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Effectiveness of Yellow Maize Testers with Varying Resistance Reactions to *Striga hermonthica* for Evaluating the Combining Ability of Maize Inbred Lines

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Abstract: The choice of an appropriate tester is important for success in resistance hybrid breeding programs. Limited information is available on the most suitable testers that allow the selection of yellow endosperm maize inbred lines with good combining ability for resistance to witchweed (*Striga hermonthica*) and superior agronomic performance in hybrids targeted to areas infested with the parasite. Testcrosses of 30 *Striga*-resistant yellow endosperm maize inbred lines with three testers having varying levels of resistance to *S. hermonthica* were evaluated at Abuja and Mokwa in Nigeria under *Striga*-infested and non-infested conditions in 2018 and 2019. The lines × tester interaction was significant for grain yield under *Striga* infestation, indicating that the performance lines in testcrosses varied with the testers. The respective average general combining ability effect of lines and testers was 1.5 and 32.4 times greater than the corresponding specific combining ability effects under infestation, showing the greater importance of additive gene action controlling the performance of testcrosses under *Striga* infestation. The different testers exhibited a different capacity to discriminate among the test lines with the susceptible tester being the least effective. Most of the criteria used to determine the best tester favored the selection of the tolerant and resistant testers as promising candidates to identify superior *Striga*-resistant yellow endosperm inbred lines for the hybridization and development of resistant hybrids. The results of this study demonstrated that testers with a high frequency of desirable alleles were superior to the tester with a low frequency of favorable alleles in hybrid breeding programs for resistance to *S. hermonthica*.

Keywords: yellow maize lines; testers; testcrosses; coefficients of concordance; *Striga hermonthica*

1. Introduction

More than 90% of maize (*Zea mays* L.) produced globally is yellow, whereas more than 90% of the total maize produced in Africa is white [1]. The preference of yellow maize over white maize by African consumers is driven primarily by tradition [2]. At present, the demand for yellow maize is increasing in sub-Saharan Africa (SSA) because of the increasing demand for human consumption

to address vitamin A deficiency as well as for animal feed as it gives a deep yellow coloration to egg yolks, poultry skin and animal fat that consumers consider healthy and fresh [3]. Breeding for yellow hybrids can then be effective to increase maize yield in SSA [4]. The yield advantage of hybrid maize over open-pollinated varieties (OPVs) is often over 15–100% [5,6]. However, considerable yield gaps in maize are still common in sub-Saharan Africa as compared to other parts of the world due to biotic and abiotic factors as well as limited use of inputs and improved crop management practices [7–11]. Amongst the biotic factors, the parasitic weed *Striga hermonthica* (Del.) Benth inflicts severe damage to maize [12] and other cereal crops as a result of the nutrients and water loss in the host plant through parasitism [13]. Grain yield losses of up to 100% have been recorded in susceptible maize varieties and hybrids [14,15]. Considering the potential benefits of hybrids in increasing maize yields in *Striga*-infested areas, significant investments have been committed by the International Institute of Tropical Agriculture (IITA) towards the development and commercialization of high yielding and resistant hybrids [16,17]. In our breeding program, tolerance to *Striga hermonthica* has been regarded as the capacity of maize plants expressing less parasite-induced leaf scorching, better plant growth and ear development and higher grain yield notwithstanding its support of a large number of emerged parasites, whereas resistance to *Striga* has been described as the capacity of maize plants to support significantly less emerged *Striga* plants and produce significantly more grain yield than susceptible plants under parasite pressure [17–19]. The polygenic nature of the inheritance of traits associated with resistance to *S. hermonthica* [20–22] prompted breeders at IITA to employ recurrent selection schemes to improve resistance source populations. *Striga*-resistant maize inbred lines with desirable agronomic attributes showing less parasite damage symptoms and supporting less emerged *Striga* plants have then been derived from these populations for developing resistant hybrids targeted to areas infested with the parasite [17,18,21,23].

The relative performance of inbred lines in testcrosses with appropriate testers has proven useful to select inbred lines with good combining abilities and superior performance in hybrids. Hybrid maize breeding for resistance to *S. hermonthica* in International Institute of Tropical Agriculture (IITA) has commonly employed *Striga*-resistant inbred testers to evaluate the performance of new inbred lines in hybrid combinations under parasite pressure. However, a single type of tester may not completely fulfil the requirement of being the best in determining the breeding value of lines to express high levels of resistance across hybrid combinations. Given the ambiguity and inconsistency associated with the choice of the most appropriate tester [24], evaluating the relative importance of several types of testers will be important in resistance hybrid breeding programs [25–27].

Many studies have been conducted to identify and use the most appropriate tester in hybrid breeding [24,28–31]. Matzinger [28] and Russell [32] considered a desirable tester as one that is simple to use and maximizes genetic difference expressed among testcrosses of new inbred lines under evaluation. Several possibilities exist in choosing testers, including those with (i) a broad versus narrow genetic base, (ii) high versus low favorable allele frequency, (iii) high versus low yielding and (iv) use of many testers versus a single tester [24,33]. Consequently, identification of desirable testers and their discriminative ability remains an unresolved problem in crop breeding. Rawlings and Thompson [29] defined a good tester as one that differentiates efficiently among lines under test and classifies them correctly based on their relative performance in hybrid combinations. Matzinger [28] and Guimarães et al. [34] considered testers that elicit the greatest genetic variances among testcrosses as suitable for evaluating a set of inbred lines.

The line \times tester mating scheme has been extensively used to determine the general combining ability (GCA) of maize inbred lines and their specific combining ability (SCA) effects [24,35]. This method has proven useful to identify superior parents of hybrids, classify inbred lines into heterotic groups and identify appropriate testers for use in a breeding program [36–38]. Rawlings and Thompson [29] suggested that a low-yielding tester possessing a low frequency of dominant alleles could provide a better discriminating capacity of the combining ability among maize inbred lines. Hallauer and Carena [39] recommended the use of testers with a high frequency of favorable alleles to identify the

best lines with the highest specific combining ability. In sharp contrast, Fato et al. [40] found that a tester with a high frequency of favorable alleles for resistance to downy mildew (DM) disease in maize was better than a susceptible tester in discriminating inbred lines in terms of resistance to the disease under infection, days to anthesis and silking and grain yield. These authors, however, recommended the need for further studies to include more potential testers to improve breeding efficiency in resistance hybrid maize breeding program in Mozambique.

Identification of better testers has the potential for increasing the rate of genetic gain in resistance hybrid maize breeding programs [34]. It is not known if the most appropriate type of tester is dependent on the objectives of a breeding program. Limited information is available regarding the most suitable testers that permit selection of yellow endosperm maize inbred lines with good combining abilities and superior agronomic performance in hybrids for *Striga*-infested areas. The present study was, therefore, conducted to determine the effectiveness of yellow endosperm maize inbred line testers with diverse reactions to *S. hermonthica* for identifying lines with a high expression of resistance to the parasite in hybrid combinations.

2. Materials and Methods

2.1. Genetic Materials

Thirty yellow endosperm *Striga*-resistant maize inbred lines and three testers with varying levels of resistance to *Striga* developed at the International Institute of Tropical Agriculture (IITA) were used in this study (Table A1). Amongst the 30 lines, 22 were derived from two biparental crosses of elite *Striga*-resistant yellow maize inbred lines, while the remaining eight *Striga*-resistant lines were derived from a synthetic (ACR97SYN-Y), an early composite (TZE COMP5) and a late-maturing experimental variety (ACR97TZL-COMP1). The three testers were a *Striga*-tolerant line (TZISTR1207) derived from a backcross containing a temperate inbred line (B73) (T1), a *Striga*-resistant line (TZSTR1106) derived from a backcross containing perennial teosinte (*Zea diploperennis*) in its genome (T2), and a *Striga*-susceptible line (TZISTR1033) derived from a biparental cross between a temperate line (9450) and a line from Thailand (KI21) (T3). The 30 inbred lines were each crossed to the three testers to generate 90 testcrosses, which were evaluated along with two checks, one tolerant (8425-8) and one susceptible (8338-1) to the parasite.

2.2. Experimental Sites and *Striga* Infestation Treatments

The study was conducted under *Striga*-infested and non-infested conditions during the 2018 and 2019 cropping seasons at Abuja (9°15' N and 7°20' E, with an altitude of 431 m.a.s.l.) and Mokwa (9°21' N and 5°1' E, with an altitude of 188 m.a.s.l.), Nigeria is where *Striga* is endemic. Annual rainfall in Abuja was 1739 in 2018 and 2031 mm in 2019; respective values in Mokwa were 1152 and 993 mm. The soil at Abuja was sandy and had 0.5 g kg⁻¹ N, 68.99 mg kg⁻¹ P and 0.25 cmol kg⁻¹ k total nitrogen, phosphorus and potassium content, respectively, while the soil at Mokwa was sandy loam with 0.4 g kg⁻¹ nitrogen, 31.5 mg kg⁻¹ P and 0.10 cmol kg⁻¹ K.

2.3. Trial Design and Field Management Practices

The 92 testcrosses were planted in a 23 × 4 alpha lattice design with two replications in a criss-cross arrangement [41]. Each hybrid was planted in adjacent infested and non-infested strips, which were located opposite to each other and separated by a 1.5 m alley. 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 0.25 m. The infested row of a hybrid was planted directly opposite to the non-infested row to obtain precise estimates of yield loss attributable to *S. hermonthica* damage [22]. Plots consisted of single rows, each 4 m long with 0.75 m between rows. The non-infested rows were treated with ethylene two weeks before planting to eliminate any potential *S. hermonthica* seeds present in the soil. The *S. hermonthica* seeds used for infested plots in each year were collected in the previous year from farmers' sorghum fields from

each of the locations. *S. hermonthica* infestation was carried out by applying 8.5 g of sand-mixed *S. hermonthica* seed inoculum into holes of about 6 cm depth and 10 cm width spaced 0.25 m apart. The estimated number of germinable *Striga* seeds per hill was 3000. Two maize seeds of each genotype were placed into the holes infested with the sand mixed with *S. hermonthica* seeds and covered with soil. Plots were thinned to one plant per hill two weeks after emergence to attain a population density of 53,333 plants per ha. Fertilizer was applied as NPK (15-15-15) at the rate of 30 kg per ha N, 60 kg per ha P and 60 kg per ha K at planting and additional 30 kg N per ha was applied as urea four weeks later. Weeds other than *S. hermonthica* were manually removed throughout the cropping season.

2.4. Maize Traits Measured

Data collected in both *Striga*-infested and non-infested conditions included plant stand, days to 50% anthesis, days to 50% silking, plant height, ear aspect and grain yield. Days to 50% anthesis and 50% silking were recorded as the number of days from planting to when 50% of the plants in a plot shed pollen and showed silk extrusion, respectively. Anthesis–silking interval was calculated as the difference between days to 50% silking and days to 50% 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 5 scale, where 1 = clean, uniform and large ears, and 5 = rotten, variable and small ears. All ears harvested from each plot were shelled to determine per cent moisture, which was used to adjust grain yield adjusted to 15% moisture. Host plant damage symptoms were visually rated in each infested row at 8 and 10 weeks after planting (WAP) 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 [20]. The number of emerged *S. hermonthica* plants in each infested row was counted at 8 and 10 WAP and divided by the number of plants to obtain the average number of emerged *Striga* plants per maize plant. At harvest, the total number of plants and ears was counted in each *Striga*-infested and non-infested plot and these were used to calculate the number of ears per plant.

Other data collected in only non-infested plots include ear height, which was measured in cm as the distance from the base of the plant to the height of the node bearing the upper ear, and husk cover, rated on a 1 to 5 scale, where 1 = husks tightly arranged and extended beyond the ear tip, and 5 = loose husks with ear tips exposed. Plant aspect was rated on a scale of 1 to 5, where 1 = excellent plant type with large and uniform ears, low ear placement, shorter plants, resistance to foliar diseases and little or no stalk and root lodging, and 5 = plants with small and variable ears, high ear placement, tall plants, susceptible to foliar diseases, with severe stalk and root lodging. Ear rot was rated on a scale of 1 to 5, where 1 = little or no visible rotting of the ears, and 5 = extensive rotting of the ears.

2.5. Data Analysis

Each location–year combination was considered a test environment. Analysis of variance was carried out following the procedure for line \times tester as described by Singh and Chaudhary [42] using the PROC MIXED procedure in SAS version 9.4 [43] by excluding checks. In the general analysis, the GLM procedure was used across environments for each of the *Striga*-infested and non-infested conditions. Environment, replication (environment) and block (replication \times environments) were considered random effects while genotypes were regarded as fixed effects. Testcross mean square was partitioned into lines, testers and line \times tester mean squares, while testcross \times environment means the square was also partitioned into line \times environment, tester \times environment and line \times tester \times environment. Two orthogonal contrasts, corresponding to the two degrees of freedom for the testers, were conducted as $1/2(T1 + T2)$ vs. $T3$ and $T1$ vs. $T2$.

The mixed model used for the analysis was:

$$Y_{ijk} = \mu + \text{Rep}_k + \text{Blk}(\text{Rep}_k) + l_i + t_j + l_i \times t_j + l_i \times e_k + t_j \times e_k + l_i + t_j \times e_k + e_{ijk}, \quad (1)$$

where Y_{ijk} = observed value of a trait; μ = overall mean; Rep_k = replication ($k = 1, 2$); $Blk(Rep_k)$ = random effect of block nested in replication k ; l_i = line effect ($i = 1, 2, \dots, 30$); t_j = tester effect ($j = 1, 2, 3$); $l_i \times t_j$ = interaction effect of the i^{th} line and the j^{th} tester; $l_i \times e_k$ = interaction effect of the i^{th} line and the k^{th} environment; $t_j \times e_k$ = interaction effect of the j^{th} tester and the k^{th} environment; $l_i + t_j \times e_k$ = interaction effect of the i^{th} line, the j^{th} tester and the k^{th} environment; ϵ = random experimental error.

