ears per plant. Line  $\times$  environment interactions were significant ( $p < 0.01$ ) for all traits except for days to anthesis, while tester  $\times$  environment interaction was significant ( $p < 0.01$ ) for grain yield, days to silking, anthesis-silking interval, ear aspect, plant height and number of ears per plant. Line  $\times$  tester  $\times$  environment interaction was not significant for any of the traits measured under infestation (Table 1).

Under natural field infestation, environment and testcrosses effects were significant ( $p < 0.05$ ) for all the traits measured under *Striga* infestation except for *Striga* damage rating at 8WAP (Table 2). Testcross  $\times$  environment interaction was only significant ( $p < 0.01$ ) for plant height, ear aspect and number of ears per plant, The GCA effects due to lines and testers were also significant ( $p < 0.01$ ) for most of the traits, whereas line  $\times$  tester interactions (SCA) were significant ( $p < 0.01$ ) for grain yield and five other traits. Both line  $\times$  environment and tester  $\times$  environment interactions were not significant for grain yield and most other traits. Again, line  $\times$  tester  $\times$  environment interaction was not significant for all the traits (Table 2). Under non-infested condition, environment and testcross mean squares were significant ( $p \leq 0.01$ ) for all the traits except for number of ears per plant for Testcrosses (Table 3). Testcross  $\times$  environment interaction was only significant for ear aspect, number of ears per plant and plant aspect. Line and tester GCA effects were significant for all the traits, except for number of ears per plant for lines and days to anthesis for testers. Line  $\times$  tester interaction was significant for grain yield and five other traits. Line  $\times$  environment interaction was significant ( $p < 0.001$ ) for all traits except days to anthesis, plant height, ear height and husk cover, while tester  $\times$  environment interaction was only significant for grain yield, ear aspect, and plant height and plant aspect. The line  $\times$

tester  $\times$  environment interaction was significant only for ear aspect and number of ears per plant (Table 3).

The genetic variances estimated for the testcrosses of the resistant tester (T1) were the highest for most of the traits measured under *Striga* infestations, while the genetic variances of the tolerant tester (T2) were highest only for days to anthesis and days to silk (Table 4). The susceptible tester (T3) had the lowest genetic variance estimates for all traits recorded under *Striga* infestation, except for number of ears per plant. Similarly, the genetic variances estimated for the testcrosses of the resistant tester (T1) were the highest for grain yield and four other traits measured under natural field infestation, while the genetic variances of the tolerant tester (T2) were highest only for ears per plants *Striga* damage rating at both 8 and 10 WAP and *Striga* emergence count at 10WAP (Table 4). The susceptible tester (T3) had the lowest genetic variance estimates for all traits recorded under natural *Striga* infestation. Again, the resistant tester followed by the tolerant tester had the highest genetic variances for most of the traits recorded under non-infested conditions (Table 5).

### **3.2 Testcrosses means under artificial, natural *Striga* infestation and non-infested conditions**

Yield reduction under *Striga* infestation relative to that under non-infested condition was 86% for the susceptible check (8338-1) and 53% for the tolerant check (9022-13) (Supplementary Table S2). The average yield losses due to *Striga* damage was 15% for testcrosses of the resistant tester (T1), 25% for those of the tolerant tester (T2) and 60% for those of the susceptible tester (T3). Yield increases over the tolerant reference check (9022-23) varied from 17 to 205% for 29 lines crossed to the resistant tester (T1), from 14 to 165% for the 30 lines crossed to the tolerant tester (T2) and from 17 to 106% for only 11 lines crossed to the susceptible tester (Supplementary Table S2). Among all the testcrosses, 35 produced significantly higher grain yields than the tolerant reference check, whereas 74 had significantly higher grain yields than the susceptible reference check (8338-1). Thirteen of the top 15 testcrosses involving the tolerant and resistant testers were crossed to common inbred lines (L02, L03, L04, L05, L06, L07, L08, L09, L20, L22, L23, L25 and L26). Also, 11 of these parental lines were represented in the top 15 testcrosses involving the susceptible tester (Supplementary Table S2). On the average, testcrosses of tester T1 produced more grain yield, had shorter anthesis-silking interval, taller plants, better ear aspect and damage scores and supported fewer emerged parasites than those of

testers T2 and T3 (Table 6). Furthermore, almost all the top 15 testcrosses involving each of the three testers exhibited less *Striga* damage symptoms and supported fewer emerged *Striga* plants. Similar average performance were observed for testcrosses of tester T1 in comparison to testcrosses of testers T2 and T3 under natural field infestation (Tables 7). Among all the testcrosses evaluated under natural field infestation, 55 produced significantly higher grain yields than the tolerance reference check (9022-23), whereas 61 had significantly higher grain yields than the susceptible reference check (8338-1). Furthermore, almost all the top 15 testcrosses involving each of the three testers exhibited less *Striga* damage symptoms and supported fewer emerged *Striga* plants under natural field infestation (Supplementary Table S2).

On the contrary, the highest mean grain yield under non-infested condition was observed in testcrosses involving the susceptible tester followed by testcrosses of the lines with the tolerant tester (Table 8). The number of testcrosses showing yield increases of 11 to 59% over the tolerant reference check were 15 for T1, 18 for T2 and 19 for T3 (Supplementary Table S2). Amongst all testcrosses, 35 produced significantly higher grain yields than the tolerance reference check, whereas 74 had significantly higher grain yields than the susceptible reference check (8338-1). Out of the top 15 testcrosses of T1 and T2, 12 involved common resistant lines (L02, L03, L04, L07, L08, L09, L19, L20, L22, L23, L24 and L26). Again, nine of these lines were represented in the top 15 testcrosses involving T3 (Supplementary Table S2).

### ***3.3 Relative Ranking of Inbred Lines across Testers and environments under Striga infestation***

Spearman's rank correlation between testcrosses involving pairs of testers were significant ( $P < 0.001$ ) and varied from 0.61 to 0.70 under *Striga* infestation. Additionally, testcrosses of each of the three testers showed significant concordance of ranks for grain yield and all other traits measured under *Striga* infestation across environments (Table 9). Testcrosses of T1 showed better concordance coefficients for grain yield and six other *Striga*-resistance associated traits in comparison to those involving T2 and T3. Testcrosses involving T3 showed the smallest concordance coefficients for grain yield and other traits recorded across environments. Similar consistency of ranks were observed for testcrosses of each tester across environments under natural field infestation (Data not shown).

