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Combining Ability Estimates for *Striga* Resistance in Maize (*Zea mays* L.): A Full Diallel Analysis

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ABSTRACT

The development of hybrid maize cultivars resistance to *Striga* is a promising solution to reducing annual crop loss in endemic areas by 20-100%. This study aims to develop high-yielding *Striga* resistance hybrid maize cultivars to reduce annual crop loss due to *Striga* in endemic areas. Seven maize parents, including three inbred lines; TZSTR 190, TZSTR 193, and TZEI 114, and four open-pollinated varieties; SAMMAZ 14, SAMMAZ 16, SAMMAZ 17, and SUWAN, were identified and crossed in a 7×7 full-dial cross according to Griffin Method 1, Model I. The 7 parents, their F_1's, reciprocals, and 3 checks; GWG 111, GWG 888, and 5005 hybrids were evaluated in a glasshouse trial for *Striga* infestation reaction screening in 2019 and 2020. Significant variations were observed across environments, treatments, and genotypes for most characters, suggesting highly variable genotypes suitable for *Striga* resistance selection due to their varying responses in different environments. Cross combinations of high-yielding but *Striga*-susceptible parents like SAMMAZ 14 and SUWAN showed some resistance to *Striga*. The study identified several resistant hybrids with low *Striga* count and damage, as well as significant performers in grain yield per hectare and most yield components. The study found significant variance in GCA (General Combining Ability), SCA (Specific Combining Ability), and

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reciprocal effects variance in *Striga* damage and *Striga* count in inoculated plants, indicating the importance of additive and non-additive gene actions and maternal gene effects.

Keywords: Additive gene, combining ability, nonadditive gene, open-pollinated variety, yield components

INTRODUCTION

Striga hermonthica (Del) Benth is a harmful parasitic weed. It severely damages staple cereal crops like maize and sorghum, reducing their yield. This species belongs to the Orobanchaceae family. It is prevalent in tropical and subtropical regions of West and Central Africa, India, Myanmar, Indonesia, and the United States (Gowda et al. 2021).

Striga, a dust-like seed plant, attacks host crops after seed germination, stealing water, nutrients, and carbohydrate requirements (Mudereri et al. 2020). Its phytotoxic effect causes significant yield losses (Sangaré et al. 2018). *Striga* seeds can remain dormant in the soil for 15-20 years. Its germination is triggered by the Strigolactones exudate from host plant roots (Yoneyama et al. 2016).

Developing hybrid host cultivars resistant to *Striga* could significantly reduce crop loss due to this pest. Information on GCA (General Combining Ability) and SCA (Specific Combining Ability) is vital in selecting parents or hybrids for effective breeding programs. Combining ability analysis is a veritable tool employed by breeders to identify superior parents that are better combiners used in hybridization programs. This allows for the exploitation of heterosis and selects better-performed crosses for direct use for commercialization or further breeding work.

Diallel mating design is a statistical method employed by most plant breeders. It statistically separates the performance of parents and progenies into GCA and SCA components. (Murtadha et al. 2018). This is one of the widely used mating designs for the study of genetic architecture in maize. It offers a more effective method of developing high-yielding hybrid(s) in maize. Breeders achieve this by crossing all possible combinations amongst the parental lines from different heterotic groups (Olayiwola et al. 2021).

There are several diallel mating designs. However, full diallel offers a more comprehensive insight into the genetics of a plant. It considers the reciprocal, maternal, and nonmaternal effects. In this study, a full diallel mating design was used in crosses between *Striga*-resistant inbred lines and high-yielding but susceptible ones. This helped to determine the gene action governing the inheritance of yield and *Striga* resistance. It also identified the best parent combinations for these characters.

Crop protectionists, weed scientists, and agronomists have all tried various approaches to eradicate this unwanted weed. However, most efforts have been unsuccessful. Even when positive results are obtained, they have no economic benefits to the poor farmers in the rural areas. These methods significantly increase the production cost (Mrema et al.

2020). Therefore, breeding for *Striga* resistant maize hybrids offers a more sustainable solution to mitigating crop losses, improving food security, and enhancing the livelihoods of farmers in *Striga* infested regions. The specific objective of this study was to investigate the effects of combining ability as well as estimate the genetic parameters (system) and mode of inheritance governing Striga resistance, earliness, growth, yield, and yield-related components in maize to identify superior parental lines (best general combining parents) and hybrids (best specific combining parents) for developing high yielding Striga resistant maize varieties.