The average relative yield loss due to *Striga* infection for each tester was computed based on the differences in performance between *Striga*-infested and non-infested conditions and then the differences were divided by the performance under the non-infested condition and expressed in percentage. The efficiency of testers was first determined based on the genetic variance estimates obtained from the analysis of variance of testcross LSMEANS across the four environments for the testers [44]. Second, the testcrosses and inbred lines LSMEANS and best linear unbiased prediction (BLUPs) across environments were ranked using PROC RANK in SAS 9.4 [43]. The resulting ranks were then used to calculate Kendall's coefficient of concordance (W) [45] to assess the similarity of the rank order of the 30 inbred lines and their testcrosses for infested and non-infested conditions. The ranking was presented in descending order where the best performing combinations came first and vice versa, but for *Striga* damage rating, the ranking was in ascending order, i.e., inbred lines with low score value ranked first and vice versa. The principal component analysis was computed in SAS using the correlation matrix of trait means-centered averaged over environments to determine the significant combination of traits to the performance of testcrosses of the three testers under both infested and non-infested conditions. Correlation analyses were conducted between each of the first two principal component axes (PC1 and PC2) scores for the 90 testcrosses to identify a combination of traits that significantly contributed to each component axis. Further, the PC1 and PC2 axes scores were plotted to assess the relative grouping of the testcrosses involving the three testers. General combining ability (GCA) and specific combining ability (SCA) effects were tested for significance by dividing the GCA and SCA values by their respective standard error, and comparing the result on t -value with tabular t -value at $p \leq 0.05$ was used to determine the level of significance. The ratio of GCA to SCA was used to determine the relative importance of additive to non-additive gene effects using the formula of Baker [46] described as:

$$\text{Relative contribution} = \frac{2\sigma_{2gca}}{2\sigma_{2gca} + \sigma_{2sca}} \quad (2)$$

3. Results

3.1. Variation among Testcrosses

Under *Striga* infestation, environment and testcrosses effects were significant ($p < 0.05$) for all the traits, except anthesis–silking interval for testcrosses (Table 1). The GCA effects due to lines and testers were significant ($p < 0.01$) for all traits except anthesis–silking interval and ears per plant for lines, indicating that the additive genetic effects were important in controlling most of the traits. Line \times tester interactions were significant ($p < 0.05$) for only grain yield and *Striga* damage rating at 10 WAP, indicating that the non-additive genetic effects were less important in controlling most traits measured in this trial. Testcross \times environment interaction was significant ($p < 0.01$) for all traits except for grain yield, *Striga* emergence count at 8 WAP and ear aspect. Line \times environment interactions were significant ($p < 0.05$) for all traits except for grain yield, plant height, *Striga* count at 10 WAP, ears per plant and ear aspect. Tester \times environment interaction was, however, significant ($p < 0.05$) for all traits measured. Line \times tester \times environment interaction was significant ($p < 0.05$) for only *Striga* damage rating at 10 WAP (Table 1). Orthogonal contrasts between $1/2(T1 + T2)$ vs. $T3$ and $T1$ vs. $T2$ were significant ($p < 0.01$) for most or all of the traits recorded under the *Striga*-infested condition. It is interesting to note that the differences between $T1$ and $T2$ were not significant for grain yield and *Striga* count.

Under the *Striga*-non-infested condition, environment and testcross mean squares were significant ($p \leq 0.01$) for all the traits except anthesis–silking interval for testcross (Table 2). Line and tester GCA

effects were significant for all traits except for anthesis–silking interval of both lines and testers, and plant aspect and ears per plant for the testers. Line \times tester interaction was not significant for grain yield and five other traits under the non-infested condition, but significant for ear height, husk cover, ear aspect score and ears per plant, and testcross \times environment interaction was significant for all traits ($p \leq 0.05$) except for grain yield, anthesis–silking interval, plant height, ear height and plant aspect score. Line \times environment interaction was significant ($p < 0.001$) for all traits except grain yield, ears per plant, plant aspect and ear height. For tester \times environment interaction, eight of the traits were significant; only days to 50% silking and anthesis–silking interval were not significant. Only ears per plant was significant for line \times tester \times environment interaction (Table 2). The contrasts between $1/2(T1 + T2)$ vs. T3 and T1 vs. T2 were significant ($p < 0.01$) for most traits measured under the non-infested condition (Table 2).

Under *Striga* infestation, genetic variances for the tolerant tester (T1) were highest for three of the 11 traits and these include two of the most important traits under *Striga* viz. grain yield and *Striga* count at 10 WAP. Genetic variances of the resistant tester (T2) were highest and significant for six traits, one of which (*Striga* rating at 8 WAP) was similar in value to the genetic variance obtained for the susceptible tester (Tables 3 and A2). The susceptible tester (T3) had the highest genetic variance in two other traits viz. *Striga* count at 8 WAP and ears per plant.

Under the *Striga*-non-infested condition, the resistant tester had the highest and significant genetic variances in 6 of the 10 traits studied, while the tolerant tester had the highest values in four traits. The susceptible tester did not have the highest value in any traits. As under the *Striga*-infested condition, the highest genetic variance for grain yield was obtained with the tolerant tester. Overall, the tolerant and resistant testers had the highest genetic variances for many traits than the susceptible tester under *Striga*-infested and non-infested conditions.

Table 1. Mean squares for grain yield and other traits of testcrosses of yellow maize inbred lines under the *Striga*-infested condition in four environments.

Source of Variation	DF	Grain Yield (Kg/ha)	Silking	Anthesis	Anthesis–Silking Interval days	Plant Height (cm)	Striga Damage Rating (1–9)		Emerged <i>Striga</i> Count (No.)		Ear Aspect (1–5)	Ear Per Plant No.
							8 WAP	10 WAP	8 WAP	10 WAP		
Env	3	468,026,713 †	5509.5 †	5663.3 †	5.4 †	96,047.1 †	76.8 †	208.0 †	133,089.7 †	486,970.1 †	29.6 †	1.70 †
Rep	1	9,969,947 ***	1.0	0.2	0.39	81.6	1.2	0.1	4005.6 **	25,521.1 †	0.6 *	0.01
REP (Env)	3	955,1116 †	17.4 †	9.2 ***	1.5 **	1056.9 †	2.2 *	2.7	3122.3 †	22,756.8 †	0.7 **	0.07 **
Block (Env × Rep)	176	1,506,294 †	4.7 †	3.9 †	0.5 **	348.0 †	0.9	1.2	797.9 †	1960.4 †	0.3 †	0.02
Genotype	91	2,375,057 †	17.3 †	15.4 †	0.37	441.3 †	2.4 †	3.9 †	940.1 †	1427.0 †	0.5 †	0.06 †
Testcross	89	3,214,385 †	25.41 †	22.31 †	0.46	623.05 †	2.92 †	4.86 †	1249.47 †	1933.8 ***	0.53 †	0.05 †
Line (GCA)	29	2,583,503 ***	39.9 †	34.7 †	0.57	1070.6 †	2.97 †	4.49 †	2152.19 †	2770.88 ***	0.64 †	0.08
Tester (GCA)	2	55,710,267 †	426.0 †	389.1 †	1.48 †	6429.2 †	57.4 †	95.4 †	5957.6 †	4949.4 *	6.4 †	0.7 **
1/2(T1 + T2) vs. T3	1	109,971,212.4 †	695.8 †	648.0 †	0.9	7200.3 †	107.8 †	158.7 †	9713.6 †	9005.0 **	7.1 †	1.07 †
T1 vs. T2	1	1,449,321.6	169.2 †	130.2 †	2.6 *	5658.1 †	7.0 **	32.0 †	2201.6	893.8	5.6 †	0.18 **
Line × Tester (SCA)	58	1,719,623 **	4.1	3.5	0.38	199.1	1.02	1.93 **	635.76	1411.21	0.28	0.07
Genotype × Env	273	793,185 *	2.9 ***	2.7 †	0.42 *	127.4	0.8	1.7 **	350.3	848.2	0.2	0.02
Testcross × Env	267	1,131,521	4.18 **	3.87 ***	0.47 *	244.9	1.2 ***	2.2 †	609.1	1420.2 **	0.23	0.02 **
Line × Env	87	1,181,929	5.7 ***	5.4 †	0.64 ***	272.9	1.53 †	2.40 †	716.15 *	1298.8	0.3	0.11
Tester × Env	6	3,695,027 **	11.94 **	15.7 †	1.01 *	682.8 **	8.2 †	14.0 †	1304.0 *	2683.1 *	1.5 †	0.32 **
Line × Tester × Env	174	1,017,921	3.2	2.7	0.37	215.7	0.7	1.7 **	531.7	1437.3	0.2	0.1
Error	359	1,108,721	3.4	2.8	0.39	219.8	0.8	1.2	535	1240.5	0.2	0.1
Repeatability		0.74	0.87	0.86	0.0	0.77	0.73	0.65	0.68	0.49	0.69	0.76
CV		23.2	2.4	2.3	29.6	6.7	24.3	20.8	60	52.1	13.1	14.6

*, **, ***, † significant at probability < 0.05, 0.01, 0.001 and 0.0001 levels, respectively. WAP = weeks after planting.

Table 2. Mean squares for grain yield and other traits of testcrosses of yellow maize inbred lines under the *Striga*-non-infested condition in four environments.

Source of Variation	DF	Grain Yield	Silking	Anthesis	Anthesis–Silking Interval	Plant Height	Ear Height	Husk Cover	Pant Aspect	Ear Aspect	Ear per Plant
		(Kg/ha)			days	(cm)	(cm)	Score (1–5)	Score (1–5)	Score (1–5)	No.
Env	3	323,822,482.5 †	5968.5 †	6276.0 †	15.12 †	81,170.4 †	80,201.7 †	13.5 †	45.3 †	28.6 †	0.31 †
Rep	1	163,309.4	0.1	0.2	0.01	1347.4 †	478.6 **	0.2	2.6 †	0.002	0.024
REP (Env)	3	1,678,492 *	18.4 †	7.2 ***	2.6 ***	566.9 ***	417.3 †	1.4 ***	0.25	0.12	0.02
Block (Env × Rep)	176	2,620,737.7 †	5.3 †	4.1 †	0.6 ***	393.1 †	247.0 †	0.3 *	0.24 ***	0.29 †	0.016
Genotype	91	2,033,955.6 †	16.1 †	14.5 †	0.45	439.1 †	214.5 †	0.3 **	0.2 *	0.3 †	0.02 *
Testcross	89	2,865,918.4 †	23.10 †	20.90 †	0.57	727.25 †	385.28 †	0.44 ***	0.26 *	0.51 †	0.021 **
Line (GCA)	29	2,641,094.2 *	36.2 †	31.2 †	0.68	1296.3 †	719.2 †	0.9 †	0.4 **	0.4 ***	0.024 *
Tester (GCA)	2	39,634,973.7 †	391.0 †	377.9 †	0.28	4107.4 †	579.8 *	3.5 †	0.1	7.8 †	0.018
1/2(T1 + T2) vs. T3	1	49,033,386.9 †	429.5 †	433.6 †	0.01	2849.9 †	147.1	0.002	0.04	2.0 ***	0.01
T1 vs. T2	1	3,852,188.78 *	118.3 †	94.9 †	1.28	1917.4 ***	254.5	8.26 †	3.9 ***	5.2 †	0.04
Line × Tester (SCA)	58	1,710,433	4.1	3.6	0.52	318.1	208.6 *	0.3 **	0.2	0.29 *	0.02 *
Genotype × Env	273	880,288.8 ***	2.8 ***	2.5 ***	0.46	105.3 *	70.0 **	0.4 †	0.2	0.2 **	0.019
Testcross × Env	267	1,510,982.2	4.42 *	3.75 **	0.51	236.62	152.32	0.46 †	0.20	0.26 *	0.019 *
Line × Env	87	1,142,066	6.6 ***	5.5 †	0.75 †	203.4	134.7	0.3 ***	0.2	0.4 ***	0.01
Tester × Env	6	7,541,546.2 †	14.8	16.5 †	0.73	721.4 **	542.7 **	0.8 ***	0.81 ***	1.6 †	0.10 †
Line × Tester × Env	174	1,487,490	3	2.4	0.38	238	147.7	0.2	0.17	0.17	0.02 *
Error	359	1,565,284	3.7	2.9	0.53	235.8	149.3	0.2	0.2	0.2	0.01
Repeatability		0.64	0.86	0.87	0.10	0.81	0.75	0.00	0.26	0.56	0.12
CV		27.8	3.4	3.1	37.99	8.9	13.9	15.9	15.6	16.2	12.22

*, **, ***, † significant at probability < 0.05, 0.01, 0.001 and 0.0001 levels, respectively.

Table 3. Estimates of genetic variance and standard error for each tester across four environments under *Striga*-infested and non-infested conditions.

<i>Striga</i> -Infested Condition				<i>Striga</i> -non-Infested Condition			
Traits	T1	T2	T3	Traits	T1	T2	T3
Grain yield (kg/ha)	2.13 ** ± 0.12	1.68 * ± 0.2	1.97 ** ± 0.1	Grain yield (kg/ha)	1.77 * ± 0.1	1.67 * ± 0.2	0.89 ± 0.1
Silking (days)	3.62 † ± 0.4	5.16 † ± 0.2	3.42 † ± 0.3	Silking (days)	3.15 † ± 0.3	4.53 † ± 0.2	3.08 † ± 0.2
Anthesis (days)	3.15 † ± 0.3	5.77 † ± 0.2	3.07 † ± 0.3	Anthesis (days)	3.22 † ± 0.2	5.06 † ± 0.2	3.13 † ± 0.2
Anthesis–silking interval (days)	1.05 ± 0.1	0.91 ± 0.1	0.94 ± 0.1	Anthesis–silking interval (days)	1.33 ± 0.1	1.23 ± 0.1	0.85 ± 0.1
<i>Striga</i> rating at 8 WAP (1–9)	1.46 ± 0.1	1.77 * ± 0.1	1.77 * ± 0.1	Husk cover(1–5)	1.84 * ± 0.1	2.76 *** ± 0.1	1.43 ± 0.1
<i>Striga</i> rating at 10 WAP (1–9)	1.46 ± 0.2	1.67 * ± 0.2	1.23 ± 0.2	Plant aspect (1–5)	0.58 ± 0.1	2.08 ** ± 0.1	1.33 ± 0.1
<i>Striga</i> count at 8 WAP (no.)	2.01 ** ± 3.1	1.54 ± 2.8	2.11 ** ± 3.5	Ear height (cm)	4.13 † ± 1.4	2.42 ** ± 1.7	1.76 * ± 1.7
<i>Striga</i> count at 10 WAP (no.)	1.56 ± 4.5	1.17 ± 4.8	1.32 ± 5.2	Plant height (cm)	3.94 † ± 1.8	2.94 † ± 2.1	1.82 * ± 2.1
Plant height (cm)	1.97 ** ± 2.3	2.57 *** ± 1.9	1.75 * ± 1.8	Ear aspect (1–5)	1.34 ± 0.1	1.65 * ± 0.1	1.39 ± 0.1
Ear aspect (1–5)	1.66 * ± 0.1	2.57 *** ± 0.1	1.62 * ± 0.06	Ear per plant (no.)	0.40 ± 0.01	2.0 ** ± 0.02	0.82 ± 0.02
Ear per plant (no.)	1.28 ± 0.01	0.56 ± 0.1	2.50 *** ± 0.02				

*, **, ***, † significant at probability < 0.05, 0.01, 0.001 and 0.0001 levels, respectively. WAP = weeks after planting. T1 = Tolerant tester, T2 = Resistant tester and T3 = Susceptible tester.