### ***3.4 Combining Ability Estimates for Testers***

Under *Striga* infestation, the resistant tester had significant and positive GCA effects for grain yield, plant height and ears per plant but negative GCA effects for the remaining traits (Table 10). The tolerant tester also had significant positive GCA effects for grain yield but negative GCA effects for *Striga* damage rating (Table 10). In contrast, the susceptible tester had a significant and negative GCA effect for grain yield, plant height and ears per plant but positive GCA effects for *Striga* damage rating, *Striga* emergence count and ear aspect (Table 10). Under natural field infestation, the resistant tester again had significant and positive GCA effects for grain yield, but had significant negative GCA effects for days to silk, days to anthesis, anthesis-silking interval, and *Striga* emergence counts at both 8 and 10WAP. On the other hand, the tolerant tester had significant negative GCA effects for grain yield, but significant and positive GCA effects for days to silking and days to anthesis. The susceptible tester had a significant and positive GCA effect for anthesis-silking interval, *Striga* emergence counts and a negative GCA effect for plant height (Table 10). Under non-infested condition, the resistant tester had significant negative GCA effects for grain yield and five other traits, while the susceptible tester had significant positive GCA effects for grain yield and three other traits but negative GCA effects for ear aspect and ear height. The GCA effect of the tolerant tester for grain yield under non-infested condition was not significant. Under *Striga* infestation (Table 11), only two lines crossed to tester T1, three lines crossed to tester T2 and a line crossed to tester T3 had significant positive SCA effects for grain yield. Under natural field infestation, three lines crossed to tester T1 and two lines crossed to tester T3 had significant positive SCA effect for grain yield. Three lines crossed to T1, two lines each crossed to T2 and T3 had significant positive SCA effects for grain yield (Table 11).

## DISCUSSION

The present study was conducted to determine the relative value of white inbred testers with varying resistance reactions to the parasite in eliciting genetic differences among new resistant maize inbred lines. The results of analyses found significant differences among testers, indicating that the testers allowed marked expression of genetic variability in grain yield and other *Striga*-resistance related traits under artificial and natural *Striga* infestation. The observed significant GCA effects of both lines and testers for most traits imply that the breeding strategy was effective in accumulating favorable alleles with additive effects on traits measured under *Striga* infested and non-infested conditions. This presents the potential that exists to further enhance resistance to *Striga* in maize using different breeding methods, consistent with findings in other studies that involved other sets of inbred lines (Yallou et al., 2009; Kim, 1994; Akanvou et al., 1997). The significant SCA effects for grain yield and other traits suggest that, promising *Striga* resistant hybrids can be developed by crossing lines with complementary heterotic groups to optimize expression of heterosis (Hallauer et al., 2010). The line x environment and tester x environment interactions were significant for most traits recorded under artificial infestation possibly due to the differential reaction of the lines and the testers to varying infection severity modulated by changes in climatic conditions and soil properties that prevailed in different years and locations (Menkir *et al.*, 2012; Menkir and Meseke, 2019). The non-significant mean squares for line x environment and tester x environment interactions observed under natural infestation could arise from the fact that both Samaru and Agwanmalamai had similar climatic conditions throughout the period of the experiment.

Furthermore, examination of concordance in ranking the *Striga* resistant lines in crosses with each of the three testers were significant for all the traits measured across environments, suggesting that the resistance or susceptibility reactions of testcrosses were consistent under both artificial and natural infestations. The resistant tester followed by the tolerant tester ranked the performance of testcrosses of the resistant lines better across environments than the susceptible tester, which is important in identifying superior single-crosses as female testers to develop three-way cross hybrids for further testing and direct use. In addition, the resistant and tolerant testers identified 13 common inbred lines that formed the top 15 testcrosses under both artificial and natural infestation and 12 common lines in the top 15 testcrosses under non-infested conditions. It is interesting to note that at least nine of the common lines identified by the

resistant and tolerant testers were also parents in the top 15 testcrosses involving the susceptible tester. Such resistant maize inbred lines may combine well with other unrelated maize inbred lines for resistance to *S. hermonthica* and can then serve as excellent sources of resistance to *Striga* for use in other resistance breeding programs for tropical lowlands infested with the parasite.

The GCA effects of testers were greater than that of lines under both artificial and natural *Striga* infestation, indicating the presence of favorable alleles that impart high grain yield, reduced *Striga* damage symptoms and less emerged parasites occurring at higher frequencies in the testers than in the lines. Studies have also shown that genetic gain from selection with inbred testers is mainly associated with an additive gene effect rather than non-additive effects (Honer et al., 1976). Similar results were reported in other studies in maize (Kim, 1994; Akanvou et al., 1997; Gethi and Smith, 2004; Badu-Apraku et al., 2007). Amongst the three testers, the resistant tester (T1) had desirable GCA effects for grain yield, *Striga* damage rating, emerged *Striga* count and other traits under both artificial and natural field infestation, indicating that the tester contains high frequency of resistance alleles with additive effects. This tester can then be regarded as a suitable tester for identifying parental lines to develop superior hybrids that can be targeted for commercialization, consistent with the findings of Hallauer and Carena (2009). The tolerant tester also combined positive GCA effect for grain yield with desirable GCA effects for other traits, but not for emerged *Striga* count. It appears that the tolerant tester contains favourable resistance alleles occurring at intermediate to higher frequency and may also be used as the second potential tester to screen early generation lines under artificial *Striga* infestation. As suggested by Keller (1949), more than one tester are recommended for accurate assessment of ranks of lines in crosses and also to obtain better variance estimates among testcrosses.