MATERIALS AND METHODS

Seven parental lines of maize, as described in Table 1, were collected based on their yield performances and reaction to *S. hermonthica.* The parental lines were crossed in all possible combinations using a full diallel mating design as described by Griffin 1958 to produce 42 hybrids (21 cross and 21 reciprocals). This research was carried out at the Faculty of Agriculture, Universiti Putra Malaysia (UPM) research farm. The 42 hybrids (21 cross and 21 reciprocals), their parents, and 3 check varieties were screened in a glasshouse for *Striga* resistance in a polyethylene *Striga* seeds inoculated potted trial at the Faculty of Agriculture, Universiti Putra Malaysia (UPM). This trial was done for two planting cycles (2019 and 2020).

Plastic pots measuring 16 cm by 16 cm were filled with about 10 kg of top soil which was mixed with lime and poultry dung. A total of 312 polyethene pots were used. 156 pots were inoculated with striga seeds and arranged in a Completely Randomized Design and replicated three times.

For uniform dispersion, a mixture of fine dry river sands and 100-150 sterilized viable Striga seeds in a ratio of 1:99 was worked down 6 to 12 cm deep in the pots. The inoculated

Table 1
Characteristics of parent maize varieties used in the study

Ent no.	Name	Maturity	Karnel colour	Reaction to *Striga*	Source
1	TZSTR 190	Late	White	Resistant	IITA
2	TZSTR 193	Late	White	Resistant	IITA
3	TZE114	Late	White	Susceptible	IITA
4	SAMMAZ 14	Medium	White	Resistant	IAR
5	SAMMAZ 16	Medium	White	Tolerant	IAR
6	SAMMAZ 17	Late	White	Susceptible	IAR
7	SUWAN	Late	Yellow	Susceptible	THAILAND
8	GWG111	?	Yellow	?	COMMERCIAL
9	5005	?	Yellow	?	COMMERCIAL
10	GWG888	?	Yellow	?	COMMERCIAL

pots were left to settle for 14 days before the maize seeds were planted. Two seeds from each of the 52 genotypes (42 crosses, 7 parents, and 3 checks) were sown in *Striga*-inoculated potted soil at a depth of 4 cm. One week after planting, the number of plants per pot was thinned to one plant per pot. Drip irrigation was used to control the watering as needed. Weeding was done frequently to protect the potted plant from weed competition. Fertilizer applications of NPK 15:15:15 were made at rates of 40N, 40P, and 40K at two and four weeks following planting, respectively.

Data Collection

Striga emergences were counted in each plot at 7 and 10 WAP (weeks after planting). The damage rate was assessed visually during each trial on the two central rows at 7 and 10 WAP, on a scale from 1 to 9 (Kim, 1994). Days to tasseling, days to silking, days to maturity, number of ears, plant height (m), ear height (m), cob length (cm), cob weight per plant (g), 100-grain weight (g), shelling percentage (%), harvest index and grain yield per hectare (g) were recorded.

Statistical Analysis

A combined analysis of variance (ANOVA) was conducted on all data to evaluate the variability among parents and their offspring utilizing SAS (Statistical Analysis Software) version 9.4 (SAS Institute Inc., Cary, NC, USA). Means comparison was performed with Fisher's Least Significant Difference (LSD) at a 5% significance level. The general combining ability of parents and the specialised combining ability of hybrids were assessed using Griffing's method 1 model 1 (fixed effects), as outlined by Singh and Chaudhary (1977), employing R software.

RESULTS AND DISCUSSION

Analysis of Variance

The mean squares across the environment for most of the characters in this study, as shown in Table 2, were highly significant except for days to 50% tasselling, shelling percentage, and harvest index. This indicates that there are variations in the environments, and the genotypes perform differently in different environments all characters except for the above-listed characters. This is in agreement with the findings of Menkir and Meseka (2019) who reported that most traits in an infested environment were significantly affected by the environment. The mean squares for treatment, as shown in Table 2, were also highly significant for all the characters. This indicates that there is great variation in the performance of the genotypes in the different treatments. Similar results were reported by Adetimirin et al. (2000); Badu-Apraku et al. (2011); Menkir and Meseka (2019).