3.2. Mean Performance of the Testcrosses

Relative to the average grain yield under the non-infested condition, yield reduction under *Striga* infestation was 68% for the susceptible check (8338-1) and 45% for the tolerant check (8425-8) (Table A3). Further, average testcross grain yield loss due to *Striga* damage was 20, 21 and 27% for T1, T2 and T3, respectively. Under the *Striga*-infested condition, the number of testcrosses with 20% higher grain yields than the tolerant check was 29 for the tolerant tester, 27 for the resistant tester and 14 for the susceptible tester. The increase in testcross grain yield over the tolerant check ranged from 19 to 51% for the tolerant tester, 17 to 54% for the resistant tester and 0 to 44% for the susceptible tester. The resistant and tolerant testers had higher minimum, maximum and mean grain yields compared to the susceptible tester (Table 4). The resistant tester had the highest average testcross grain yield in testcrosses evaluated across environments. Of the top-ranking 15 testcrosses under *Striga* infestation, 8 to 10 were formed with the resistant tester (Table A3). Moreover, most hybrids formed from crosses of the resistant inbred lines with resistant and tolerant testers showed less *Striga* damage symptoms and supported fewer emerged parasites, while those formed from crosses of resistant inbred lines with the susceptible tester showed more *Striga* damage symptoms and supported many emerged *Striga* plants (Table 4).

Similarly, the highest mean grain yield under the *Striga*-non-infested condition was observed in crosses between resistant inbred lines and the resistant tester followed by testcrosses of the tolerant tester (Table 5). Mean grain yield of some testcrosses was significantly greater than that of the standard tolerant check hybrid across environments (Table A3). Three testcrosses involving the tolerant tester and nine testcrosses formed with the resistant tester had 20% higher grain yields than the standard tolerant check under the *Striga*-non-infested condition. Testcrosses from the resistant and tolerant tester had the highest minimum, maximum and mean grain yields (Table 5). Amongst the 15 top-performing testcrosses, 11 involved the resistant tester. The average performance of testcrosses involving the three testers was similar for other traits. Lines L12, L3, L14, L1, L23, L25, L18, L6, L19, L17, L10, L28, L21, L16 and L29 showed better performance in crosses with the three testers across environments and can then be considered as good candidates to form single cross hybrids with high grain yields.

3.3. Relative Ranking of Inbred Lines across Testers and Testers across Lines

Significant coefficients of concordance were obtained for grain yield ranks of the lines ($W = 0.57$) and testers ($W = 0.44$) under *Striga*-infested and for lines ($W = 0.45$) and testers ($W = 0.50$) under non-infested conditions. Significant coefficients of concordance of ranks of lines and testers were also obtained for most other agronomic traits under both infested and non-infested conditions (Table A4). The ranking based on BLUP values also showed similar coefficient of concordance with some discrepancies under infested and non-infested conditions (Table A5). Testcrosses involving the three testers showed significant concordance in ranks for grain yield and most other traits across environments under *Striga* infestation (Table 6). Amongst the testers, the tolerant and susceptible testers showed better rankings of the lines across environments under infestation. However, testcrosses of the susceptible tester showed below-average mean grain yields under *Striga* infestation resulting in discarding most resistant lines as undesirable parents (Tables A6–A8). On the other hand, testcrosses involving the three testers exhibited significant concordance in ranks for anthesis and silking days, plant height and ear height across environments under the *Striga*-non-infested condition. Only testcrosses of the tolerant tester had significant rank concordance for grain yield across environments, while those of the resistant tester had significant rank concordance for plant and ear aspect scores, husk cover and ears per plant under the non-infested condition (Table 6).

Table 4. Means, maximum, minimum and standard error (Stderr) of agronomic traits for the testcrosses of yellow maize from three testers under the *Striga*-infested condition across four environments.

Variable	Tolerant Tester (T1)				Resistant Tester (T2)				Susceptible Tester (T3)			
	Min	Max	Mean	Stderr	Min	Max	Mean	Stderr	Min	Max	Mean	Stderr
Grain yield (kg/ha)	2823	4685	3705	89	2734	4960	3815	105	2032	4074	2931	79
Silking (days)	56.1	61.1	58.5	0.2	56.4	62.6	59.7	0.3	54.1	59.8	57	0.3
Anthesis (days)	54.3	58.8	56.5	0.2	54.8	60.8	57.6	0.3	52.8	57.8	55	0.2
Anthesis–silking interval (days)	1.4	2.4	2	0.04	1.5	2.5	2.1	0.04	1.4	2.5	2	0.04
<i>Striga</i> rating at 8 WAP (1–9)	2.5	4.3	3.1	0.1	2.4	4.6	3.3	0.1	3.1	4.9	4	0.1
<i>Striga</i> rating at 10 WAP (1–9)	3.3	5.8	4.6	0.1	3.9	6.6	5.1	0.1	4.9	6.8	5.8	0.1
<i>Striga</i> count at 8 WAP (no.)	11.3	56.1	31.9	2.2	11.4	44.4	27.6	1.8	17.5	79.1	37.5	2.5
<i>Striga</i> count at 10 WAP (no.)	24.1	75.6	49.3	2.8	23.3	76.8	46.6	2.6	29	88.4	55.4	3
Ear aspect (1–5)	2.5	3.3	2.8	0.04	2.6	3.7	3	0.1	2.8	3.6	3.1	0.04
Plant height (cm)	138.6	176	158.9	1.6	153.3	183.1	165.8	1.5	143	166.4	155.7	1.2
Ear per plant (no.)	0.8	1	0.9	0.01	0.7	1	0.9	0.01	0.6	1	0.8	0.02

WAP = weeks after planting.

Table 5. Means, maximum, minimum and standard error (Stderr) of agronomic traits for the testcrosses of yellow maize from three testers under the *Striga*-non-infested condition across four environments.

Traits	Tolerant Tester (T1)				Resistant Tester (T2)				Susceptible Tester (T3)			
	Min	Max	Mean	Stderr	Min	Max	Mean	Stderr	Min	Max	Mean	Stderr
Grain yield (kg/ha)	3744.6	5514	4641.9	86.5	2926	5786	4803.4	115.8	3029	4738.4	4032.8	66.1
Silking (days)	55.4	59.9	57.8	0.2	56	62.2	59	0.3	53.5	59.1	56.4	0.3
Anthesis (days)	53.8	57.9	56	0.2	54.1	60.4	57.1	0.3	52.1	57.1	54.6	0.2
Anthesis–silking interval (days)	1.0	2.38	1.87	0.05	1.13	2.88	1.94	0.05	1.38	2.38	1.89	0.04
Husk cover (1–5)	2.38	3.06	2.73	0.04	2.13	3.31	2.68	0.05	2.38	3.25	2.79	0.04
Plant aspect (1–5)	2.6	3.1	2.8	0.0	2.4	3.5	2.9	0.0	2.6	3.2	2.8	0
Ear height (cm)	71.9	102	87.2	1.4	77.6	103.8	89.1	1.3	77.5	100	86	1
Plant height (cm)	156.4	185	170.6	1.8	158.8	195	175.5	1.8	152	182.5	167.2	1.3
Ear aspect (1–5)	2.25	3.06	2.59	0.04	2.5	3.31	2.89	0.04	2.56	3.31	2.91	0.04
Ear per plant (no.)	0.95	1.04	1.0	0.0	0.72	1.08	0.98	0.01	0.93	1.1	0.99	0.01

Table 6. Kendall's coefficient of concordance (W) for ranks of yellow maize inbred lines by each tester across environments under *Striga*-infested and non-infested conditions.

<i>Striga</i> -Infested Condition				<i>Striga</i> -non-Infested Condition			
Traits	T1	T2	T3	Traits	T1	T2	T3
Grain yield (kg/ha)	0.44 **	0.35 *	0.40 **	Grain yield (kg/ha)	0.39 **	0.33	0.25
Silking (days)	0.56 †	0.63 †	0.50 ***	Silking (days)	0.49 †	0.59 †	0.50 †
Anthesis (days)	0.54 †	0.66 †	0.49 ***	Anthesis (days)	0.54 †	0.62 †	0.50 †
Anthesis–silking interval (days)	0.23	0.24	0.24	Anthesis–silking interval (days)	0.30	0.26	0.24
<i>Striga</i> rating at 8 WAP (1–9)	0.30	0.35 *	0.35 *	Husk cover (1–5)	0.38 *	0.51 †	0.34
<i>Striga</i> rating at 10 WAP (1–9)	0.38 *	0.35 *	0.32	Plant aspect (1–5)	0.18	0.39 **	0.3
<i>Striga</i> count at 8 WAP (no.)	0.42 **	0.40 **	0.38 *	Ear height (cm)	0.60 †	0.44 ***	0.41 **
<i>Striga</i> count at 10 WAP (no.)	0.39 **	0.32	0.29	Ear aspect (1–5)	0.30	0.37 *	0.34
Ear aspect (1–5)	0.33	0.46 ***	0.36 *	Plant height (cm)	0.58 †	0.50 †	0.36 *
Plant height (cm)	0.46 ***	0.46 ***	0.37 *	Ear per plant (no.)	0.16	0.42 **	0.18
Ear per plant (no.)	0.26	0.16	0.39 **				

*, **, ***, † significant at $p < 0.05, 0.01, 0.001$ and 0.0001 levels, respectively. WAP = weeks after planting. T1 = Tolerant tester, T2 = Resistant tester and T3 = Susceptible tester.

3.4. Combining Ability Estimates for Testers

Under *Striga* infestation, the tolerant and resistant testers had significant and positive GCA effects for grain yield and negative GCA effects for *Striga* damage rating and *Striga* emergence count. In contrast, the susceptible tester had a significant and negative GCA effect for grain yield and positive GCA effect for *Striga* damage rating and *Striga* emergence count. The resistant tester had significant and positive GCA effects for anthesis and silking days as well as plant height under *Striga* infestation, while the susceptible tester had negative and significant GCA effects for these traits. The tolerant tester had a significant and desirable negative GCA effect for ear aspect, while the susceptible tester had a significant and undesirable GCA effect for this trait under *Striga* infestation. The resistant tester had significant and positive GCA effects for grain yield, anthesis and silking days, as well as plant height, while the susceptible tester had significant and negative GCA effects for these traits under the *Striga*-non-infested condition (Table 7). The GCA effect of the tolerant tester for grain yield under the non-infested condition, though positive, was not significant.

Table 7. Estimates of general combining ability (GCA) effects for three testers under *Striga*-infested and non-infested conditions.

<i>Striga</i> -Infested Condition				<i>Striga</i> -non-Infested Condition			
Traits	T1	T2	T3	Traits	T1	T2	T3
Grain yield (kg/ha)	221.4 *	331.3 **	−552.7 ***	Grain yield (kg/ha)	149.2	310.7 *	−459.8 **
Silking (days)	0.11	1.3 ***	−1.42 †	Silking (days)	0.07	1.24 ***	−1.31 ***
Anthesis (days)	0.15	1.19 ***	−1.34 ***	Anthesis (days)	0.1	1.20 ***	−1.3 ***
Anthesis–silking interval (days)	−0.05	0.09	−0.04	Anthesis–silking interval (days)	−0.03	0.04	−0.01
<i>Striga</i> rating at 8 WAP (1–9)	−0.39 *	−0.15	0.55 **	Husk cover (1–5)	−0.13 *	0.11 *	0.02
<i>Striga</i> rating at 10 WAP (1–9)	−0.6 **	−0.07	0.66 **	Plant aspect (1–5)	−0.01	0.02	−0.01
<i>Striga</i> count at 8 WAP (no.)	−0.46	−4.74 *	5.19 *	Ear height (cm)	−0.3	1.79	−1.46
<i>Striga</i> count at 10 WAP (no.)	−1.14	−3.87	5	Ear aspect (1–5)	−0.2 **	0.1	0.11
Ear aspect (1–5)	−0.18 *	0.03	0.14 *	Plant height (cm)	−0.56	4.56 **	−3.98 *
Plant height (cm)	−1.20	5.67 ***	−4.47 **	Ear per plant (no.)	0.007	−0.01	0.002
Ear per plant (no.)	0.026	0.034	−0.061				

*, **, ***, † significant at $p < 0.05, 0.01, 0.001$ and 0.0001 levels, respectively. WAP = weeks after planting. T1 = Tolerant tester, T2 = Resistant tester and T3 = Susceptible tester.

3.5. Principal Components (PC) for Agronomic Traits for Each Tester

The principal component analysis was computed to determine the combination of traits that significantly contributed to the performance of testcrosses of the three testers. The first two principal component axes (PC1 and PC2) together accounted for 64% of the total variation among testcrosses under *Striga* infestation (Table 8). The PC1 axis scores of the 90 testcrosses were significantly associated with earlier anthesis and silking, shorter anthesis and silking interval, increases in *Striga* damage symptoms and *Striga* count, less number of ears per plant and grain yield. Further, all traits, except

Striga damage rating at 10 WAP, significantly contributed to the PC2 axis score of testcrosses under *Striga* infestations. Under the *Striga*-non-infested condition, PC1 and PC2 jointly explained 53% of the total variation among 90 testcrosses (Table 8). The PC1 axis scores of the 90 testcrosses were associated with significant increases in all traits except for husk cover, plant aspect and ears per plant. Testcrosses had PC2 axis scores that were significantly correlated with delays in anthesis and silking, undesirable husk cover, plant aspect and ear aspect scores, lower ear placement, shorter plants, reduced number of ears per plant and grain yield (Table 8). It is interesting to note that grain yield showed significant negative associations with PC1 and PC2 axes scores of testcrosses under *Striga* infestation but had a significant positive correlation with PC1 axis scores and negative correlation with PC2 axis scores of testcrosses under the non-infested condition (Table 8). As shown in Figure 1, most of the testcrosses involving the tolerant (T1) and resistant (T2) testers had negative PC1 axis scores, whereas most testcrosses of the susceptible (T3) tester had positive PC1 axis scores. These results indicated that the testcrosses involving T1 and T2 combined high grain yields with other desirable traits recorded under infestation. Further, many testcrosses of T1 and T2 had positive PC1 axis scores under the non-infested condition, while many of the T3 testcrosses had negative PC1 axis scores (Figure 1). Once again, these results indicated that testcrosses of both T1 and T2 combined high grain yields with other desirable agronomic properties, whereas those of T3 showed low grain yields with undesirable agronomic traits even under the non-infested condition.