One of the criteria used to identify a good tester is its ability to elicit greater expression of genetic difference among testcrosses of new inbred lines under evaluation (Matzinger, 1953; Russell, 1961; Hallauer et al., 2010; Guimaraes et al., 2012; Miotto et al., 2016). In the current study, testcrosses involving the resistant tester had the largest genetic variance estimates for grain yield and other *Striga*-related traits under both artificial and natural *Striga* infestation as well as under non-infested conditions, while testcrosses of the susceptible tester had the lowest genetic variance estimates for grain yield and other traits under these growing conditions. These results suggest that the resistant tester may either differ from the resistant lines in the frequency

of resistance alleles occurring at many loci or carry different sets of alleles at different loci that contributed to the large genetic variances observed amongst testcrosses. This finding contradicts the reports in other studies (Rawlings and Thompson, 1962; Hallauer and Lopez-Perez, 1979) who considered a low-performing tester with a low frequency of favorable alleles at important loci being more effective in differentiating the potential value of inbred lines. It seems that the observed intermediate and low variance estimates for testcrosses of the tolerant and susceptible testers may arise from the occurrence of resistance alleles at intermediate and low frequencies, respectively. The large genetic variance estimates obtained for testcrosses of the resistant and tolerant testers coupled with the identification of the largest number of testcrosses out-yielding the tolerant check by more than 15% suggest that these testers have the potential to effectively discriminate among the resistant maize inbred lines. This is consistent with studies of Fato et al., (2012), who found that the resistant tester was superior to the susceptible tester in identifying maize inbred lines with high levels of resistance to downy mildew and high yield potential in hybrids.

The choice of an appropriate tester should also depend on the relative ranges in mean values for the traits under test (Lopez-Perez, 1979). In this study, the testcross genetic variance increased with increasing range in means for most of the traits measured under infested and non-infested conditions. Testcrosses of the resistant tester had the greatest range for grain yield and other traits under artificial and natural infestation as well as under non-infested conditions. Hence, the resistant tester can be used as a suitable tester in resistance hybrid breeding programs. Furthermore, most testcrosses involving the resistant and tolerant testers showed less *Striga* damage symptoms and supported fewer emerged parasites than the susceptible tester. It appears that the susceptible tester possess dominant susceptible alleles to *S. hermonthica* at many loci which may have adversely affected the performance of testcrosses, leading to very low testcross grain yields particularly under artificial and natural field infestations.

In conclusion, this study was conducted to examine the performance of three white maize inbred testers with varying resistance reactions to *S. hermonthica* for evaluating the combining ability of resistant white maize inbred lines. The results of our study clearly showed that the resistant and tolerant tester showing desirable GCA effects for grain yield and other *Striga*-related traits, broader testcross performance, greater genetic variance estimates and consistency in ranking testcrosses for grain yield and other traits across environments under both artificial and natural

infestation as well as under non-infested conditions can be used as suitable testers. As many breeding programs focus on developing viable hybrids for commercialization, the resistant and tolerant testers are then considered suitable for effectively selecting superior *Striga* resistant parental lines that facilitate profitable production and marketing of hybrids.

#### **Author's contributions**

AM contributed in the conception of the research, extensively reviewed and gave final approval of the manuscript; MO, USA, MS, MW and MG also reviewed the manuscript; SOA analyzed and interpreted the data, and wrote the manuscript.

#### **Conflict of interest statements**

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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**Table 1: Analysis of variance for combining ability effects of different traits of the 90 testcrosses evaluated under artificial *Striga* infestation in Abuja and Mokwa in 2017 and 2018.**

| Source of Variation | df  | Grain yield (Kg ha <sup>-1</sup> ) | Days to Silk | Days to anthesis | Anthesis-Silking Interval | Ears aspect | Plant height | Ears per plant | Striga Rating (8WAP) | Striga Rating (10WAP) | Striga Count (8WAP) | Striga Count (10WAP) |
|---------------------|-----|------------------------------------|--------------|------------------|---------------------------|-------------|--------------|----------------|----------------------|-----------------------|---------------------|----------------------|
| Environment (ENV)   | 3   | 7211847.1**                        | 5179.0**     | 4961.8**         | 23.4**                    | 2.4**       | 82685.5**    | 2.78**         | 56.76**              | 75.72**               | 86441.4**           | 285215.8**           |
| Rep (ENV)           | 3   | 7514579.9**                        | 84.80**      | 83.1**           | 1                         | 0.7**       | 1199.5**     | 0.16**         | 7.60**               | 3.96**                | 2753.0**            | 3088.5**             |
| Blk (ENV*Rep)       | 176 | 1418310.4**                        | 11.1**       | 10.5**           | 0.6                       | 0.2*        | 432.0**      | 0.03           | 1.41**               | 1                     | 815.1**             | 1460.7**             |
| Testcrosses         | 91  | 7211847.1**                        | 7.20**       | 6.4**            | 0.7**                     | 1.0**       | 536.9**      | 0.17**         | 11.00**              | 8.89**                | 2267.4**            | 2857.5**             |
| ENV x Testcrosses   | 273 | 974777.7**                         | 4.00**       | 3.3              | 0.7**                     | 0.2*        | 157          | 0.03           | 0.85                 | 0.92                  | 804.6**             | 1331.9**             |
| Line (GCA)          | 29  | 14621232.4**                       | 23.40**      | 23.8**           | 0.5                       | 1.3**       | 1881.4**     | 0.17**         | 12.22**              | 11.61**               | 2997.7**            | 3484.2**             |
| Tester (GCA)        | 2   | 213803303.6**                      | 47.00**      | 9                | 11.1**                    | 36.5**      | 3178.9**     | 7.52**         | 569.93**             | 418.59**              | 92882.0**           | 121888.8**           |
| ENV x line          | 87  | 1503030.6**                        | 6.5          | 5.9              | 0.6                       | 0.3**       | 292.1        | 0.04*          | 1.34                 | 1.37**                | 1289.5**            | 1801.1**             |
| ENV x tester        | 6   | 8480279.9**                        | 22.60**      | 9.1              | 5.9**                     | 2.4**       | 604.3*       | 0.11**         | 2.79**               | 12.29**               | 4617.8**            | 13470.4**            |
| Line x tester       | 58  | 1708384.2**                        | 7.7          | 7.4              | 0.9**                     | 0.3**       | 410.2**      | 0.05**         | 1.47                 | 1.15                  | 543.2               | 1114.7               |
| ENV x line x tester | 174 | 1031663.2                          | 6.9          | 6.6              | 0.6                       | 0.2         | 319.7        | 0.03           | 1.22                 | 0.9                   | 747                 | 1170                 |
| Error               | 359 | 1111714                            | 7.5          | 7.2              | 0.5                       | 0.2         | 290.9        | 0.03           | 1.18                 | 0.97                  | 618.7               | 1114                 |
| GCA/SCA ratio       |     | 0.2                                | 0.5          | 0.4              | 10.5                      | 0.6         | 0.3          | 0.6            | 0.2                  | 0.3                   | 1.7                 | 2.2                  |
| <b>CV</b>           |     | <b>29.1</b>                        | <b>2.9</b>   | <b>3</b>         | <b>36.5</b>               | <b>13.3</b> | <b>7.5</b>   | <b>23.05</b>   | <b>18.73</b>         | <b>14.05</b>          | <b>43.7</b>         | <b>46.9</b>          |