Table 2
Mean squares of analysis of variance for Striga *resistance, growth, yield, and characters of full diallel cross involving seven parents of maize and three checks varieties in combined analysis*

SOV	df	SCT7	SCT10	SDM7	SDM10	DTFT	DTFS	DTFM	PLHT	EHT	CLHT	CWPP	GYPH	HGWT	SHGP	HIDX
Season	1	42.94**	91.91**	44.69**	24.64**	9.75	3414.17**	166.94**	42948.03**	26386.62**	314.23**	29428.89**	71.31**	3381.30**	44.18	0.008
Rep.	2	4.10	21.18**	0.84	2.51	69.14**	230.79**	10.68	1189.85	47.77	1.04	2736.00**	26.19**	96.60	750.53	0.022*
Rep (Sea)	2	6.77*	13.63**	0.44	2.28	46.19**	9.70	2.72	75.66	143.31	22.10*	4570.46**	4.87**	6.46	251.00	0.010
Gen	51	3.46*	3.86	1.87**	5.94**	6.13**	10.86**	41.08**	2366.64**	841.25**	38.00**	1823.16**	4.15**	109.85**	754.22**	0.016**
Gen × sea	51	2.62	4.97**	0.89	2.20*	3.26	5.51	40.95**	1494.78**	412.51**	11.49**	648.62**	1.75**	45.56	484.56	0.006
Error	204	2.25	2.96	1.03	1.45	2.93	3.65	12.00	873.83	333.55	9.95	317.52	0.77	29.49	373.22	0.005
Total	311															

SCT7= *Striga* count at 7weeks, SCT10= *Striga* count at 10weeks, SDM7=*Striga* damage at 7 weeks, SDM10=*Striga* damage at 10 weeks, DTFT=Days to 50% tasselling, DTFS=Days to 50% Silking, DTFM=Days to 50% maturity, PLHT=Plant height, EHT=Ear height, CLHT=Cob length, CWPP= Cob weight/plant, GYPH=Grain yield/ha, HGWT=100 grain weight, SHGP=Shelling%, HIDX=Harvest index

The mean square for genotype for most characters was highly significant, except *Striga* count at 10 weeks after planting, suggesting that there was great variation among the genotypes, hence the difference in their performances. Similar trends were reported by Badu-Apraku et al. (2015); Menkir and Meseka (2019); Solomon et al. (2020).

However, the point of divergence with the present study was in the non-significance of the above listed *Striga* characters. This could be attributed to the death of some of the parasites before week 10 and before the host plant maturity, when the *Striga* plants were harvested. The death of the parasites could probably be due to high humidity in the greenhouse. Similarly, the mean square for genotype × environment was highly significant except *Striga* count at 7weeks, *Striga* damage at 7weeks, days to 50% tasselling, and days to 50% silking which indicate the dependence of the performance of the genotypes on the environment, this highlight the need for multi-environment trials to ensure stable performance across different agro-ecological zones. (Menkir and Meseka 2019; Ngugi et al. 2013, 2015).

Genetic Component

The mean square due to general combining ability (GCA) variance (additive gene effects) were not significant for all characters under study except for *Striga* damage at 10 weeks and days to 50% tasselling, which were significant at p=0.01 (Table 3). However, the variance due to specific combining ability (non-additive gene effects) for most characters were significant at p=0.01 and p=0.05 (days to 50% tasselling) except Striga count at 7, cob length, plant height, and ear height. The predominance of non-additive gene effect over additive gene effect in most of the characters under study except in Striga count at week 7, Striga damage at week 10, days to 50% tasseling, plant height at maturity, ear height at maturity and cob length where GCA was greater than SCA which suggests the importance of additive gene action in these characters (Olaoye and Bello 2009). SCA for Striga count at 10 weeks was higher when compared to the GCA, suggesting the preponderance of non-additive genes in controlling the numbers of Striga emergence. This is in agreement with the findings of Badu-Apraku et al. (2011). The ratio of δ2 GCA/ δ2SCA for all the characters were less than unity, which indicates the preponderance of non-additive gene effects in all the characters. Grain yield per hectare showed zero (0) GCA/SCA variance ratio, which suggests the involvement of both additive and non-additive gene action (codominance) in the two characters. The predominance of non-additive gene effects for most traits suggests that hybrid breeding strategies, such as reciprocal recurrent selection and heterosis exploitation, could be effective in improving maize performance (Fasahat et al. 2016).