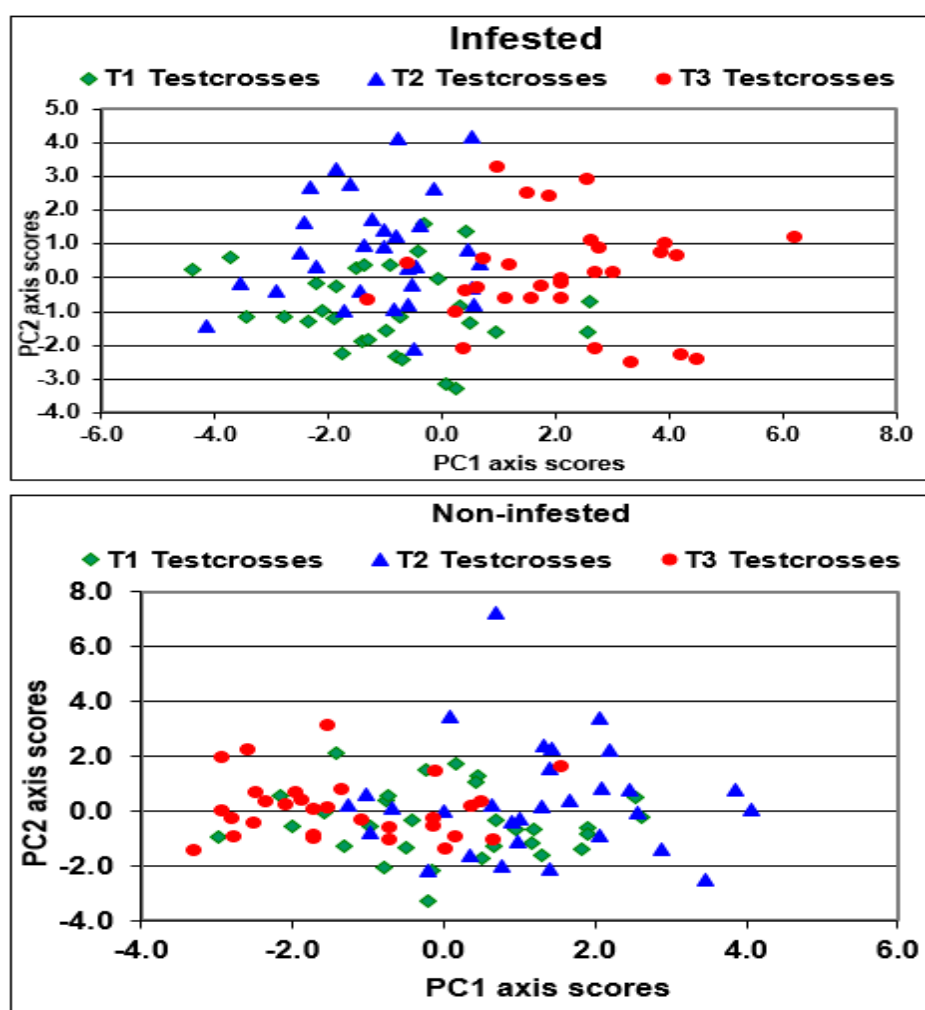


Figure 1. Scatter plot of testcrosses involving three testers evaluated under *Striga*-infested and non-infested conditions at four test environments in Nigeria. Where T1 = Tolerant tester, T2 = Resistant tester and T3 = Susceptible tester.

Table 8. Eigenvectors of the first two principal component axes (PC1 and PC2) for yellow maize testcrosses involving the testers evaluated under *Striga*-infested and non-infested conditions.

Traits	Infested		Traits	Non-Infested	
	PC1	PC2		PC1	PC2
Grain yield (kg/ha)	−0.37 †	−0.23 ***	Grain yield (kg/ha)	0.32 †	−0.36 †
Silking (days)	−0.30 †	0.43 †	Silking (days)	0.46 †	0.33 †
Anthesis (days)	−0.29 †	0.41 †	Anthesis (days)	0.46 †	0.30 †
Anthesis–silking interval (days)	−0.11 *	0.33 †	Anthesis–silking interval (days)	0.15 *	0.26 †
Striga rating at 8 WAP (1–9)	0.35 †	−0.16 *	Husk cover (1–5)	−0.20 **	0.31 †
Striga rating at 10 WAP (1–9)	0.31 †	−0.12	Plant height (cm)	0.46 †	−0.23 †
Striga count at 8 WAP (no.)	0.38 †	0.16 *	Ear height (cm)	0.44 †	−0.19 **
Striga count at 10 WAP (no.)	0.38 †	0.21 **	Plant aspect (1–5)	0.02	0.36 †
Plant height (cm)	−0.25 †	0.18 **	Ear aspect (1–5)	−0.02	0.38 †
Ear aspect (1–5)	0.21 †	0.45 †	Ear per plant (no.)	−0.10	−0.38 †
Ear per plant (no.)	−0.27 †	−0.37 †	Variance	0.29	0.24
Variance	0.41	0.23			

*, **, ***, † significant correlation with axis scores at $p < 0.05, 0.01, 0.001$ and 0.0001 levels, respectively. WAP = weeks after planting.

4. Discussion

Considerable progress has been made in breeding maize hybrids that are resistant and tolerant to *Striga hermonthica* in West and Central Africa (WCA) [17,18,47,48]. An understanding of the relative value of different types of testers in eliciting genetic differences among new lines is important in resistance hybrid breeding programs [25–27]. In the present study, the significant GCA effects of both lines and testers for most traits as well as the significant SCA effects for many traits under *Striga*-infested and non-infested conditions imply that both additive and non-additive gene effects were important in controlling the measured traits. The fact that the average GCA effect of the lines was 1.5 times greater than their SCA effect and that of the testers was 32.4 times greater than the SCA effects, the additive gene action of the testers was more important in controlling the overall performance of testcrosses. Studies have shown that genetic gain from selection with inbred testers is mainly associated with an additive gene effect rather than non-additive effects [49,50]. Karaya et al. [51] reported significant GCA effects of *Striga* rating and *Striga* count at 8, 10 and 12 WAP. Our study showed that the genetic variation for resistance to *S. hermonthica* among lines was mostly controlled by the additive type of gene action. In line with this result, additive genetic effects were more important in controlling host plant damage syndrome rating and grain yield, while a non-additive gene action was involved in controlling the number of emerged *Striga* plants under *Striga* infestation [18,52,53]. As the relative value of the yellow testers differed markedly with their resistance reactions to *Striga hermonthica* in our study, the deployment of appropriate testers has a good prospect to further increase genetic gains in resistance hybrid development programs targeting at increasing maize yield in *Striga*-endemic areas of WCA.

Several factors including gene frequency of favorable alleles, average testcrosses performance, the magnitude of variance estimates and GCA effects have been considered useful to choose appropriate testers in hybrid breeding [33,34,54]. In our study, testcrosses of the tolerant tester had the largest genetic variance for grain yield under *Striga*-infested and non-infested conditions, possibly because the tester carried favorable alleles at an intermediate to a higher frequency for resistance to the parasite that induced the largest genetic differences among testcrosses for grain yield and most other traits under the *Striga*-infested condition. In contrast, the susceptible tester had a moderate variance estimate for grain yield, and many of its testcrosses performed poorly across environments. These results contradict the idea of Rawlings and Thompson [29] and Hallauer and Lopez-Perez [55], who reported that a low-performing tester with a low frequency of favorable alleles at important loci would be more effective in differentiating the potential value of inbred lines. A tester with the greatest testcross genetic variance could discriminate groups of inbred lines and identify the best lines among testcrosses

in trials [34]. The tolerant tester could thus be regarded as a suitable tester for use in breeding for *Striga*-resistant hybrids. However, Keller [56] suggested the use of more than one tester for an accurate assessment of the ranking of lines in crosses with testers and to obtain better variance estimates among testcrosses involving each tester. Consequently, the resistant tester may also be used as an alternative tester to evaluate the inbred lines for *Striga* resistance breeding.

The selection of an appropriate tester should not rely solely on the magnitude of the genetic variance but also ranges and mean values of traits under study. Lopez-Perez [54] found that larger genetic variance estimates of testcrosses were associated with a broader range in mean values for all the measured traits. In our study, testcrosses of the tolerant tester had the largest genetic variance for grain yield but showed the lowest range for testcross mean grain yields. In contrast, testcrosses of the resistant tester exhibited the greatest range for mean grain yields but had the lowest genetic variance, indicating that this tester also provided greater opportunity to discriminate among the *Striga*-resistant lines. Furthermore, most hybrids formed from crosses of resistant inbred lines with the resistant and tolerant testers showed less *Striga* damage symptoms and supported fewer emerged parasites than the susceptible tester. These results coupled with the results from orthogonal contrasts clearly showed that the tolerant and resistant testers had a higher frequency of favorable alleles for resistance to *S. hermonthica* in comparison to the susceptible tester that allowed them to form high-yielding testcrosses with other desirable agronomic features under both infested and non-infested conditions. It appears that the susceptible tester had dominant unfavorable alleles for resistance to *S. hermonthica* at many loci that adversely affected the performance of hybrids, particularly under the infested condition. According to Tandon and Batra [57], most productive lines tend to make high-yielding crosses, whereas poor inbred lines formed crosses with poor yield performance. In a breeding program focusing on developing viable hybrids for commercialization, the best tester is the one that is high yielding, has good discriminating ability among lines and forms productive hybrid combinations. Therefore, the tolerant and resistant testers can be considered suitable for evaluating and effectively selecting promising parental lines in resistance hybrid breeding programs.

Breeders are mainly interested in selecting inbred lines that are high yielding as lines and in testcrosses with other lines. The tolerant and resistant testers with positive GCA effects for grain yield under *Striga*-infested and non-infested conditions can then be regarded as suitable testers. The tolerant and resistant testers with large GCA effects for grain yield seem to have the highest frequency of favorable alleles for use as a good tester to characterize the yield potential and *Striga* resistance-related traits of new yellow maize inbred lines under *Striga* infestation. This is consistent with studies of Fato et al. [40], 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.

Testers with a high frequency of favorable alleles can also be used to identify the best lines with the highest specific combining ability [39]. The tolerant tester identified two lines forming testcrosses and the resistant tester identified four lines forming testcrosses showing significant and positive SCA effects for grain yield in the present study, whereas the susceptible tester did not identify any line in testcrosses having a significant and positive SCA effect under the two growing conditions (Table A9a,b). Therefore, the tolerant and resistant testers that identified lines with desirable SCA effects can serve as suitable testers to evaluate inbred lines in *Striga* resistance breeding programs.

A suitable tester should provide a correct ranking of the relative merit of lines under test [50]. The tolerant and resistant testers ranked the yellow endosperm maize inbred lines better for *Striga* damage rating and *Striga* count in the present study. These testers ranked the performance of inbred lines better across environments, which is important in identifying good testcrosses for further testing and direct use or as potential female parents to develop three-way cross hybrids. Further, the tolerant and resistant testers consistently identified most of the inbred lines that formed the top 15 testcrosses identified under the two growing conditions in the present study, although the relative ranks were not identical. In contrast, only one testcross of the susceptible tester was found among the top 15 testcrosses identified under infestation and no testcross of this tester ranked in the top 15 testcrosses

under the non-infested condition. As testcrosses of the susceptible tester that produced low grain yields showed severe *Striga* damage symptoms and supported more emerged *Striga* plants, many useful inbred lines with high yield potential under infestation could be discarded. Genter [58] concluded that during a testcross evaluation, a gene from a tester parent might mask and interact with the inbred line under test that may affect the accuracy of determining the genotype of the line under study. These results confirmed the effectiveness of the tolerant and resistant testers for evaluating the yellow endosperm-resistant maize inbred lines, consistent with the conclusions of Rawlings and Thompson [29].

Lopez-Perez [54] indicated that testers should not be selected based on their yielding ability alone but also based on other important agronomic traits. In our study, the results of principal component analyses showed that testcrosses involving all three testers combined high grain yields with favorable performance in other traits notwithstanding the observed difference of the three testers having different sets of traits that contributed significantly to PC1 and PC2 axes scores. Genter [58] recommended that a hybrid breeding program must focus on the development of inbred lines with simultaneous selection for many traits which determine the net worth of the lines. Further, Hallauer [50] suggested that effective selection for desirable agronomic traits and resistance to diseases and insects in crosses with an inbred tester can enhance the development of new superior lines that are useful in combination with other elite lines. Both the tolerant and resistant testers showing sets of key traits contributing significantly to desirable performance in testcrosses are thus suitable for screening *Striga*-resistant yellow endosperm maize inbred lines in resistance hybrid breeding programs.

In conclusion, this study was conducted to determine the effectiveness of three yellow endosperm maize inbred testers with diverse resistance reactions to *S. hermonthica* for selecting lines with a high expression of resistance to the parasite in hybrid combinations. Our study clearly demonstrated that the tolerant and resistant testers that combined positive GCA effects with greater genetic variances, broader range in mean grain yields among testcrosses and consistent ranking of testcross grain yields across environments under both infested and non-infested conditions can be considered as suitable testers for resistance hybrid breeding targeting *Striga*-affected areas. In maize breeding programs that do not have established testers, the tolerant and resistant lines may serve as suitable testers to separate yellow endosperm maize inbred lines into heterotic groups to optimize heterosis in hybrids. The two testers can also be used as sources of favorable alleles to create new allelic combinations with elite lines belonging to established heterotic groups to generate diverse parental lines that can be used as parents to develop new superior resistant hybrids.

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Conflicts of Interest: The authors declare that we have no conflict of interest.