NOTE: \* = Significant at ( $P < 0.05$ ), \*\* = Significant at ( $P < 0.01$ ) and \*\*\* Significant at ( $P < 0.001$ )

**Table 2: Analysis of variance for combining ability effects of different traits of the 90 testcrosses evaluated under natural field infestation in Agwanmalamai and Samaru in 2017 and 2018.**

| Source of Variation | df  | Grain yield (Kg ha <sup>-1</sup> ) | Days to Silk | Days to anthesis | Anthesis-Silking Interval | Ears aspect  | Plant height | Ears per plant | Striga Rating (8WAP) | Striga Rating (10WAP) | Striga Count (8WAP) |
|---------------------|-----|------------------------------------|--------------|------------------|---------------------------|--------------|--------------|----------------|----------------------|-----------------------|---------------------|
| Evn                 | 3   | 34663677.00**                      | 296.67**     | 433.43**         | 13.38**                   | 20.83**      | 47216.81**   | 1.19**         | 14.93**              | 33.80**               | 8708.87**           |
| Rep (Evn)           | 3   | 8039414.40**                       | 6.64         | 1.3              | 2.43                      | 0.83         | 2556.19**    | 0.49**         | 17.23**              | 7.65**                | 52.74               |
| Blk (Evn*rep)       | 176 | 1503344.70**                       | 3.59**       | 2.92             | 1.3                       | 0.72**       | 421.40**     | 0.03           | 5.55                 | 2.00**                | 203.80**            |
| Testcrosses         | 91  | 2963801.50**                       | 7.13**       | 4.94**           | 2.24**                    | 0.76**       | 484.13**     | 0.04**         | 5.89                 | 1.93**                | 129.59**            |
| Env x Testcrosses   | 273 | 1048578.8                          | 3.53         | 3.09             | 1.34                      | 0.52**       | 272.79**     | 0.03**         | 5.33                 | 1.31                  | 91.45               |
| Line (GCA)          | 29  | 4897322.30**                       | 6.86**       | 6.00**           | 3.02**                    | 1.04**       | 1117.25      | 0.04**         | 10.59**              | 3.89**                | 395.51**            |
| Tester (GCA)        | 2   | 12398409.00**                      | 147.60**     | 91.21**          | 25.68**                   | 1.47         | 997.54       | 0.01           | 6.81                 | 23.49**               | 1090.47**           |
| Evn x line          | 87  | 1165115                            | 3.16         | 3.26             | 1.17                      | 0.52         | 455.91       | 0.03           | 6.77                 | 2.12**                | 246.07**            |
| Env x tester        | 6   | 1405139.2                          | 10.18**      | 6.66**           | 2.29                      | 0.74         | 723.45       | 0.08**         | 15.97**              | 15.95**               | 288.45              |
| Line x tester       | 58  | 2298720.70**                       | 6.02**       | 4.07**           | 1.6                       | 0.80**       | 448.93**     | 0.05**         | 4.75                 | 1.69                  | 96.01               |
| Evn x line x tester | 174 | 1164120.8                          | 3.71         | 3.22             | 1.44                      | 0.56         | 381.13       | 0.04**         | 5.57                 | 1.24                  | 116.17              |
| Error               | 359 | 1334227                            | 3.32         | 2.78             | 1.41                      | 0.54         | 313.17       | 0.02           | 5.59                 | 1.65                  | 142.91              |
| GCA/SCA ratio       | 1   |                                    | 9.7          | 2                | 0.4                       | 3.4          | 0.6          | -8             | 0.4                  | 0.1                   | 0.5                 |
| <b>CV</b>           |     | <b>41.11</b>                       | <b>2.67</b>  | <b>2.53</b>      | <b>20.3</b>               | <b>20.65</b> | <b>9.31</b>  | <b>17.12</b>   | <b>43.55</b>         | <b>16.92</b>          | <b>48.5</b>         |

NOTE: \* = Significant at (P < 0.05), \*\* = Significant at (P < 0.01) and \*\*\* Significant at (P < 0.001)

**Table 3: Analysis of variance for combining ability effects of different traits of the 90 testcrosses evaluated under Striga non-infested condition in Abuja and Mokwa in 2017 and 2018.**