The reciprocal mean square of most characters was highly significant (p=0.01). However, there was no significant difference in Striga damage at 7 weeks, days to 50%

Table 3
Mean squares value of analysis of variance, general combining ability, specific combining ability, reciprocal, maternal, and interactions for Striga *resistance, earliness, growth, yield and yield component characters for inoculated and non-inoculated potted experiment*

Variation	df	SCT7	SCT10	SDM7	SDM10	DTFT	DTFS	DTFM	PLHT	EHT	CLHT	CWPP	GYPH	HGWT	SHGP	HIDX
Env	1	10.80**	8.64**	3.32**	11517.60*	0.11*	9.17	8.66	173.18	10475.47*	14984.26**	1444159.51**	2.31E+09**	12306.26*	74696219862*	3393977.16
Rep (Env)	4	0.94	0.07	0.24	6123.54	0.13**	3.64	2.17	5003.95	830.64	422.53	8844.99*	2.58E+08	3714.37	24554981204	77498809.86*
Gen	48	0.59	0.22*	0.51**	4728.80	0.03**	7.49**	15.28**	2855.81	1959.92	589.10	10095.16	6.84E+08*	5197.79*	23239543026**	55259756.33**
GCA	6	0.82	0.17	1.64**	4233.44	0.07**	4.07	5.13	3239.15	2454.70	560.32	6585.63	2.47E+08	468.62	6621314303	17491675.72
SCA	21	0.45	0.27**	0.38**	4381.44**	0.03*	9.53**	17.48**	3037.93	1495.68	541.26	12128.82**	9.35E+08**	6669.27**	37611075599**	75562447.88**
REC	21	0.67*	0.18	0.32**	5217.70*	0.01	6.43**	15.97**	2564.17	2282.80	645.16	9064.23**	5.58E+08**	5077.51**	13616075803	45747944.95*
Mater	6	0.94*	0.31*	0.45**	3849.07	0.02	8.65**	17.97**	3104.98	2334.09	920.83	6815.40	6.68E+08*	2176.69	13298920263	54895113.93
No Mat	15	0.57	0.13	0.28*	5765.15*	0.01	5.54*	15.17**	2347.85	2262.28	534.90	9963.76**	5.14E+08*	6237.84**	13742938019	42089077.35
Gen × Env	48	0.41	0.14	0.25**	3782.78	0.01	4.04	6.42	2950.25	2448.15	435.50	7922.08**	4.14E+08*	3168.77	12222551047	28376293.55
GCA × Env	6	0.19	0.10	0.33*	2656.98	0.02	1.50	5.59	2533.58	786.96	435.69	2934.91	2.95E+08	1966.39	9955467725	21933350.34
SCA × Env	21	0.60	0.21*	0.29**	5210.44*	0.01	5.48*	7.20	3625.69	2672.07	389.40	10619.27**	3.98E+08	4240.42*	14400315070	34741769.58
REC × Env	21	0.28	0.08	0.20	2676.79	0.01	3.34	5.87	2393.86	2698.86	481.55	6649.80*	4.65E+08*	2440.67	10692525117	23851658.45
Mat × Env	6	0.41	0.14	0.16	3036.06	0.01	0.98	1.93	3505.24	2169.33	800.45	3162.31	6.92E+08*	1736.07	4927431689	16887447.50
No mat × Env	15	0.23	0.05	0.21	2533.08	0.01	4.28	7.45	1949.30	2910.67	353.98	8044.80**	3.74E+08	2722.51	12998562488	26637342.83
Residual	192	0.41	0.14	0.15	3038.58	0.02	3.10	5.98	2734.83	1818.07	485.89	3482.07	2.68E+08	2624.45	11825782571	27729032.39
σ^2GCA/ σ^2SCA		0.73	0.02	0.46	0.06	0.36	0.01	-0.01	0.12	-0.14	0.10	0.03	0.00	-0.04	-0.01	-0.02
H^2		0.84	0.81	0.96	0.81	0.89	0.85	0.82	0.78	0.78	0.77	0.88	0.84	0.74	0.81	0.80
h^2		0.66	0.45	0.86	0.53	0.74	0.39	0.30	0.53	0.60	0.52	0.46	0.29	0.09	0.21	0.25

SCT7= *Striga* count at 7weeks, SCT10= *Striga* count at 10weeks, SDM7=*Striga* damage at 7 weeks, SDM10=*Striga* damage at 10 weeks, DTFT=Days to 50% tasselling, DTFS=Days to 50% Silking, DTFM=Days to 50% maturity, PLHT=Plant height, EHT=Ear height, CLHT=Cob length, CWPP= Cob weight/plant, GYPH=Grain yield/ha, HGWT=100 grain weight, SHGP=Shelling%, HIDX=Harvest index

tasselling, plant height, and ear height, suggesting that maternal gene effects exist in most characters, especially the Striga resistance characters. The maternal variance showed significance in only 8 characters. Striga damage at 10 weeks, days to 50% silking, days to 50% maturity, Number of seeds per row, and grain yield per plant were significant at p=0.01, while grain yield per hectare, *Striga* count, and *Striga* damage at 7 weeks were significant at 0.05% significance level. This suggests the presence of maternal gene effects on those characters which show significance in the infested environment. Additionally, the importance of maternal effects in certain traits emphasizes the need for careful selection of parental lines in breeding programs.