Appendix A

Table A1. Description of *Striga*-resistant inbred lines and the three testers used in the experiment.

Lines	Name	Pedigree
L1	TZISTR1224	(ACR97SYN-Y-S1-79-B×4/ACR97TZLComp1-YS155-4-1-3-B×4)-9-1-BB-B
L2	TZISTR1215	(ACR97SYN-Y-S1-79-B×4/ACR97TZLComp1-YS155-4-1-3-B×4)-62-1-B-B
L3	TZISTR1220	(ACR97SYN-Y-S1-24-B×4/ACR97TZLComp1-YS155-4-1-3-B×4)-13-1-BB-B
L4	TZISTR1222	(ACR97SYN-Y-S1-24-B×4/ACR97TZLComp1-YS155-4-1-3-B×4)-42-1-BB-B
L5	TZISTR1223	(ACR97SYN-Y-S1-24-B×4/ACR97TZLComp1-YS155-4-1-3-B×4)-44-1-BB-B
L6	TZISTR1225	(ACR97SYN-Y-S1-79-B×4/ACR97TZLComp1-YS155-4-1-3-B×4)-14-1-BB-B
L7	TZISTR1226	(ACR97SYN-Y-S1-79-B×4/ACR97TZLComp1-YS155-4-1-3-B×4)-19-1-BB-B
L8	TZISTR1227	(ACR97SYN-Y-S1-79-B×4/ACR97TZLComp1-YS155-4-1-3-B×4)-24-1-BB-B
L9	TZISTR1228	(ACR97SYN-Y-S1-79-B×4/ACR97TZLComp1-YS155-4-1-3-B×4)-26-1-BB-B
L10	TZISTR1230	(ACR97SYN-Y-S1-79-B×4/ACR97TZLComp1-YS155-4-1-3-B×4)-31-1-BB-B
L11	TZISTR1231	(ACR97SYN-Y-S1-79-B×4/ACR97TZLComp1-YS155-4-1-3-B×4)-46-1-BB-B
L12	TZISTR1232	(ACR97SYN-Y-S1-79-B×4/ACR97TZLComp1-YS155-4-1-3-B×4)-50-1-BB-B
L13	TZISTR1235	(ACR97SYN-Y-S1-79-B×4/ACR97TZLComp1-YS155-4-1-3-B×4)-66-1-BB-B
L18	TZISTR1214	(ACR97SYN-Y-S1-79-B×4/ACR97TZLComp1-YS155-4-1-3-B×4)-61-1-B-B
L22	TZISTR1233	(ACR97SYN-Y-S1-79-B×4/ACR97TZLComp1-YS155-4-1-3-B×4)-55-1-BB-B
L14	TZISTR1236	(ACR97TZLComp1-YS155-4-1-3-B×4/ACR97SYN-Y-S1-76-B×4)-1-1-BB-B
L15	TZISTR1237	(ACR97TZLComp1-YS155-4-1-3-B×4/ACR97SYN-Y-S1-76-B×4)-9-1-BB-B
L16	TZISTR1238	(ACR97TZLComp1-YS155-4-1-3-B×4/ACR97SYN-Y-S1-76-B×4)-10-1-BB-B
L17	TZISTR1211	(ACR97TZLComp1-YS155-4-1-3-B×4/ACR97SYN-Y-S1-76-B×4)-20-1-B-B
L19	TZISTR1216	(ACR97TZLComp1-YS155-4-1-3-B×4/ACR97SYN-Y-S1-76-B×4)-21-1-BB-B
L20	TZISTR1217	(ACR97TZLComp1-YS155-4-1-3-B×4/ACR97SYN-Y-S1-76-B×4)-32-1-BB-B
L21	TZISTR1218	(ACR97TZLComp1-YS155-4-1-3-B×4/ACR97SYN-Y-S1-76-B×4)-44-1-BB-B
L23	TZSTRI109	ACR97SYN-Y-S1-79-B-B-B
L24	TZSTRI110	ACR97SYN-Y-S1-24-B-B-B
L25	TZSTRI112	TZE COMP5-25-1-1-3-#-2-B-B-B
L26	TZSTRI113	TZEComp.5-Y-20-1-1-3-#-2-B-B-B-B
L27	TZSTRI114	TZECOMP5-Y-C7-S3-55-B-B-B
L28	TZISTR1028	ACR97TZL-CCOMP1-Y-S3-33-6-B×8
L29	TZISTR1029	ACR97TZL-CCOMP1-Y-S3-12-2-B×8
L30	TZISTR1030	ACR97TZL-CCOMP1-Y-S3-6-1-B×9
Testers		
T1	TZISTR1207 (T)	9450×CM 116×9450)-3-3-1-2-1-B×8
T2	TZSTRI106 (R)	Z.diplo.BC4-376-1-1-#-3-1-B-2-B×8
T3	TZISTR1033 (S)	9450×KI21-3-2-2-2-1-B×8
		Standard hybrid checks
1	8425-8	Tolerant
2	8338-1	Susceptible

Table A2. Mean squares of testcrosses for each tester across four environments under *Striga*-infested non-infested conditions.

<i>Striga</i> -Infested Condition						<i>Striga</i> -non-Infested Condition					
Traits	Testers	Environment	Testcross	Mean	CV	Traits	Testers	Environment	Testcross	Mean	CV
DYSK	T1	841.4 †	7.2 †	58.5	2.4	DYSK	T1	903.5 †	6.0 †	57.8	2.4
	T2	824.9 †	9.2 †	59.6	2.2		T2	898.5 †	8.4 †	59.0	2.3
	T3	1079.4 †	7.7 †	57.0	2.6		T3	1174.7 †	7.7 †	56.4	2.8
DYSP	T1	875.9 †	5.8 †	56.5	2.4	DYSP	T1	962.5 †	5.0 †	55.9	2.2
	T2	805.3 †	8.76 †	57.6	2.1		T2	913.3 †	7.6 †	57.0	2.1
	T3	1120.9 †	6.3 †	55.0	2.6		T3	1241.4 †	6.7 †	54.5	2.7
ASI	T1	1.0 **	0.21	1.93	23.2	ASI	T1	1.99 †	0.3	1.87	25.7
	T2	0.3	0.22	2.08	23.9		T2	2.1 ***	0.4	1.93	27.6
	T3	2.0 †	0.23	1.94	25.6		T3	4.5 †	0.2	1.89	26.0
PL HT	T1	13,309.2 †	302.9 **	158.9	7.8	PL HT	T1	11,702.9 †	394.9 †	170.6	5.9
	T2	20,825.3 †	264.9 ***	165.8	6.1		T2	18,456.6 †	390.0 †	175.4	6.6
	T3	13,835.6 †	166.6 *	155.7	6.3		T3	11,183.3 †	194.6 *	167.2	6.2
STRRAT1	T1	3.8 ***	0.8	3.1	23.7	EHT	T1	13,011.9 †	242.8 †	87.2	8.8
	T2	11.1 †	0.9 *	3.3	21.7		T2	17,085.1 †	208.0 ***	89.1	10.4
	T3	32.0 †	0.82 *	4.0	16.8		T3	10,648.8 †	123.6 *	86.0	9.7
STRRAT2	T1	14.6 †	1.3	4.6	20.9	HUSK	T1	7.3 †	0.2 *	2.5	12.8
	T2	46.8 †	1.7 *	5.1	20.0		T2	4.7 †	0.4 ***	2.8	13.8
	T3	56.8 †	1.1	5.8	16.5		T3	7.8 †	0.15	2.7	11.8
STRCO1	T1	19,346.1 †	561.7 **	31.9	52.5	PASP	T1	9.0 †	0.06	2.8	11.0
	T2	18,533.6 †	372.7	27.6	56.4		T2	5.2 †	0.23 **	2.9	11.5
	T3	26,704.6 †	777.5 **	37.5	51.1		T3	8.3 †	0.11	2.8	9.9
STRCO2	T1	67,040.7 †	926.9	49.3	49.4	EASP	T1	2.9 †	0.16	2.6	13.5
	T2	72,326.6 †	791.2	46.5	55.9		T2	5.5 †	0.18 *	2.9	11.6
	T3	93,144.5 †	1078.5	55.4	51.6		T3	7.1 †	0.16	2.9	11.7
EASP	T1	3.4 †	0.15 *	2.8	10.7	EPP	T1	0.02 *	0.002	1.00	7.9
	T2	4.8 †	0.3 ***	3.0	11.3		T2	0.17 †	0.02 **	0.98	11.3
	T3	8.3 †	0.16 *	3.1	10.1		T3	0.05 ***	0.01	0.99	8.3
EPP	T1	0.19 †	0.01	0.94	8.4	YLD	T1	33,821,388.6 †	898,294.7 *	4641.9	15.3
	T2	0.21	0.08	0.95	39.3		T2	82,146,365.9 †	1,608,539.2 *	4803.4	20.5
	T3	0.9 †	0.03 ***	0.85	13.1		T3	51,251,103.6 †	524,149.6	4032.8	19.0
YLD	T1	54,630,065.1 †	945,426.1 **	3704.9	18.0						
	T2	95,250,316.6 †	1,313,011 *	3814.8	23.2						
	T3	88,841,722.3 †	752,937.4 **	2930.8	21.1						

*, **, ***, † significant at $p < 0.05$, 0.01, 0.001 and 0.0001 levels, respectively. ASI = anthesis–silking interval, DYSK = days to 50% silking, DYPOL = days to 50% anthesis, PLHT = plant height (cm), STRRAT1 and STRRAT2 = *Striga* damage rating (rating at a scale of 1–9) at 8 and 10 WAP, respectively, STRCO1 and STRCO2 = *Striga* emergence count at 8 and 10 WAP, respectively, EASP = ear aspect (rating at a scale of 1–5), PASP = qualitative observation of plant ideotype rated using a scale of 1 to 5, HUSK = the degree of the husk covering the tip of the ear using a scale of 1 to 5, EPP = ears per plant and YLD = grain yield (kg/ha).

Table A3. Agronomic performance of testcrosses for some selected traits under artificial *Striga* infestation.

Testcrosses	YLDIN	YLDUN	RED (%)	DYSK	DYSP	EASP	EPP	CO1	CO2	RAT1	RRAT2
L1 × T1	4015.7	4535.8	11.5	59.1	57.1	2.6	1.0	15.1	31.1	2.5	3.9
L2 × T1	3228.2	4453.8	27.5	60.0	58.1	2.8	0.9	27.0	37.5	3.6	4.0
L3 × T1	4610.3	5033.8	8.4	58.6	56.9	2.6	0.9	17.9	26.3	2.8	4.5
L4 × T1	3280.5	3891.1	15.7	59.5	57.4	2.9	0.9	44.8	62.4	3.3	4.6
L5 × T1	3355.8	4798.6	30.1	60.5	58.4	3.1	0.9	34.5	52.8	3.8	5.6
L6 × T1	3714.4	4387.1	15.3	59.3	57.5	2.7	1.0	39.6	54.9	2.5	3.9
L7 × T1	3706.4	4409.6	15.9	58.8	56.5	2.7	0.9	25.9	35.9	2.6	4.5
L8 × T1	3878.8	4866.4	20.3	56.3	54.6	2.5	1.0	48.1	73.9	3.4	4.8
L9 × T1	3821.3	4819.6	20.7	59.6	57.6	2.7	0.9	31.8	52.4	2.5	3.5
L10 × T1	4066.4	5020.9	19.0	57.5	55.8	2.8	0.9	15.5	33.9	2.9	4.3
L11 × T1	3515.4	4317.6	18.6	57.5	55.8	2.6	1.0	28.0	41.8	2.6	4.0
L12 × T1	4204.2	4522.9	7.0	61.1	58.8	2.7	1.0	11.3	24.1	2.8	3.3
L13 × T1	2912.5	3964.7	26.5	59.9	57.5	3.3	0.9	39.6	66.4	3.1	5.1
L14 × T1	4286.3	5213.0	17.8	57.3	55.4	2.6	0.9	36.1	71.3	2.6	4.4
L15 × T1	3064.4	4465.4	31.4	57.4	55.5	3.2	1.0	34.5	45.8	3.3	4.8
L16 × T1	3124.0	4238.5	26.3	59.5	57.5	3.1	0.9	29.8	51.8	3.3	5.0
L17 × T1	3923.2	4314.4	9.1	58.0	56.1	2.6	1.0	18.4	37.1	3.1	4.8
L18 × T1	4068.0	5090.8	20.1	59.0	56.8	2.9	1.0	25.3	30.9	3.3	4.6
L19 × T1	3921.9	4649.2	15.6	56.9	55.5	2.7	1.0	41.3	65.5	2.9	4.9
L20 × T1	2822.8	4828.7	41.5	58.1	56.3	2.9	0.9	52.9	69.6	4.1	5.8
L21 × T1	3794.6	4072.8	6.8	57.1	55.3	2.7	1.0	37.5	54.6	2.9	4.3
L22 × T1	3026.7	3744.6	19.2	56.5	54.6	2.8	0.9	38.3	47.9	3.3	5.0
L23 × T1	3761.7	4662.7	19.3	58.0	56.0	2.8	0.9	33.9	45.4	3.0	4.4
L24 × T1	3084.7	3793.3	18.7	58.6	56.6	3.1	0.9	25.1	46.6	3.0	4.5
L25 × T1	3478.3	5288.0	34.2	56.1	54.3	2.9	0.9	56.1	70.3	4.3	5.6
L26 × T1	3918.3	4884.8	19.8	57.1	55.1	2.8	0.9	22.5	39.1	2.9	4.3
L27 × T1	3680.6	5340.4	31.1	58.1	56.4	2.8	0.9	51.8	75.6	3.3	4.8
L28 × T1	4161.9	5514.3	24.5	58.5	56.9	2.8	1.0	33.9	61.9	3.0	4.5
L29 × T1	4684.6	5095.5	8.1	60.9	58.6	2.9	1.0	18.5	39.1	2.8	4.5
L30 × T1	4034.5	5038.4	19.9	58.8	57.0	2.9	0.8	21.4	32.6	3.3	5.0
L1 × T2	4314.9	5160.9	16.4	59.3	57.1	2.9	1.0	23.5	42.5	2.9	4.1
L2 × T2	3625.2	5298.3	31.6	60.6	58.5	3.2	0.9	32.4	50.3	3.4	4.9
L3 × T2	3595.0	5309.6	32.3	61.3	59.3	3.4	0.8	19.9	46.4	3.1	5.0
L4 × T2	3973.6	4634.3	14.3	59.6	57.6	2.9	0.9	17.0	31.5	4.3	6.3
L5 × T2	3718.5	5365.1	30.7	61.3	59.3	3.3	0.9	18.8	28.9	3.3	5.5
L6 × T2	4959.7	5785.8	14.3	58.9	56.9	2.6	1.0	21.5	38.0	2.4	3.9
L7 × T2	3861.3	4434.4	12.9	60.5	58.0	3.1	0.9	38.5	57.4	3.1	5.5
L8 × T2	3745.1	4743.9	21.1	58.8	56.5	2.7	0.8	42.9	54.5	3.3	5.1
L9 × T2	2833.6	4007.8	29.3	61.3	59.1	3.2	0.9	38.6	62.9	2.8	5.1
L10 × T2	3545.4	4588.6	22.7	57.9	55.6	3.1	1.0	27.0	44.1	2.6	4.6
L11 × T2	3947.3	4016.0	1.7	58.9	56.8	2.7	1.0	44.4	55.3	3.6	4.9
L12 × T2	4894.5	5380.7	9.0	60.0	58.0	2.6	0.9	11.9	23.3	3.1	4.5
L13 × T2	3135.6	4773.0	34.3	60.4	58.1	3.3	0.8	28.4	43.1	3.6	5.5
L14 × T2	4271.7	5026.5	15.0	58.9	56.5	2.9	0.9	11.4	27.5	3.3	4.8
L15 × T2	4040.7	4616.9	12.5	58.0	56.1	2.9	1.0	24.3	34.4	3.0	5.0
L16 × T2	3840.9	5173.6	25.8	60.1	57.6	2.9	0.9	30.5	74.3	3.0	5.0
L17 × T2	3696.2	4641.1	20.4	58.1	56.0	3.0	0.9	25.0	43.6	4.6	5.8
L18 × T2	3946.3	5717.2	31.0	60.0	57.9	2.8	0.9	31.8	54.9	3.5	5.5
L19 × T2	3744.6	4785.2	21.7	59.4	57.1	3.0	0.9	29.3	76.8	3.5	6.4
L20 × T2	4255.3	4470.3	4.8	60.3	58.4	3.0	0.9	16.1	41.6	3.1	4.4
L21 × T2	3688.1	4295.6	14.1	60.4	58.4	2.9	0.9	26.4	35.9	3.6	5.5
L22 × T2	3753.9	4988.7	24.8	57.3	55.1	3.0	0.9	40.5	63.0	3.3	5.3
L23 × T2	4675.2	5298.2	11.8	58.8	56.8	2.8	0.9	38.9	66.1	3.3	5.4
L24 × T2	4115.3	5218.5	21.1	60.3	58.3	3.2	0.9	14.5	24.6	3.8	4.5
L25 × T2	4728.0	5651.6	16.3	56.4	54.8	2.8	0.9	38.8	47.8	3.8	4.6
L26 × T2	3319.7	4813.7	31.0	57.8	55.9	3.3	0.9	27.4	43.3	3.0	4.1
L27 × T2	3466.0	5161.8	32.9	58.3	56.8	3.2	0.9	37.5	60.1	3.4	5.4
L28 × T2	3277.3	4102.5	20.1	62.6	60.4	3.4	0.8	23.9	50.9	2.6	4.5
L29 × T2	2740.8	2926.2	6.3	62.4	60.8	3.7	0.7	13.6	31.1	3.5	4.8
L30 × T2	2733.9	3715.3	26.4	61.9	59.5	3.4	0.8	33.3	42.5	4.0	6.6
L1 × T3	3488.2	4323.4	19.3	56.8	54.5	2.9	0.9	34.3	46.3	3.9	5.6
L2 × T3	3198.5	4493.6	28.8	58.5	56.5	2.9	0.9	33.1	49.9	4.5	6.1
L3 × T3	4074.4	4738.4	14.0	57.5	55.5	2.9	0.9	17.5	36.8	3.1	4.9
L4 × T3	2832.5	3806.8	25.6	57.3	55.4	3.3	0.8	41.4	52.4	4.4	6.3
L5 × T3	2755.8	4152.8	33.6	59.0	56.5	3.4	0.8	35.8	57.4	4.0	5.9