| Source of Variation | DF  | Grain yield<br>(Kg ha <sup>-1</sup> ) | Days to<br>Silk | Days to<br>anthesis | Anthesis-<br>Silking<br>Interval | Ears<br>aspect | Plant<br>height | Ears<br>height | Ears<br>per<br>plant | Plant<br>Aspect | Husk<br>cover |
|---------------------|-----|---------------------------------------|-----------------|---------------------|----------------------------------|----------------|-----------------|----------------|----------------------|-----------------|---------------|
| Evn                 | 3   | 251771843.0**                         | 5717.2**        | 5763.1**            | 19.36**                          | 177.53**       | 79077.7**       | 31604.1**      | 146.50**             | 455.11**        | 15.88**       |
| Rep (Evn)           | 3   | 4062532.0**                           | 107.7**         | 100.3**             | 0.63                             | 0.1            | 5505.8**        | 3945.8**       | 0.22**               | 1.3             | 0.25          |
| Blk (Evn*rep)       | 176 | 1274415.7                             | 10.6**          | 10.2**              | 0.29                             | 0.14           | 368.7**         | 180.2**        | 0.08                 | 0.74            | 0.23          |
| Testcrosses         | 91  | 5636843.0**                           | 8.5**           | 7.5**               | 0.61**                           | 0.34**         | 786.5**         | 348.9**        | 0.09                 | 2.01**          | 0.60**        |
| Env x Testcrosses   | 273 | 1157181.1                             | 4.4             | 4.3                 | 0.42                             | 0.18**         | 207.3           | 121.3          | 0.12**               | 0.93**          | 0.25          |
| Line (GCA)          | 29  | 13668543.7**                          | 22.5**          | 20.1**              | 0.66**                           | 0.56**         | 2266.8**        | 1114.6**       | 0.09                 | 3.56**          | 1.17**        |
| Tester (GCA)        | 2   | 25105415.6**                          | 32.1**          | 7.5                 | 17.13**                          | 2.28**         | 3586.8**        | 958.1**        | 0.72**               | 19.72**         | 6.91**        |
| Evn x line          | 87  | 1717737.2**                           | 5.3             | 5.4                 | 0.47**                           | 0.30**         | 321.4           | 203.1          | 0.11**               | 1.59**          | 0.33**        |
| Env x tester        | 6   | 3176067.1**                           | 19.8**          | 8.4                 | 6.25**                           | 0.86**         | 383.8           | 216.9          | 1.06**               | 3.26**          | 0.32          |
| Line x tester       | 58  | 2951634.3**                           | 8.4             | 7.8                 | 0.27                             | 0.27**         | 452.6**         | 229.3          | 0.1                  | 1.26**          | 0.30          |
| Evn x line x tester | 174 | 986366                                | 7.2             | 7.3                 | 0.29                             | 0.16**         | 281.3           | 163.6          | 0.10**               | 0.73            | 0.21          |
| Error               | 359 | 1205695                               | 8.2             | 7.8                 | 0.31                             | 0.13           | 319.2           | 186.1          | 0.08                 | 0.66            | 0.23          |
| GCA/SCA ratio       |     | 0.3                                   | 0.2             | 0.3                 | 5                                | 2.7            | 0.2             | 0.4            | 10.5                 | 1.9             | 0.8           |
| <b>CV</b>           |     | <b>24.2</b>                           | <b>4.8</b>      | <b>4.8</b>          | <b>29.45</b>                     | <b>15.45</b>   | <b>9.8</b>      | <b>15.4</b>    | <b>19.72</b>         | <b>18.90</b>    | <b>17.74</b>  |

NOTE: \* = Significant at ( $P < 0.05$ ) \*\* = Significant at ( $P < 0.01$ ) and \*\*\* Significant at ( $P < 0.001$ )

**Table 4: Genetic variance between testcrosses obtained for the testcrosses of each tester (T1, T2 and T 3) under artificial and natural Striga infestation evaluated at two sites in 2107 and 2018.**

| Traits                     | Striga Infested condition |                 |                 | Natural field infestation |                 |                 |
|----------------------------|---------------------------|-----------------|-----------------|---------------------------|-----------------|-----------------|
|                            | $T1 \sigma_g^2$           | $T2 \sigma_g^2$ | $T3 \sigma_g^2$ | $T1 \sigma_g^2$           | $T2 \sigma_g^2$ | $T3 \sigma_g^2$ |
| Grain yield/ha (Kg/ha)     | 10.386 ± 9.524            | 3.740 ± 446.595 | 3.640 ± 394.501 | 5.074 ± 1118.569          | 3.108 ± 892.653 | 0.879 ± 608.636 |
| Days to 50% Silking        | 1.647 ± 0.884             | 2.984 ± 0.861   | 1.333 ± 1.005   | 2.544 ± 1.602             | 1.550 ± 1.021   | 1.153 ± 0.980   |
| Days to 50% Pollen         | 1.552 ± 0.869             | 2.685 ± 0.859   | 1.841 ± 0.947   | 2.215 ± 1.461             | 0.969 ± 0.736   | 0.949 ± 0.950   |
| Anthesis/ Silking Interval | 1.011 ± 0.254             | 1.134 ± 0.187   | 1.472 ± 0.346   | 1.151 ± 0.533             | 1.572 ± 0.657   | 1.713 ± 0.701   |
| Ears Aspect                | 3.532 ± 0.165             | 2.370 ± 0.161   | 2.927 ± 0.167   | 1.683 ± 0.528             | 1.046 ± 0.356   | 2.034 ± 0.355   |
| Plant height               | 5.064 ± 5.265             | 3.107 ± 5.558   | 1.752 ± 7.733   | 2.223 ± 13.400            | 1.797 ± 13.154  | 1.185 ± 11.293  |
| Ears per plant             | 1.910 ± 0.050             | 2.474 ± 0.062   | 2.658 ± 0.084   | 1.412 ± 0.126             | 1.151 ± 0.100   | 1.154 ± 0.075   |
| Striga Rating (8WAP)       | 4.839 ± 0.386             | 3.058 ± 2.475   | 4.017 ± 0.444   | 0.971 ± 1.920             | 2.684 ± 0.898   | 1.379 ± 0.617   |
| Striga Rating (10WAP)      | 5.766 ± 0.377             | 3.594 ± 0.389   | 3.664 ± 0.317   | 1.493 ± 0.860             | 2.061 ± 0.834   | 1.213 ± 0.0563  |
| Striga Count (8WAP)        | 2.914 ± 6.366             | 1.773 ± 10.378  | 1.014 ± 14.182  | 1.071 ± 5.979             | 1.389 ± 8.253   | 1.155 ± 6.101   |
| Striga Count (10WAP)       | 2.283 ± 9.247             | 1.436 ± 12.671  | 1.061 ± 16.479  | 1.348 ± 7.012             | 1.701 ± 9.508   | 1.091 ± 6.286   |

**Table 5: Genetic variance between testcrosses obtained for the testcrosses of each tester (T1, T2 & Tester 3) under Striga non-infested condition evaluated at two sites in 2107 and 2018**

|                         | $T1 \sigma_g^2$  | $T2 \sigma_g^2$ | $T3 \sigma_g^2$ |
|-------------------------|------------------|-----------------|-----------------|
| Grain yield/ha (Kg/ha)  | 10.595 ± 340.318 | 5.153 ± 392.855 | 2.217 ± 13.826  |
| Days to 50% Silking     | 1.387 ± 0.941    | 2.888 ± 0.869   | 1.815 ± 0.912   |
| Days to 50% Pollen      | 1.196 ± 0.929    | 2.729 ± 0.865   | 1.580 ± 0.937   |
| Anthesis/ Silking Inter | 1.377 ± 0.804    | 1.510 ± 0.187   | 0.659 ± 0.217   |
| Ears Aspect             | 2.485 ± 2.456    | 1.093 ± 0.154   | 1.194 ± 0.141   |
| Plant height            | 5.744 ± 6.078    | 3.212 ± 6.409   | 1.613 ± 5.704   |
| Ear height              | 5.174 ± 4.071    | 5.570 ± 3.924   | 0.732 ± 5.857   |
| Ears per plant          | 0.945 ± 2.452    | 0.908 ± 0.107   | 0.808 ± 0.129   |
| Husk cover              | 0.983 ± 0.172    | 2.816 ± 0.179   | 3.208 ± 0.177   |
| Plant aspect            | 2.395 ± 0.430    | 1.780 ± 0.341   | 1.353 ± 0.282   |