The variance component of all the interactions with the environment, were significant, both p=0.01 (Gen × Env., SCA × Env., Rec × Env and No Mat × Env) and p=0.05 (Mat × Env.) except GCA × Env. Both Gen × env. and Mat × Env were significant at 1% while SCA × Env and Rec × Env were significant at 5% for harvest index, suggesting the influence of environment on the performance of the genotypes. A similar trend was reported by Murtadha et al. (2018). Most mean interactions of the variance components with the environment for some characters were not significant, except for some *Striga*, yield and yield characters. Cob weight per plant and grain yield per hectare were significant at p=0.05 for Rec × Env. While grain yield per hectare and cob weight per plant were significant at 5% and 1% for Mat × Env and no mat × env respectively. This indicates the importance of the interaction of the genetic and environmental components in the resistance of *S. hermonthica* by the genotypes in the *Striga* inoculated pots. Similarly, a report has been published by Badu-Apraku et al. (2018) and Mohemed et al. (2016).

The broad sense heritability and narrow sense heritability estimates are also presented in Table 3. From the result, broad-sense heritability estimates were higher in magnitude (74% - 98%) for all characters are less than the narrow-sense heritability (9% - 88%). This is a result of the influence of non-additive gene action. The narrow sense heritability is most important in plant selection programs, as it captures only the proportion of genetic variation that is due to additive genetic value, which shows resemblance between relatives (Steinsaltz et al. 2020) . High, moderate, and low narrow-sense heritability were recorded, as also reported by Olaoye and Bello (2009).

Mean Performance of Parent

The mean performance of the parent varieties (*per se* performance) is presented in Table 4, with rankings based on their significance for *Striga* characteristics, earliness, growth, yield, and yield components. At week 7, Sammaz 16 recorded the lowest average *Striga* emergence/count, with only 0.08, while TZSR 193 had the highest count at 1.17. By week 10, TZSR 190 had the lowest *Striga* count, averaging 0.08, whereas Sammaz 16 exhibited the highest count at 1.33. In terms of *Striga* damage, TZE114 recorded the highest damage scores at both week 7 (2.42) and week 10 (4.17), while TZSR 190 showed the least *Striga* damage. With respect to characters that designate earliness among the parental lines, SUWAN took the longest number of days (55.33 days) to attain 50% tasseling while SAMMAZ 17 took the shortest days of 51.87 to attain 50% tasseling. SAMMAZ 16 had the highest day of 59.83 days to attain 50% silking while SAMMAZ 14 took the shortest days of 57.08 days to attain 50% silking SAMMAZ 17 took the longest days of 95.25 days to attain 50% maturity while TZSR 193 had the least days of 92.13 to attain 50% maturity.

With regard to the growth characters, SAMMAZ 17 was observed to be the tallest parent with a height of 183.18cm, while TZEI 114 and TZSR 190 were the shortest parents with 126.68cm and 128.42cm, respectively. A similar trend was also observed for ear height. SAMMAZ 16 exhibited the highest cob length (12.90) while TZSR 190 had the lowest cob length of 6.73cm.

SAMMAZ 16 equally showed to have the highest grain yield per hectare of 48.06g and 3.34tons per hectare, respectively, while TZSR 190 and TZEI 114 recorded the least values of 10.26g, 0.73tons, and 10.86 g, 0.77 tons, respectively, for both characters. SAMMAZ 16 also had the highest 100 grain weight (26.67g while TZEI 114 had the least of 10.51g. SAMMAZ 16 had the highest shelling percentage of 71.90 % while TZEI 114 and TZSR 190 recorded the least with 0.091 and 0.099, respectively.

Mean Performance of all the Genotypes

Table 4 presents the ranked mean values for the genotypes in this study. The findings indicate significant differences among all the genotypes (crosses and reciprocals derived from seven parents and three check varieties) across all measured traits. This suggests that the genotypes are suitable for selection procedures (Bahari et al., 2012; Fasahat et al., 2016).

At week 7, the cross TZSR 190 × SAMMAZ 16 had the lowest *Striga* count/emergence, with a value of 0.08, while the reciprocal cross SAMMAZ 14 × TZSR 193 recorded the highest *Striga* count of 2.58. In week 10, the reciprocal cross SUWAN × SAMMAZ 16 and the cross SAMMAZ 14 × SUWAN both had the lowest *Striga* count, each with a value of 0.33. The highest *Striga* count at week 10, 2.83, was observed in the reciprocal cross SAMMAZ 14 × TZSR 193.