Table A3. Cont.

Testcrosses	YLDIN	YLDUN	RED (%)	DYSK	DYSP	EASP	EPP	CO1	CO2	RAT1	RRAT2
L6 × T3	2721.0	3969.8	31.5	57.3	55.4	2.9	0.9	33.8	56.4	3.4	5.6
L7 × T3	2512.2	4076.1	38.4	56.9	54.9	3.2	0.7	42.6	74.8	4.5	6.4
L8 × T3	2031.9	3936.4	48.4	56.3	55.3	3.4	0.6	79.1	88.4	4.6	6.5
L9 × T3	2709.3	3029.1	10.6	58.3	56.1	3.2	0.9	31.9	51.1	3.4	5.3
L10 × T3	2876.5	3798.8	24.3	56.3	54.4	3.4	0.9	33.6	43.4	3.8	5.3
L11 × T3	2610.6	4074.7	35.9	55.8	53.8	3.2	0.8	36.1	53.0	4.1	6.3
L12 × T3	3515.0	3991.9	11.9	59.1	57.0	2.9	0.9	22.3	43.9	3.6	5.3
L13 × T3	2595.3	3836.9	32.4	57.0	54.6	3.3	0.8	39.1	55.9	4.1	5.9
L14 × T3	3576.3	4027.0	11.2	55.8	54.1	2.8	0.9	24.4	39.8	3.6	4.9
L15 × T3	2350.8	3587.4	34.5	55.9	53.8	3.3	0.8	37.8	65.0	4.5	6.8
L16 × T3	3255.8	3793.4	14.2	56.8	54.6	3.0	0.9	27.4	42.9	3.5	5.4
L17 × T3	2990.0	4176.8	28.4	55.8	53.9	3.3	0.8	25.8	38.9	4.1	5.5
L18 × T3	3387.8	4265.6	20.6	57.1	55.1	2.9	0.9	27.5	59.1	4.3	5.9
L19 × T3	3073.5	3514.2	12.5	56.5	54.8	3.1	1.0	23.0	30.1	3.4	5.5
L20 × T3	2891.3	4028.7	28.2	56.4	54.6	3.2	0.8	28.4	39.9	3.9	5.6
L21 × T3	2779.2	3285.9	15.4	56.6	54.6	3.2	0.9	36.0	57.6	3.8	5.3
L22 × T3	3147.1	4263.5	26.2	54.1	52.8	3.1	0.9	53.4	78.5	4.4	6.8
L23 × T3	3337.0	4374.1	23.7	55.4	53.5	2.8	0.8	71.3	85.4	4.1	5.8
L24 × T3	2618.9	4069.8	35.7	59.1	57.1	3.3	0.7	33.9	52.3	4.0	6.1
L25 × T3	3257.7	4391.2	25.8	55.0	53.3	3.0	1.0	55.9	72.8	4.3	6.0
L26 × T3	2763.4	4180.0	33.9	55.0	53.6	3.2	0.9	45.9	50.8	3.8	5.1
L27 × T3	2654.8	4481.6	40.8	56.9	55.0	3.1	0.7	50.1	74.3	4.6	6.6
L28 × T3	2918.0	4393.9	33.6	57.6	55.6	2.9	0.7	49.6	87.9	3.6	5.8
L29 × T3	2707.4	3964.8	31.7	59.8	57.8	3.6	0.8	26.3	29.0	4.5	6.0
L30 × T3	2293.3	3957.4	42.1	59.0	57.0	3.3	0.7	28.6	48.9	4.9	6.4
8425-8	2280.7	4174.1	45.4	59.1	56.8	3.5	0.8	37.3	59.3	4.4	6.4
8338-3	1050.3	3303.9	68.2	60.9	59.0	4.2	0.3	92.1	132.6	6.6	8.6
Mean	3444.0	4476.3	23.2	58.4	56.4	3.0	0.9	33.0	51.4	3.5	5.2
LSD (0.05)	911.9	946.7		1.75	1.71	0.43	0.14	19.02	28.63	0.97	1.42

DYSK = days to 50% silking, DYSP = days to 50% anthesis, PLHT = plant height (cm), RAT1 and RAT2 = *Striga* damage rating (scale of 1–9) at 8 and 10 WAP, respectively, CO1 and CO2 = *Striga* emergence count at 8 and 10 WAP, respectively, EASP = ear aspect (rating at a scale of 1–5), EHT = plant height from base to the node of the ear (cm), PASP = qualitative observation of plant ideotype rated using a scale of 1 to 5, HUSK = the degree of the husk covering the tip of the ear using a scale of 1 to 5, ASI = anthesis–silking interval, EPP = ears per plant, YLDIN and YLDUN = grain yield (kg/ha) under *Striga*-infested and non-infested conditions and RED% = per cent grain yield reduction due to *Striga* infestation.

Table A4. Consistency of line and tester rankings using Kendall's coefficient of concordance (W) across environment under (a) *Striga*-infested and (b) non-infested conditions.

(a) <i>Striga</i> -Infested Condition			(b) <i>Striga</i> -non-Infested Condition		
Tester Rankings	Line Rankings		Tester Rankings	Line Rankings	
Traits	W	W	Traits	W	W
Grain yield (kg/ha)	0.44 *	0.57 †	Grain yield (kg/ha)	0.50 **	0.45 †
Silking (days)	0.84 †	0.86 †	Silking (days)	0.80 †	0.84 †
Anthesis (days)	0.83 †	0.80 †	Anthesis (days)	0.81 †	0.75 †
Anthesis–silking interval (days)	0.42	0.07	Anthesis–silking interval (days)	0.42	0.02
<i>Striga</i> rating at 8 WAP (1–9)	0.64 †	0.61 †	Husk cover (1–5)	0.57 ***	0.05
<i>Striga</i> rating at 10 WAP (1–9)	0.58 ***	0.63 †	Plant aspect (1–5)	0.47 *	0.02
<i>Striga</i> count at 8 WAP (no.)	0.61 ***	0.12 *	Ear aspect (1–5)	0.43	0.58 †
<i>Striga</i> count at 10 WAP (no.)	0.48 *	0.10 *	Ear height (cm)	0.63 †	0.14 *
Ear aspect (1–5)	0.54 **	0.44 †	Plant height (cm)	0.71 †	0.42 †
Plant height (cm)	0.73 †	0.40 †	Ear per plant (no.)	0.37	0.03
Ear per plant (no.)	0.47 *	0.38 †			

*, **, ***, † significant at $p < 0.05, 0.01, 0.001$ and 0.0001 levels, respectively. WAP = weeks after planting.

Table A5. Kendall’s coefficient of concordance (W) based on BLUP for ranks of yellow maize inbred lines by each tester across environments under *Striga*-infested and non-infested conditions.

<i>Striga</i> -Infested Condition				<i>Striga</i> -non-Infested Condition			
Traits	T1	T2	T3	Traits	T1	T2	T3
Grain yield (kg/ha)	0.38 *	0.38 *	0.42 **	Grain yield (kg/ha)	0.39 **	0.41 **	0.31
Silking (days)	0.55 †	0.74 †	0.51 †	Silking (days)	0.53 †	0.69 †	0.52 †
Anthesis (days)	0.55 †	0.75 †	0.47 ***	Anthesis (days)	0.53 †	0.74 †	0.52 †
Anthesis–silking interval (days)	0.21	0.26	0.24	Anthesis–silking interval (days)	0.19	0.30	0.28
<i>Striga</i> rating at 8 WAP (1–9)	0.32	0.33	0.35 *	Husk cover (1–5)	0.23	0.28	0.33
<i>Striga</i> rating at 10 WAP (1–9)	0.39 **	0.33	0.33	Plant aspect (1–5)	0.25	0.33	0.26
<i>Striga</i> count at 8 WAP (no.)	0.43 **	0.48 ***	0.45 **	Ear height (cm)	0.59 †	0.56 †	0.54 †
<i>Striga</i> count at 10 WAP (no.)	0.32	0.42 **	0.36 *	Ear aspect (1–5)	0.28	0.34	0.35 *
Ear aspect (1–5)	0.26	0.48 ***	0.35 *	Plant height (cm)	0.64 †	0.62 †	0.61 †
Plant height (cm)	0.51 †	0.54 †	0.61 †	Ear per plant (no.)	0.15	0.44 ***	0.19
Ear per plant (no.)	0.36 *	0.44 ***	0.41 **				

*, **, ***, † significant at $p < 0.05, 0.01, 0.001$ and 0.0001 levels, respectively. WAP = weeks after planting. T1 =Tolerant tester, T2 = Resistant tester and T3 = Susceptible tester.

Table A6. Ranking *Striga*-resistant inbred lines based on average yield (kg/ha) performance across each environment in the combined analysis at Abuja and Mokwa, Nigeria for each tester under *Striga* infestation.