**Table 6: Minimum, maximum and mean values of agronomic traits for the testcrosses of three testers evaluated under artificial *Striga* infested conditions across four environments**

| Traits                     | T1      |         |         | T2      |         |         | T3     |         |         |
|----------------------------|---------|---------|---------|---------|---------|---------|--------|---------|---------|
|                            | Min     | Max     | Mean    | Min     | Max     | Mean    | Min    | Max     | Mean    |
| Grain yield/ha (kg/ha)     | 1571.82 | 5752.35 | 3545.52 | 2150.46 | 4992.59 | 3514.68 | 662.2  | 3891.63 | 1926.80 |
| Days to 50% Silking        | 57.5    | 62.38   | 59.9    | 56.75   | 63.25   | 60.62   | 58.13  | 63.25   | 60.73   |
| Days to 50% Pollen         | 55.63   | 60.38   | 58.2    | 55.00   | 61.00   | 58.58   | 55.75  | 61.25   | 58.33   |
| Anthesis/ Silking Interval | 1.25    | 2.38    | 1.70    | 1.75    | 2.38    | 2.04    | 1.13   | 2.63    | 2.10    |
| Ears Aspect                | 2.25    | 3.56    | 2.75    | 2.56    | 3.50    | 3.04    | 3.00   | 4.19    | 3.51    |
| Plant height               | 147.13  | 193.25  | 169.32  | 149.75  | 184     | 165.89  | 139.88 | 179.63  | 161.77  |
| Ears per plant             | 0.77    | 1.10    | 0.95    | 0.73    | 1.10    | 0.93    | 0.38   | 0.94    | 0.64    |
| Striga Rating (8WAP)       | 2.5     | 5.75    | 3.93    | 3.50    | 5.25    | 4.15    | 4.5    | 8.00    | 6.63    |
| Striga Rating (10WAP)      | 4.00    | 7.38    | 5.65    | 4.25    | 7.00    | 5.93    | 6.00   | 9.00    | 8.00    |
| Striga Count (8WAP)        | 8.38    | 61.13   | 26.57   | 28.38   | 95.63   | 47.32   | 42.00  | 97.75   | 65.13   |
| Striga Count (10WAP)       | 10.13   | 71.13   | 34.96   | 43.88   | 107.75  | 61.01   | 53.88  | 109.38  | 79.43   |

**Table 7: Minimum, maximum and mean values of agronomic traits for the testcrosses of three testers evaluated under natural field infestation across four environments**

| Traits                     | T1     |         |        | T2      |         |         | T3      |         |         |
|----------------------------|--------|---------|--------|---------|---------|---------|---------|---------|---------|
|                            | Min    | Max     | Mean   | Min     | Max     | Mean    | Min     | Max     | Mean    |
| Grain yield/ha (kg/ha)     | 696.08 | 4006.81 | 2757.4 | 1180.47 | 3324.12 | 2313.59 | 1514.71 | 3191.81 | 2050.29 |
| Days to 50% Silking        | 61.75  | 65.63   | 63.6   | 63.88   | 66.25   | 65.13   | 63.38   | 65.88   | 64.67   |
| Days to 50% Pollen         | 61.13  | 65.13   | 62.92  | 63.25   | 65.00   | 64.13   | 62.00   | 64.63   | 63.33   |
| Anthesis/ Silking Interval | 0.13   | 1.75    | 0.68   | 0.13    | 2.00    | 1.00    | 0.25    | 3.00    | 1.33    |
| Ears Aspect                | 2.19   | 3.75    | 2.91   | 2.56    | 3.63    | 3.06    | 2.19    | 3.75    | 2.96    |
| Plant height               | 126.38 | 170.5   | 152.83 | 133.38  | 171.25  | 148.77  | 129     | 170.63  | 150.45  |
| Ears per plant             | 0.69   | 1.03    | 0.96   | 0.8     | 1.16    | 0.96    | 0.79    | 1.22    | 0.97    |
| Striga Rating (8WAP)       | 4.13   | 11.75   | 5.08   | 4.38    | 6.88    | 5.38    | 4.25    | 6.25    | 5.37    |
| Striga Rating (10WAP)      | 5.00   | 7.38    | 6.23   | 5.88    | 8.25    | 6.85    | 5.50    | 7.50    | 6.57    |
| Striga Count (8WAP)        | 0.50   | 23.00   | 3.87   | 1.75    | 28.63   | 6.84    | 2.63    | 19.25   | 8.00    |
| Striga Count (10WAP)       | 1.88   | 28.13   | 5.88   | 3.13    | 37.13   | 9.56    | 3.38    | 20.38   | 10.39   |

**Table 8: Minimum, maximum and mean values of agronomic traits for the testcrosses of three testers evaluated under Striga non-infested conditions across four environments**

| Traits | T1 | T2 | T3 |
|--------|----|----|----|
|--------|----|----|----|

|                            | <b>Min</b> | <b>Max</b> | <b>Mean</b> | <b>Min</b> | <b>Max</b> | <b>Mean</b> | <b>Min</b> | <b>Max</b> | <b>Mean</b> |
|----------------------------|------------|------------|-------------|------------|------------|-------------|------------|------------|-------------|
| Grain yield/ha (kg/ha)     | 1432.94    | 5925.02    | 4172.49     | 3156.95    | 6342.38    | 4702.42     | 3432.39    | 5848.24    | 4758.70     |
| Days to 50% Silking        | 56.63      | 61.38      | 59.24       | 55.88      | 62.25      | 59.88       | 56.88      | 62.63      | 59.87       |
| Days to 50% Pollen         | 55.13      | 60.00      | 57.61       | 54.13      | 60.13      | 57.95       | 55.00      | 60.5       | 57.71       |
| Anthesis/ Silking Interval | 1.00       | 2.13       | 1.63        | 1.50       | 2.50       | 1.92        | 1.75       | 2.63       | 2.16        |
| Ears Aspect                | 1.84       | 2.84       | 2.25        | 2.08       | 2.68       | 2.41        | 1.79       | 2.67       | 2.23        |
| Plant height, cm           | 140        | 206.00     | 180.28      | 159.75     | 203.75     | 180.47      | 169.25     | 198.75     | 187.07      |
| Ear height, cm             | 73.88      | 104.75     | 89.66       | 74         | 106.5      | 89.62       | 75.38      | 96.13      | 86.18       |
| Ears per plant             | 1.16       | 1.62       | 1.36        | 1.29       | 1.68       | 1.46        | 1.24       | 1.65       | 1.44        |
| Husk cover                 | 2.25       | 2.88       | 2.54        | 2.31       | 3.69       | 2.87        | 2.13       | 3.38       | 2.67        |
| Plant aspect               | 2.9375     | 5.625      | 3.99792     | 3.5        | 5.0625     | 4.375       | 3.875      | 5.375      | 4.560417    |