At week 7, the reciprocal cross SAMMAZ 17 × TZSR 190 and the cross SAMMAZ 14 × SUWAN had the lowest *Striga* damage, both recording a value of 1.17, while the check GWG 111 showed the highest *Striga* damage at 3.00. By week 10, the reciprocal cross SAMMAZ 17 × TZSR 190 still had the least *Striga* damage rate at 1.58, whereas check 111 experienced the most damage, with a value of 4.42. Interestingly, some hybrids, such as TZSR 190 × SUWAN, with low *Striga* counts, were significantly damaged by *Striga* due to the subterranean germination of the parasites, which did not emerge at the surface. Conversely, hybrids like the reciprocal cross SAMMAZ 14 × TZSR 193 and SUWAN ×

TZSR 193, which had higher *Striga* counts, also suffered considerable damage due to their high susceptibility to *Striga* evasion. On the other hand, hybrids such as SAMMAZ 17 × TZSR 190, which had high Striga counts, showed little to no damage due to their tolerance to the parasite. Resistant hybrids, including SAMMAZ 14 × SUWAN, TZSR 190 × TZSR 193, TZSR 193 × TZSR 190, TZSR 190 × SAMMAZ 16, SAMMAZ 16 × TZSR 190, and check 5005, exhibited minimal Striga counts and damage. These hybrids also performed well in terms of yield and yield components. Similar trends were observed in previous studies by Gowda et al. (2021), Olakojo and Olaoye (2005), Sangaré et al. (2018), and Yallou et al. (2009). Kim (1994) emphasized that genotypes with low Striga counts but high Striga damage are not useful for breeding programs aimed at *Striga* resistance.

For characters of earliness, among all the genotypes (Crosses, reciprocals, and checks) evaluated, cross SAMMAZ 14 × SAMMAZ 17 recorded the shortest number of days (48.79 days) to attain 50% tasseling, while cross SAMMAZ 17 × SUWAN took the longest of 53.92 days to attain 50% tasseling. Similarly, reciprocal SAMMAZ 14 × TZSR 190 took the shortest number of days of 51.58 days, to attain 50% silking, whereas cross SAMMAZ 17 × SUWAN and SUWAN × TZEI 114 had the highest number of days of 57.75 days each, to attain 50% silking.

For days to 50% maturity, cross SAMMAZ 14 × SAMMAZ 17 had the least number of days of 84.54 days to attain 50% maturity, while reciprocal SUWAN × TZEI 114 had the longest days of 96.50 days to attain 50% maturity.

For growth characters, recip. SUWAN × SAMMAZ 14 recorded the highest plant height of 183.65cm at maturity, making it the tallest hybrid, while recip. SUWAN × TZSR 193 and check GWG 888 were the shortest among the hybrids, with 126.69cm and 128.90cm high, respectively. For cob length at maturity, check 5005 had the highest cob length of 15.67cm at maturity, while cross TZSR 190 × SAMMAZ 14 had the least cob length of 7.80cm.

From Table 4, it is observed that cross SAMMAZ 16 × SAMMAZ 17 had the highest grain yield in tons per ha of 51.50g and 3.56tons respectively, followed by cross TZEI 114 × SUWAN (50.45g and 3.52 tons), recip. SAMMAZ 16 × TZSR 193 with 48.52g and 3.34 tons, check 5005 with 48.19 and 3.33, SAMMAZ 14 × SUWAN with 47.46g and 3.29tons, TZEI 114 × SAMMAZ 16 46.41g and 3.23tons while recip. SAMMAZ 17 × SAMMAZ 16, check GWG 111 recorded the lowest yield per ha of 25.10g, 1.77tons and 26.39g, 1.89tons respectively. The highest shelling percentage of 73.20% was recorded in cross TZEI 114 × SAMMAZ 16, while check GWG 888 had the least shelling percentage of 49.30%. For harvest index, recip. SAMMAZ 16 × TZSR 190 had the highest harvest index of 0.271, while recip. SUWAN × TZSR 193 had the lowest harvest index of 0.131.