Rank	T1					T2					T3				
	AB18	AB19	MK18	MK19	χ^i	AB18	AB19	MK18	MK19	χ^i	AB18	AB19	MK18	MK19	χ^i
1	L9	L12	L3	L30	L29	L12	L6	L4	L23	L6	L20	L14	L12	L3	L3
2	L6	L26	L5	L28	L3	L25	L11	L23	L6	L12	L12	L16	L14	L1	L14
3	L3	L14	L29	L29	L14	L6	L12	L24	L7	L25	L25	L25	L23	L22	L12
4	L21	L8	L18	L23	L12	L19	L17	L20	L25	L23	L19	L3	L18	L23	L1
5	L22	L29	L30	L14	L28	L18	L1	L16	L14	L1	L3	L17	L1	L18	L18
6	L28	L10	L19	L3	L18	L1	L14	L14	L12	L14	L11	L10	L10	L16	L23
7	L29	L1	L12	L19	L10	L15	L8	L7	L16	L20	L23	L2	L22	L5	L25
8	L19	L18	L14	L1	L30	L5	L18	L15	L22	L24	L16	L19	L29	L27	L16
9	L12	L28	L4	L26	L1	L28	L27	L1	L17	L15	L28	L18	L19	L2	L2
10	L8	L9	L7	L10	L17	L24	L26	L22	L18	L4	L6	L1	L3	L28	L22
11	L10	L25	L23	L17	L19	L13	L20	L2	L29	L11	L17	L26	L9	L29	L19
12	L14	L3	L1	L27	L26	L27	L10	L3	L21	L18	L18	L28	L2	L12	L17
13	L17	L24	L10	L11	L8	L8	L25	L25	L11	L7	L26	L27	L4	L14	L28
14	L27	L17	L17	L25	L9	L9	L29	L12	L20	L16	L14	L4	L21	L21	L20
15	L16	L7	L26	L18	L21	L20	L3	L21	L10	L22	L2	L7	L30	L24	L10
16	L30	L27	L25	L7	L23	L4	L5	L19	L15	L8	L4	L22	L17	L13	L4
17	L1	L6	L9	L8	L6	L22	L23	L6	L1	L19	L27	L12	L7	L25	L21
18	L24	L5	L21	L15	L7	L3	L15	L11	L5	L5	L1	L6	L6	L15	L26
19	L11	L23	L16	L21	L27	L21	L24	L8	L8	L17	L9	L9	L5	L26	L5
20	L18	L21	L27	L12	L11	L11	L19	L5	L24	L21	L24	L21	L24	L8	L6
21	L26	L11	L11	L20	L25	L23	L2	L28	L2	L2	L10	L13	L20	L9	L9
22	L23	L2	L13	L6	L5	L2	L7	L27	L13	L3	L21	L5	L13	L4	L29
23	L2	L15	L8	L13	L4	L10	L4	L10	L28	L10	L22	L11	L25	L11	L27
24	L7	L22	L2	L4	L2	L17	L30	L26	L26	L27	L13	L15	L26	L17	L24
25	L4	L4	L6	L2	L16	L14	L21	L17	L19	L26	L5	L20	L28	L20	L11
26	L15	L19	L15	L22	L24	L26	L9	L18	L3	L28	L8	L29	L16	L6	L13
27	L13	L13	L28	L16	L15	L16	L16	L13	L30	L13	L7	L24	L11	L10	L7
28	L5	L20	L20	L5	L22	L7	L22	L30	L27	L9	L15	L30	L15	L7	L15
29	L20	L16	L24	L9	L13	L30	L13	L9	L4	L29	L29	L23	L8	L30	L30
30	L25	L30	L22	L24	L20	L29	L28	L29	L9	L30	L30	L8	L27	L19	L8
W			0.44 **					0.35 *					0.40 **		
# lines	10	12	11	10		8	8	11	10		11	9	9	10	

χ^i = ranking based on the mean of each tester across the environment; W = Kendall’s coefficient of concordance where * and ** are significant levels of probability at 0.05 and 0.01, respectively. AB18, AB19, MK18 and MK19 are Abuja and Mokwa environments in the 2018 and 2019 cropping seasons, respectively; note: number of lines (# lines) are based on top 15 lines ranks indicated in yellow color in descending order, i.e., inbred lines performed best ranked first and poor performing inbred lines ranked last.

Table A7. Ranking of *Striga*-resistant inbred lines based on average yield (kg/ha performance across each environment in the combined analysis at Abuja and Mokwa, Nigeria for each tester in the *Striga*-non-infested condition.

Rank	T1					T2					T3				
	AB18	AB19	MK18	MK19	Xi	AB18	AB19	MK18	MK19	Xi	AB18	AB19	MK18	MK19	Xi
1	L30	L9	L29	L10	L28	L25	L27	L5	L5	L6	L28	L3	L11	L3	L3
2	L27	L12	L28	L28	L27	L6	L18	L24	L14	L18	L20	L11	L16	L27	L2
3	L14	L1	L3	L3	L25	L3	L6	L18	L16	L25	L11	L5	L21	L25	L27
4	L10	L25	L27	L26	L14	L22	L5	L3	L25	L12	L27	L29	L9	L16	L28
5	L15	L28	L19	L14	L29	L18	L12	L16	L23	L5	L6	L1	L3	L1	L25
6	L2	L27	L8	L18	L18	L23	L10	L2	L8	L3	L3	L7	L15	L2	L23
7	L18	L10	L25	L25	L30	L27	L1	L13	L12	L2	L2	L18	L29	L24	L1
8	L16	L26	L18	L21	L3	L8	L2	L21	L2	L23	L24	L22	L24	L28	L18
9	L29	L5	L20	L5	L10	L26	L25	L7	L13	L24	L22	L2	L20	L13	L22
10	L8	L3	L26	L20	L26	L1	L14	L10	L6	L16	L23	L23	L19	L18	L26
11	L25	L13	L14	L30	L8	L17	L30	L23	L20	L27	L4	L25	L10	L17	L17
12	L9	L17	L21	L23	L20	L12	L11	L15	L24	L1	L26	L15	L27	L19	L5
13	L6	L29	L23	L12	L9	L13	L26	L6	L7	L14	L17	L12	L28	L8	L7
14	L28	L14	L7	L29	L5	L19	L16	L1	L26	L22	L16	L13	L4	L5	L11
15	L19	L24	L30	L8	L23	L4	L28	L12	L15	L26	L29	L17	L13	L10	L24
16	L20	L18	L5	L11	L19	L24	L4	L22	L3	L19	L14	L21	L2	L21	L20
17	L22	L7	L13	L19	L1	L14	L17	L9	L29	L13	L8	L14	L22	L14	L14
18	L23	L8	L9	L15	L12	L28	L19	L4	L19	L8	L25	L26	L17	L11	L12
19	L11	L2	L6	L1	L15	L2	L15	L25	L18	L17	L10	L16	L5	L26	L6
20	L12	L20	L2	L27	L2	L11	L22	L19	L22	L4	L18	L30	L8	L22	L29
21	L5	L6	L11	L7	L7	L20	L21	L20	L28	L15	L15	L10	L6	L23	L30
22	L7	L16	L17	L17	L6	L9	L23	L17	L1	L10	L5	L24	L14	L4	L8
23	L1	L4	L1	L22	L11	L15	L3	L27	L21	L20	L7	L27	L1	L7	L13
24	L17	L23	L15	L6	L17	L29	L24	L11	L10	L7	L30	L19	L25	L20	L4
25	L3	L15	L16	L9	L16	L16	L8	L14	L27	L21	L1	L8	L7	L29	L10
26	L4	L30	L24	L2	L21	L7	L9	L8	L17	L28	L9	L20	L18	L12	L16
27	L26	L22	L4	L4	L13	L10	L20	L26	L4	L11	L21	L6	L26	L30	L15
28	L24	L11	L10	L13	L4	L21	L7	L30	L30	L9	L12	L9	L23	L15	L19
29	L21	L19	L12	L16	L24	L30	L13	L28	L9	L30	L19	L4	L12	L9	L21
30	L13	L21	L22	L24	L22	L5	L29	L29	L11	L29	L13	L28	L30	L6	L9
W			0.39 **					0.33				0.25			
# line	10	10	12	13		9	12	11	10		9	10	5	9	

Xⁱ = Ranking based on the mean of each tester across the environment; W = Kendall’s coefficient of concordance where ** = significant levels of probability at 0.01. AB18, AB19, MK18 and MK19 are Abuja and Mokwa environments in the 2018 and 2019 cropping seasons, respectively; note: number of lines (# lines) is based on the top 15 lines ranks indicated in yellow color in descending order, i.e., inbred lines performed best ranked first and poor performing inbred lines ranked last.

Table A8. Ranking *Striga*-resistant inbred lines for *Striga* rating (1–9 scale) at 10 WAP across each environment in the combined analysis at Abuja and Mokwa, Nigeria for each tester.

Rank	T1					T2					T3				
	AB18	AB19	MK18	MK19	X ⁱ	AB18	AB19	MK18	MK19	X ⁱ	AB18	AB19	MK18	MK19	X ⁱ
1	L9	L2	L12	L11	L12	L26	L6	L24	L16	L6	L12	L16	L3	L23	L14
2	L12	L14	L6	L12	L9	L28	L20	L1	L25	L26	L9	L14	L17	L21	L3
3	L28	L9	L11	L2	L1	L1	L29	L14	L2	L20	L19	L3	L9	L1	L21
4	L3	L12	L2	L1	L6	L6	L24	L6	L11	L1	L20	L10	L6	L8	L26
5	L6	L3	L1	L23	L2	L10	L17	L28	L14	L24	L3	L26	L29	L17	L10
6	L10	L6	L23	L30	L11	L12	L26	L9	L22	L28	L6	L17	L14	L26	L12
7	L23	L10	L9	L15	L10	L15	L12	L22	L23	L10	L10	L1	L26	L13	L19
8	L24	L8	L18	L27	L21	L13	L8	L29	L3	L25	L16	L25	L19	L20	L16
9	L26	L26	L7	L9	L26	L20	L1	L26	L1	L12	L21	L18	L23	L18	L9
10	L29	L29	L19	L21	L14	L3	L11	L10	L6	L14	L7	L21	L4	L3	L20
11	L1	L1	L10	L18	L23	L9	L25	L15	L28	L29	L24	L5	L16	L14	L17
12	L7	L21	L29	L7	L3	L11	L2	L16	L26	L3	L26	L2	L10	L12	L18
13	L13	L4	L3	L19	L7	L16	L10	L23	L10	L15	L28	L15	L21	L28	L23
14	L14	L24	L30	L22	L24	L19	L3	L4	L21	L16	L1	L12	L2	L11	L28
15	L16	L11	L21	L20	L28	L2	L27	L20	L13	L2	L5	L9	L12	L5	L1
16	L17	L16	L26	L6	L29	L5	L14	L12	L24	L11	L13	L19	L28	L25	L6
17	L11	L17	L4	L26	L4	L8	L28	L8	L29	L8	L14	L6	L13	L9	L5
18	L21	L18	L28	L4	L18	L18	L15	L25	L20	L9	L23	L28	L11	L4	L13
19	L22	L25	L24	L28	L8	L21	L9	L27	L12	L21	L25	L30	L5	L10	L2
20	L30	L28	L17	L8	L15	L23	L5	L7	L7	L23	L27	L29	L20	L2	L24
21	L4	L7	L14	L24	L17	L25	L7	L18	L18	L27	L30	L20	L7	L24	L25

Table A8. Cont.

Rank	T1					T2					T3				
	AB18	AB19	MK18	MK19	χ^i	AB18	AB19	MK18	MK19	χ^i	AB18	AB19	MK18	MK19	χ^i
22	L8	L13	L13	L17	L27	L27	L18	L21	L5	L22	L4	L7	L24	L30	L29
23	L15	L15	L15	L16	L19	L4	L16	L2	L9	L18	L11	L24	L22	L6	L11
24	L18	L27	L27	L25	L16	L7	L21	L3	L15	L5	L18	L13	L1	L29	L7
25	L19	L5	L22	L10	L22	L14	L22	L5	L27	L7	L22	L27	L18	L19	L30
26	L27	L22	L20	L14	L30	L22	L30	L13	L4	L13	L29	L23	L15	L27	L4
27	L2	L19	L5	L5	L13	L24	L13	L19	L8	L17	L2	L4	L8	L7	L8
28	L5	L23	L8	L29	L5	L29	L19	L17	L17	L19	L8	L11	L25	L22	L22
29	L25	L20	L16	L13	L25	L30	L23	L11	L30	L4	L15	L22	L30	L15	L27
30	L20	L30	L25	L3	L20	L17	L4	L30	L19	L30	L17	L8	L27	L16	L15
W	0.38 *					0.35 *					0.32				
# lines	13	12	11	8		11	11	11	10		11	10	12	11	

χ^i = ranking based on the mean of each tester across the environment; W = Kendall's coefficient of concordance where * = significant levels of probability at 0.05. AB18, AB19, MK18 and MK19 are Abuja and Mokwa environments in the 2018 and 2019 cropping seasons, respectively; note: number of lines (# lines) is based on the top 15 lines highlighted in yellow color in ascending order, i.e., inbred lines with lower value ranked 1 = resistant, and highly scored inbred lines ranked 30, which is susceptible. WAP = weeks after planting.

Table A9. (a) Estimates of specific combining ability (SCA) effects of selected line × tester crosses evaluated for grain yield and other related traits across environments under *Striga* infestation. (b) Estimates of specific combining ability (SCA) effects of selected line × tester crosses evaluated for *Striga* resistance and agro-morphological traits at Mokwa and Abuja in the combined analysis under the *Striga* non-infested condition.