**Table 9: Kendall's Coefficient of concordance of ranking of the 3 testers across the 30 inbred lines for each trait under artificial Striga infestation across four environments**

| Striga Infested condition |                     |                     |                     |
|---------------------------|---------------------|---------------------|---------------------|
| -----                     |                     |                     |                     |
| Traits                    | T 1                 | T 2                 | T 3                 |
| Grain yield/ha            | 0.773**             | 0.592**             | 0.546**             |
| Days to 50% Silking       | 0.410**             | 0.536**             | 0.365 <sup>ns</sup> |
| Days to 50% Pollen        | 0.412**             | 0.516**             | 0.432**             |
| Anthesis/Silking Int.     | 0.296 <sup>ns</sup> | 0.266 <sup>ns</sup> | 0.348*              |
| Ears Aspect               | 0.535**             | 0.406**             | 0.452**             |
| Plant height              | 0.644**             | 0.528**             | 0.472**             |
| Ears per plant            | 0.404**             | 0.493**             | 0.466**             |
| Striga Rating (8WAP)      | 0.627**             | 0.508**             | 0.598**             |
| Striga Rating (10WAP)     | 0.686**             | 0.566**             | 0.557**             |
| Striga Count (8WAP)       | 0.470**             | 0.302 <sup>ns</sup> | 0.214 <sup>ns</sup> |
| Striga Count (10WAP)      | 0.435**             | 0.255 <sup>ns</sup> | 0.224 <sup>ns</sup> |

**Table 10: General combining ability effects of the three testers evaluated under artificial Striga infestation, natural infestation and non-infested conditions in 2017 and 2018.**

| TESTERS/EVN                                 | Grain yield<br>(Kg ha-1) | Days<br>to Silk     | Days to<br>anthesis  | Anthesis-<br>Silking<br>Interval | Ears<br>aspect       | Plant<br>height     | Ears<br>per<br>plant | Striga<br>Rating<br>(8WAP) | Striga<br>Rating<br>(10WAP) | Striga<br>Count<br>(8WAP) |
|---------------------------------------------|--------------------------|---------------------|----------------------|----------------------------------|----------------------|---------------------|----------------------|----------------------------|-----------------------------|---------------------------|
| <b>Artificial Striga-Infested condition</b> |                          |                     |                      |                                  |                      |                     |                      |                            |                             |                           |
| Resistant (T1)                              | 560.280***               | -0.508*             | -0.159 <sup>ns</sup> | -0.245**                         | -0.351**             | 3.569**             | 0.109**              | -0.995***                  | -0.895***                   | -20.025                   |
| Tolerant (T2)                               | 529.440***               | 0.208 <sup>ns</sup> | 0.215 <sup>ns</sup>  | 0.095 <sup>ns</sup>              | -0.068 <sup>ns</sup> | 0.136 <sup>ns</sup> | 0.094**              | -0.779***                  | -0.620**                    | 0.725 <sup>ns</sup>       |
| Susceptible (T3)                            | -1089.720***             | 0.300 <sup>ns</sup> | -0.055 <sup>ns</sup> | 0.150 <sup>ns</sup>              | 0.419**              | -3.705**            | -0.204**             | 1.775***                   | 1.516***                    | 19.300*                   |
| SE                                          | 153.481                  | 0.25                | 0.25                 | 0.127                            | 0.081                | 1.295               | 0.017                | 0.088                      | 0.184                       | 3.581                     |
| <b>Natural Infested condition</b>           |                          |                     |                      |                                  |                      |                     |                      |                            |                             |                           |
| Resistant (T1)                              | 0.25***                  | -0.87***            | -0.54***             | -0.32***                         | -0.07 <sup>ns</sup>  | 2.14 <sup>ns</sup>  | 0.01 <sup>ns</sup>   | -0.19 <sup>ns</sup>        | -0.32 <sup>ns</sup>         | -2.37**                   |
| Tolerant (T2)                               | -0.19**                  | 0.66***             | 0.67***              | -0.01 <sup>ns</sup>              | 0.09 <sup>ns</sup>   | -1.92 <sup>ns</sup> | 0.01 <sup>ns</sup>   | 0.10 <sup>ns</sup>         | 0.30 <sup>ns</sup>          | 0.60 <sup>ns</sup>        |
| Susceptible (T3)                            | -0.06 <sup>ns</sup>      | 0.20 <sup>ns</sup>  | -0.13 <sup>ns</sup>  | 0.33***                          | -0.02 <sup>ns</sup>  | -0.23*              | -0.01 <sup>ns</sup>  | 0.09 <sup>ns</sup>         | 0.02 <sup>ns</sup>          | 1.77*                     |
| SE                                          | 0.06                     | 0.17                | 0.14                 | 0.08                             | 0.05                 | 1.42                | 0.02                 | 0.21                       | 0.21                        | 0.9                       |
| <b>Non-Infested Condition</b>               |                          |                     |                      |                                  |                      |                     |                      |                            | <b>Ears<br/>height</b>      | <b>Plant<br/>Aspect</b>   |
| Resistant (T1)                              | -372.047***              | -0.422*             | -0.145 <sup>ns</sup> | -0.276**                         | -0.041 <sup>ns</sup> | -2.329**            | -0.062 <sup>ns</sup> |                            | 1.176*                      | -0.313*                   |
| Tolerant (T2)                               | 157.883 <sup>ns</sup>    | 0.215 <sup>ns</sup> | 0.195 <sup>ns</sup>  | 0.019 <sup>ns</sup>              | 0.111***             | -2.133**            | 0.041 <sup>ns</sup>  |                            | 1.130*                      | 0.063 <sup>ns</sup>       |
| Susceptible (T3)                            | 214.164**                | 0.206 <sup>ns</sup> | -0.050 <sup>ns</sup> | 0.256**                          | -0.070*              | 4.462***            | 0.020 <sup>ns</sup>  |                            | -2.306**                    | 0.249**                   |
| SE                                          | 93.927                   | 0.234               | 0.152                | 0.131                            | 0.048                | 1.032               | 0.054                |                            | 0.776                       | 0.095                     |