It is interesting to note that all the crosses that exhibited high performance in most characters and *Striga* resistance characters were a combination of one or two of the *Striga* resistance parental varieties, such as TZSR 190, SAMMAZ 16, and TZSR 193; however,

Table 4
Mean performance for Striga *resistance, growth, yield, and characters of forty-two hybrids (crosses and reciprocals), seven parents and three varieties of maize combined*

SOV	SCT7	SCT10	SDM7	SDM10	DTFT	DTFS	DTFM	PLHT	EHT	CLHT	CWPP	GYPH	HGWT	SHGP	HIDX
Genotype															
Parents															
TZSTR 190	0.25	0.08	1.33	1.33	54.17	59.53	93.58	128.42	56.84	6.25	14.07	0.73	17.44	49.30	0.091
TZSTR 193	1.17	0.42	1.92	2.33	52.50	58.33	92.13	148.74	68.87	7.83	31.53	1.68	20.09	66.70	0.143
TZEI 114	0.67	0.33	2.42	4.17	53.08	58.80	93.23	126.68	62.86	6.73	16.70	0.77	10.51	41.30	0.099
SAMMAZ 14	0.92	0.75	1.75	2.83	52.75	57.08	93.00	162.30	79.82	11.34	38.13	2.00	18.68	52.70	0.136
SAMMAZ 16	0.08	1.33	1.67	2.25	53.33	59.83	94.83	164.76	79.24	12.90	66.42	3.34	26.67	71.9	0.250
SAMMAZ 17	0.25	0.50	1.50	2.75	51.83	57.92	95.25	183.18	94.93	11.67	40.87	1.85	23.10	58.8	0.126
SUWAN	0.17	1.00	1.67	2.42	55.33a	59.50	95.17	170.26	79.38	11.46	47.89	2.40	22.28	67.10	0.181
Crosses															
TZSTR 190 × TZSTR 193	0.33	0.50	1.50	1.67	52.00	57.33	91.17	166.19	72.86	10.62	55.51	2.85	23.13	70.20	0.200
TZSTR 190 × TZEI 114	1.08	1.75	1.58	2.50	52.33	60.67	92.42	152.58	67.50	10.15	47.61	2.35	25.84	69.20	0.198
TZSTR 190 × SAMMAZ 14	0.83	0.67	1.67	2.92	52.58	57.71	89.83	164.19	81.31	7.8	42.77	2.27	20.80	61.60	0.186
TZSTR 190 × SAMMAZ 16	0.08	0.92	1.50	2.00	53.17	58.50	93.54	162.65	76.66	8.97	50.26	2.54	21.86	56.20	0.157
TZSTR 190 × SAMMAZ 17	1.08	0.50	2.00	2.25	53.50	58.93	93.05	177.97	89.10	9.29	60.12	2.80	23.31	59.80	0.163
TZSTR 190 × SUWAN	0.33	0.83	1.25	2.42	52.58	58.08	93.08	162.45	79.65	11.02	66.41	2.95	27.42	63.10	0.197
TZSTR 193 × TZEI 114	0.58	1.25	1.25	2.00	52.17	58.58	93.50	158.57	69.68	10.31	55.99	2.84	20.64	71.50	0.209
TZSTR 193 × SAMMAZ 14	0.25	1.42	1.50	2.58	52.92	58.92	93.25	157.36	72.67	12.21	52.42	2.45	22.09	66.40	0.190
TZSTR 193 × SAMMAZ 16	0.42	1.08	1.67	2.58	53.17	58.62	92.21	158.36	72.90	9.02	48.58	2.44	19.44	60.20	0.187
TZSTR 193 × SAMMAZ 17	0.83	0.67	1.58	3.25	52.17	61.33	92.67	154.36	72.50	9.81	53.31	2.72	22.54	71.70	0.209