Crosses	(a)										
	DYSK	DYSP	RAT1	RAT2	CO1	CO2	EASP	EPP	YLD	YLDUN	
L1 × T1	0.64	0.73	-0.19	-0.08	-8.71	-7.7	-0.05	0.017	-145.3	-286.7	
L2 × T1	0.18	0.27	0.19	-0.41	-3.38	-7.24	0.03	-0.044	-343.9	-443.9	
L3 × T1	-0.61	-0.48	0.14	0.3	-0.09	-9.07	-0.22	0.018	295.7	-142.6	
L4 × T1	0.60	0.43	-0.31	-0.49	10.83	14.76	0.07	0.049	-303.1	-368.9	
L5 × T1	0.14	0.18	0.48 *	0.55	5.29	7.55	0.03	-0.023	-142.3	-122.8	
L6 × T1	0.68	0.77	0.14	0.01	8.46	6.26	0.15	0.017	-305.4	-476.3	
L7 × T1	-0.07	-0.11	-0.4	-0.37	-9.34	-18.99	-0.14	0.004	125.1	-46.3	
L8 × T1	-0.63	-0.98	0.02	-0.12	-8.13	2.76	-0.18	0.116	438.8	201.6	
L9 × T1	-0.19	-0.15	0.02	-0.53	-1.88	-1.95	-0.16	0.016	478.5	718.3 *	
L10 × T1	0.18	0.35	0.19	0.13	-9.42	-5.45	-0.14	-0.052	348.9	402.3	
L11 × T1	0.01	0.18	-0.44	-0.45	-7.71	-7.11	-0.03	-0.004	-63.8	32.3	
L12 × T1	0.93	0.68	-0.02	-0.49	-3.42	-5.16	0.11	0.005	-221.8	-258.1	
L13 × T1	0.68	0.60	-0.11	0.22	4.37	12.39	0.16	-0.004	-190	-376.1	
L14 × T1	-0.15	-0.11	-0.15	0.3	12.62 *	26.22 *	0.03	-0.019	20.1	308.3	
L15 × T1	0.18	0.23	0.06	-0.16	2.79	-1.49	0.26 *	0.044	-309	92.9	
L16 × T1	0.60	0.77	0.39	0.47	1.00	-3.41	0.30 **	0.02	-504.3	-312.5	
L17 × T1	0.60	0.64	-0.44	0.01	-4.21	-1.61	-0.18	0.016	165.3	-212.3	
L18 × T1	0.18	0.02	-0.02	-0.12	-2.46	-16.28	0.18	0.026	45.9	-82.9	
L19 × T1	-0.82	-0.44	0.02	-0.12	10.54	9.18	-0.05	-0.051	120.5	183.8	
L20 × T1	-0.24	-0.32	0.81 ***	1.09 **	20.87 **	20.39	0.07	-0.031	-721.8 **	236.9	
L21 × T1	-1.03 *	-0.98 *	-0.15	-0.16	4.66	6.39	-0.05	0.007	152.6	38.9	
L22 × T1	0.43	0.31	0.02	-0.08	-5.34	-14.11	0.01	-0.036	-503.9	-736.8	
L23 × T1	0.51	0.43	-0.06	-0.2	-13.7 *	-19.11	0.2	0.027	-384.4	-264.9	
L24 × T1	-0.82	-0.86	-0.19	0.05	1.08	6.59	0.09	0.048	-409.6	-716.5 *	
L25 × T1	0.18	0.02	0.56 *	0.80 *	6.33	7.8	0.18	-0.084	-564.4 *	28.5	
L26 × T1	0.39	0.10	0.06	0.34	-8.96	-4.11	-0.14	0.006	363.1	109.4	
L27 × T1	0.26	0.18	-0.11	-0.24	5.75	6.76	-0.05	0.03	192.1	196.6	
L28 × T1	-1.19 *	-0.9 **	0.31	0.17	-1.46	-3.86	-0.07	0.059	488.1	694.9 *	
L29 × T1	-0.24	-0.57	-0.44	0.01	-0.5	7.18	-0.3 **	-0.18 *	1085.6 ***	950.8 **	
L30 × T1	-1.24 *	-0.98 *	-0.4	-0.41	-5.92	-7.57	-0.14	0.003	792.6 **	652.2	
L1 × T2	-0.42	-0.32	-0.06	-0.34	3.95	6.41	0.05	-0.044	44	176.8	
L2 × T2	-0.38	-0.40	-0.31	-0.05	6.28	8.24	0.2	0.007	-56.7	239.0	
L3 × T2	0.83	0.85	0.28	0.28	6.2	13.78	0.45 ***	-0.047	-829.6 **	-28.4	
L4 × T2	-0.47	-0.36	0.44	0.62	-12.6 *	-13.38	-0.14	-0.047	280.1	212.9	
L5 × T2	-0.30	0.02	-0.26	-0.09	-6.18	-13.59	-0.05	0.02	110.5	282.3	
L6 × T2	-0.88	-0.9 ***	-0.22	-0.51	-5.39	-7.88	-0.18	0.001	830.1 **	760.9 *	
L7 × T2	0.49	0.35	-0.14	0.12	7.57	5.24	0.09	-0.012	170	-183.0	
L8 × T2	0.68	-0.15	-0.35	-0.26	-9.09	-13.88	-0.2	0.028	195.2	-82.4	
L9 × T2	0.24	0.31	0.03	0.57	9.28	11.28	0.13	-0.033	-619.1 *	-255.0	
L10 × T2	-0.63	-0.82	-0.31	-0.01	6.36	7.53	-0.03	0.014	-282	-191.5	
L11 × T2	0.20	0.14	0.32	-0.09	12.95 *	9.12	-0.18	0.032	258.3	-430.8	

Table A9. Cont.

(a)										
Crosses	DYSK	DYSP	RAT1	RAT2	CO1	CO2	EASP	EPP	YLD	YLDUN
L12 × T2	-1.38 *	-1.11 *	0.11	0.24	1.49	-3.3	-0.16	-0.041	358.6	438.2
L13 × T2	-0.01	0.18	0.15	0.07	-2.59	-8.13	-0.05	-0.013	-76.8	270.8
L14 × T2	0.28	-0.03	0.24	0.16	-7.84	-14.8	0.07	-0.041	-104.4	-39.7
L15 × T2	-0.38	-0.19	-0.43	-0.43	-3.18	-10.13	-0.26 *	0.019	557.4 *	83.0
L16 × T2	0.03	-0.15	-0.1	-0.05	6.03	21.82 *	-0.16	-0.034	102.7	461.0
L17 × T2	-0.47	-0.53	0.82 ***	0.49	6.7	7.62	-0.01	-0.068	-171.6	-47.0
L18 × T2	-0.01	0.10	-0.01	0.24	8.32	10.45	-0.1	-0.051	-185.7	382.0
L19 × T2	0.49	0.14	0.4	0.87 *	2.82	23.16 *	0.05	-0.045	-166.7	158.3
L20 × T2	0.70	0.77	-0.43	-0.80 *	-11.59	-4.88	-0.08	0.036	600.9 *	-282.9
L21 × T2	1.03 *	1.10 *	0.36	0.57	-2.18	-9.63	-0.08	-0.059	-63.8	100.2
L22 × T2	-0.01	-0.23	-0.22	-0.34	1.2	3.74	-0.01	-0.024	113.4	345.8
L23 × T2	0.08	0.14	-0.06	0.28	-4.39	4.37	-0.08	-0.04	419.3	209.2
L24 × T2	-0.38	-0.28	0.32	-0.47	-5.26	-12.68	-0.05	0.051	511	547.3
L25 × T2	-0.76	-0.53	-0.18	-0.72 *	-6.76	-11.97	-0.16	-0.057	575.4 *	230.6
L26 × T2	-0.17	-0.19	-0.06	-0.3	0.2	2.74	0.15	-0.056	-345.4	-123.2
L27 × T2	-0.80	-0.48	-0.22	-0.13	-4.22	-6.01	0.11	0.043	-132.4	-143.5
L28 × T2	1.74 ***	1.56 **	-0.31	-0.34	-7.18	-12.13	0.34 **	-0.025	-506.4	-878.4 **
L29 × T2	0.08	0.52	0.07	-0.26	-1.09	1.91	0.26 *	0.485 †	-968.1 ***	-1380.0 ***
L30 × T2	0.70	0.48	0.11	0.7	10.24	5.03	0.15	0.002	-618.0 *	-832.5 *
L1 × T3	-0.20	-0.41	0.24	0.42	4.76	1.29	0	0.027	101.3	109.9
L2 × T3	0.21	0.13	0.12	0.46	-2.9	-1.0	-0.23	0.037	400.6	204.9
Crosses	DYSK	DYSP	RAT1	RAT2	CO1	CO2	EASP	EPP	YLD	YLDUN
L3 × T3	-0.20	-0.37	-0.42	-0.58	-6.11	-4.71	-0.23	0.03	533.8	171.0
L4 × T3	-0.12	-0.08	-0.13	-0.12	1.81	-1.38	0.07	-0.002	23	155.9
L5 × T3	0.17	-0.20	-0.21	-0.46	0.89	6.04	0.02	0.003	31.8	-159.5
L6 × T3	0.21	0.13	0.08	0.5	-3.07	1.62	0.03	-0.018	-524.7	-284.5
L7 × T3	-0.41	-0.24	0.54 *	0.25	1.76	13.75	0.04	0.007	-295.1	229.3
L8 × T3	-0.52	1.13	0.33	0.38	17.22 **	11.12	0.38 **	-0.144	-634.0 *	-119.3
L9 × T3	-0.04	-0.16	-0.05	-0.04	-7.4	-9.33	0.02	0.017	140.6	-463.2
L10 × T3	0.46	0.47	0.12	-0.12	3.06	-2.08	0.17	0.038	-66.9	-210.8
L11 × T3	-0.20	-0.33	0.12	0.54	-5.24	-2.0	0.21	-0.028	-194.5	398.5
L12 × T3	0.46	0.43	-0.09	0.25	1.93	8.46	0.04	0.036	-136.8	-180.0
L13 × T3	-0.66	-0.78	-0.05	-0.29	-1.78	-4.25	-0.1	0.017	266.8	105.3
L14 × T3	-0.12	0.13	-0.09	-0.46	-4.78	-11.4	-0.1	0.061	84.2	-268.6
L15 × T3	0.21	-0.03	0.37	0.59	0.39	11.62	0.00	-0.064	-248.5	-175.9
L16 × T3	-0.62	-0.62	-0.3	-0.41	-7.03	-18.4	-0.14	0.014	401.6	-148.5
L17 × T3	-0.12	-0.12	-0.38	-0.5	-2.49	-6.0	0.19	0.052	6.3	259.3
L18 × T3	-0.16	-0.12	0.04	-0.12	-5.86	5.83	-0.08	0.024	139.8	-299.1
L19 × T3	0.34	0.30	-0.42	-0.75 *	-13.4 *	-32.3 **	0.00	0.097	46.2	-342.1
L20 × T3	-0.45	-0.45	-0.38	-0.29	-9.28	-15.5	0.00	-0.005	120.9	46.0
L21 × T3	0.01	-0.12	-0.21	-0.41	-2.49	3.3	0.13	0.052	-88.8	-139.0
L22 × T3	-0.41	-0.08	0.2	0.42	4.14	10.4	0.00	0.06	390.6	391.1
L23 × T3	-0.58	-0.58	0.12	-0.08	18.06 **	14.8	-0.12	0.013	-34.9	55.7
L24 × T3	1.21 *	1.13 *	-0.13	0.42	4.18	6.1	-0.04	-0.099	-101.4	169.2
L25 × T3	0.59	0.51	-0.38	-0.08	0.43	4.2	-0.02	0.141	-11	-259.1
L26 × T3	-0.20	0.09	-0.01	-0.04	8.76	1.4	-0.02	0.05	-17.7	13.7
L27 × T3	0.55	0.30	0.33	0.38	-1.53	-0.8	-0.06	-0.072	-59.7	-53.1
L28 × T3	-0.54	-0.66	-0.01	0.17	8.64	16.0	-0.27	-0.034	18.3	183.6
L29 × T3	0.17	0.05	0.37	0.25	1.6	-9.1	0.07	-0.3 ***	-117.5	429.2
L30 × T3	0.55	0.51	0.29	-0.29	-4.32	2.5	-0.02	-0.006	-174.6	180.3
SCASE	0.50	0.47	0.24	0.37	6.54	10.8	0.12	0.091	286.4	346.2
SE (S _{ij} - S _{ki})	1.83	1.67	0.9	1.1	23.1	35.2	0.5	0.3	1053.0	1251.1
(b)										
Crosses	DYSK	DYSP	PL HT	EHT	HUSK	PASP	EASP	EPP	YLD	
L29 × T1	-0.44	-0.85	6.74	1.95	-0.24	-0.20	-0.17	0.086 *	950.8 **	
L6 × T2	-0.74	-0.66	11.15 **	5.46	-0.11	-0.05	0.07	0.005	760.9 *	
L9 × T1	-0.57	-0.39	3.35	5.45	-0.29	-0.17	-0.33	-0.022	718.3 *	
L28 × T1	-0.73	-0.72	1.52	0.49	-0.06	-0.03	-0.08	0.031	694.9 *	
L30 × T1	-0.94	-0.68	8.93 *	7.57 *	0.13	0.18	0.01	-0.072	652.2	
L24 × T2	-0.87	-0.70	2.48	6.54	-0.13	-0.15	-0.10	0.035	547.3	
L12 × T2	-1.03 *	-1.04 *	6.86	1.50	0.33 **	0.16	-0.12	0.043	438.2	
L29 × T3	0.18	0.18	9.78 *	9.59 **	-0.08	-0.07	0.01	0.080	429.2	
L10 × T1	0.48	0.70	10.10 *	7.49 *	-0.18	-0.15	-0.17	-0.027	402.3	
L16 × T2	0.05	-0.20	6.28	2.92	-0.11	-0.17	-0.35 **	-0.004	461.0	
L22 × T3	-0.40	-0.28	5.02	5.46	0.00	0.05	-0.01	0.008	391.1	
L18 × T2	0.05	0.00	1.82	1.54	0.04	0.14	-0.39 ***	0.061	382.0	
L25 × T2	-0.58	-0.62	6.82	2.21	0.16	0.06	-0.16	0.013	230.6	
L7 × T3	-0.48	-0.45	0.94	-2.00	-0.27 *	-0.03	-0.19	0.028	229.3	

Table A9. Cont.

(b)									
Crosses	DYSK	DYSP	PL HT	EHT	HUSK	PASP	EASP	EPP	YLD
L30 × T3	0.31	0.34	2.35	−1.79	−0.15	−0.26 *	0.02	0.079 *	180.3
L8 × T1	−1.32	−0.93 *	5.64	6.24	−0.14	−0.09	−0.13	−0.025	201.6
L3 × T3	−0.19	0.01	−1.15	−1.04	0.12	−0.03	−0.11	0.012	171.0
L29 × T2	0.26	0.67	−18.25 ***	−12.95 ***	0.33 **	0.27 *	0.15	−0.166 ***	−1379.9 ***
L28 × T2	0.97 *	1.05 *	−3.60	−1.25	0.08	0.25 *	0.30 **	−0.013	−878.4 **
SCASE	0.49	0.44	4.38	3.45	0.13	0.12	0.12	0.039	346.2
SE (S _{ij} − Sk _i)	1.93	1.70	15.35	12.22	0.42	0.31	0.45	0.12	1251.1

(a) *, **, ***, † significant at $p < 0.05$, 0.01, 0.001 and 0.0001 levels, respectively. DYSK = days to 50% silking, DYSP = days to 50% anthesis, RAT1 and RAT2 = *Striga* damage rating (scale of 1–9) at 8 and 10 WAP, respectively, CO1 and CO2 = *Striga* emergence count at 8 and 10 WAP, respectively, EASP = ear aspect (score at a scale of 1–5), EPP = ears per plant, YLD and YLDUN = grain yield (kg/ha) under *Striga*-infested and non-infested conditions, respectively. (b) *, **, ***, † significant at $p < 0.05$, 0.01, 0.001 and 0.0001 levels, respectively. DYSK = days to 50% silking, DYSP = days to 50% anthesis, PLHT = plant height (cm), EHT = plant height from base to the node of the ear (cm), HUSK = the degree of the husk covering the tip of the ear using a scale of 1 to 5, PASP = qualitative observation of plant ideotype rated using a scale of 1 to 5, EASP = ear aspect (rating at a scale of 1–5), EPP = ear per plant and YLD = grain yield (kg/ha).

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