NOTE: \* = Significant at ( $P < 0.05$ ), \*\* = Significant at ( $P < 0.01$ ) and \*\*\* Significant at ( $P < 0.0$

**Table 11: Specific combining ability effects of grain yield for the 90 testcrosses evaluated under artificial and natural *Striga* infestation and non-infested conditions across four environments in 2017 and 2018**

| Lines | Artificial infested condition |          |          | Natural infested condition |         |           | Non-infested condition |           |           |
|-------|-------------------------------|----------|----------|----------------------------|---------|-----------|------------------------|-----------|-----------|
|       | T1                            | T2       | T3       | T1                         | T2      | T3        | T1                     | T2        | T3        |
| L1    | -1123.27**                    | 595.79** | 527.48   | -1351.14**                 | -100.57 | 1451.70** | 1677.53**              | 329.37    | 1348.17** |
| L2    | -174.36                       | 574.4**  | -400.05  | -66.76                     | 132.27  | -65.51    | -109.1                 | 648.7**   | -539.61   |
| L3    | -232.66                       | 364.14   | -131.48  | -266.23                    | 428.75  | -162.53   | -61.04                 | -52.08    | 113.13    |
| L4    | 368.01                        | 60.85    | -428.86  | 623.44**                   | -35.5   | -587.94   | 275.52                 | 344.1     | -619.62** |
| L5    | -384.18                       | 190.4    | 193.78   | 237.25                     | 404.14  | -641.38** | -730.45                | 577.57**  | 152.88    |
| L6    | 361.9                         | -163.12  | -198.78  | -170.3                     | 411.29  | -240.99   | 76.82                  | -164.32   | 87.5      |
| L7    | 313.98                        | -34.84   | -279.14  | -77.1                      | 103.71  | -26.61    | 508.64                 | -127.31   | -381.32   |
| L8    | 228.06                        | -561.29  | 333.22   | -124.13                    | 355.02  | -230.89   | 260.51                 | -233.55   | -26.96    |
| L9    | 485.51                        | -243.4   | -242.11  | 368.82                     | -347.3  | -21.52    | 435.87                 | -81.11    | -354.76   |
| L10   | -485.78                       | 304.82   | 180.96   | -12.08                     | -545.54 | 557.62    | -687.16**              | 71        | 616.15**  |
| L1    | -236.02                       | 339.66   | -103.65  | 103.78                     | -410.85 | 307.06    | -402.63                | 396.6     | 6.04      |
| L12   | -159.4                        | -261.05  | 420.45   | -478.87                    | 531.82  | -52.94    | -476.96                | -57.69    | 534.65    |
| L13   | -246.12                       | -619.9   | 866.01** | -11.02                     | -176.88 | 187.9     | 336.3                  | -181.16   | -155.14   |
| L14   | 263.8                         | -162.27  | -101.53  | 54.9                       | 192.94  | -247.85   | -80.92                 | -283.71   | 364.63    |
| L15   | 57.73                         | -293.79  | 236.06   | -232.02                    | 38.45   | 193.57    | -62.61                 | -883.96** | 946.57    |
| L16   | -646.53**                     | 196.89   | 449.64   | -420.71                    | 14.15   | 406.57    | -396.06                | 569       | -172.94   |
| L17   | 100.83                        | -330.55  | 229.71   | -640.4**                   | 225.26  | 415.14    | -250.21                | -202.55   | 452.76    |
| L18   | -151.74                       | 128.35   | 23.39    | -356.4                     | -258.04 | 614.43**  | -17.06                 | -516.39   | 533.45    |

|           |                |          |           |               |           |           |                |           |            |
|-----------|----------------|----------|-----------|---------------|-----------|-----------|----------------|-----------|------------|
| L19       | 68.97          | -99.93   | 30.96     | 207.41        | 443.64    | -651.05** | 616.4**        | 551.84    | -1168.24** |
| L20       | 689.93**       | 84.45    | -774.38** | -358.24       | 511.17    | -152.93   | 459.4          | -761.62** | 302.22     |
| L21       | 282.37         | 253.94   | -536.31** | 239.27        | 490.04    | -729.31   | 322.68         | 414.56    | -737.24**  |
| L22       | -126.62        | 232.35   | -105.72   | 975.89**      | -514.47   | -461.42   | 307.77         | 286.68    | -594.45**  |
| L23       | 11.54          | 679.86** | -691.41** | 590.67        | -397.83   | -192.84   | 187.6          | 36.26     | -223.86    |
| L24       | 352.98         | -104.69  | -248.3    | 352.31        | 6.97      | -359.28   | -275.16        | 320.95    | -45.79     |
| L25       | -418.22        | 199.65   | 218.58    | 677.6**       | -650.63** | -26.96    | 1058.93**      | -709.14** | -349.79    |
| L26       | 214.49         | -15.46   | -199.03   | 22.38         | 354.51    | -376.89   | 176.86         | 229.27    | -406.12    |
| L27       | 481.21         | -415.62  | -65.58    | 169.24        | -390.14   | 220.9     | 598.91**       | -989.01** | 390.09     |
| L28       | 625.26**       | -423.82  | -201.44   | 178.3         | -587.53   | 409.23    | 62.44          | 87.49     | -149.93    |
| L29       | -342.38        | -200.73  | 543.11    | 428.36        | -405.49   | -22.87    | -25.9          | 182.03    | -156.14    |
| L30       | -179.3         | -275.1   | 454.41    | -664.22**     | 176.64    | 487.59    | -431.87        | 198.17    | 233.69     |
| <b>SE</b> | <b>288.281</b> |          |           | <b>306.23</b> |           |           | <b>281.882</b> |           |            |