Table 4 *(continue)*

SOV	SCT7	SCT10	SDM7	SDM10	DTFT	DTFS	DTFM	PLHT	EHT	CLHT	CWPP	GYPH	HGWT	SHGP	HIDX
TZSTR 193 × SUWAN	1.17	0.75	2.00	2.58	53.42	59.42	93.53	154.45	67.55	9.53	58.90	2.91	22.44	63.90	0.210
TZEI 114 × SAMMAZ 14	1.58	1.58	2.17	3.58	52.92	58.96	92.21	168.87	79.56	9.78	41.52	2.08	17.97	58.70	0.157
TZEI 114 × SAMMAZ 16	0.25	0.92	1.42	2.17	52.75	59.58	94.83	174.42	81.03	13.21	61.75	3.23	22.84	73.2a	0.224
TZEI 114 × SAMMAZ 17	0.42	1.33	1.67	2.67	52.83	58.83	93.33	167.57	80.18	11.17	50.76	2.41	21.80	69.00	0.192
TZEI 114 × SUWAN	1.08	1.00	1.75	2.75	52.08	57.83	93.08	177.48	82.16	12.58	77.39	3.52	24.13	67.20	0.242
SAMMAZ 14 × SAMMAZ 16	0.83	1.42	1.50	2.33	52.08	57.92	91.33	159.80	80.89	10.29	50.59	2.64	24.86	72.90	0.207
SAMMAZ 14 × SAMMAZ 17	1.67	1.25	2.42	3.92	52.58	57.58	90.67	145.93	73.19	10.13	54.86	2.73	19.65	71.10	0.234
SAMMAZ 14 × SUWAN	0.50	0.33	1.17	2.92	53.58	59.08	91.33	156.69	81.23	12.48	69.92	3.29	24.04	68.20	0.248
SAMMAZ 16 × SAMMAZ 17	0.67	0.67	2.00	3.25	52.67	57.50	90.67	157.43	79.19	10.64	71.50	3.56	22.34	68.11	0.223
SAMMAZ 16 × SUWAN	1.20	1.30	1.50	2.67	52.33	58.25	92.08	163.45	77.85	11.13	55.61	2.36	21.15	53.70	0.140
SAMMAZ 17 × SUWAN	0.17	1.00	1.75	2.50	52.67	57.83	98.17	166.29	79.78	10.84	45.50	2.10	24.52	55.80	0.143
Reciprocals															
TZSTR 193 × TZSTR 190	0.58	1.58	1.50	2.00	53.08	57.58	92.92	163.38	90.49	11.01	66.04	3.18	21.11	67.20	0.192
TZEI 114 × TZSTR 190	0.50	0.83	1.67	2.33	51.83	57.83	91.58	144.77	75.79	10.02	53.66	2.45	24.35	64.50	0.188
TZEI 114 × TZSTR 193	0.50	1.25	1.25	2.75	52.75	57.83	95.25	158.96	69.85	9.43	51.83	2.55	21.45	72.70	0.197
SAMMAZ 14 × TZSTR 190	1.08	1.33	2.08	3.08	52.00	59.42	93.33	155.90	78.52	9.18	44.09	2.18	23.79	64.50	0.182
SAMMAZ 14 × TZSTR 193	2.58	2.83	2.08	4.25	52.08	60.75	90.92	150.84	76.14	8.73	53.51	2.65	21.25	72.50	0.224

Table 4 *(continue)*

SOV	SCT7	SCT10	SDM7	SDM10	DTFT	DTFS	DTFM	PLHT	EHT	CLHT	CWPP	GYPH	HGWT	SHGP	HIDX
SAMMAZ 14 × TZEI 114	1.42	1.50	1.67	3.00	52.00	58.17	91.50	156.10	79.69	9.02	49.33	2.45	22.53	72.80	0.206
SAMMAZ 16 × TZSTR 190	1.33	1.33	1.58	1.83	52.92	58.83	94.42	168.59	86.00	11.01	58.74	3.03	25.06	71.80	0.271
SAMMAZ 16 × TZSTR 193	0.75	1.25	1.58	3.17	52.83	59.00	93.83	151.03	84.79	12.44	70.94	3.34	21.14	67.70	0.209
SAMMAZ 16 × TZEI 114	0.58	1.08	1.58	2.17	53.17	57.58	92.08	183.51	90.27	12.88	62.79	3.16	23.34	70.70	0.201
SAMMAZ 16 × SAMMAZ 14	1.75	0.75	2.33	3.75	53.08	59.17	93.17	150.81	71.18	11.01	55.53	2.65	20.64	57.90	0.166
SAMMAZ 17 × TZSTR 190	0.25	2.00	1.17	1.58	52.00	58.50	93.67	180.42	87.98	12.64	57.61	2.86	24.94	68.80	0.192
SAMMAZ 17 × TZSTR 193	0.92	2.17	1.58	2.83	51.33	56.79	92.08	155.91	79.83	10.70	50.02	2.37	18.79	56.20	0.160
SAMMAZ 17 × TZEI 114	1.08	0.83	1.67	2.50	53.50	58.92	98.83	160.18	74.34	12.78	53.46	2.71	23.35	71.30	0.197
SAMMAZ 17 × SAMMAZ 14	0.17	1.83	1.42	2.08	53.08	60.33	94.67	168.87	83.42	10.99	56.62	2.77	22.88	70.00	0.213
SAMMAZ 17 × SAMMAZ 16	1.08	1.08	1.83	3.33	52.75	57.92	94.35	143.08	75.97	8.68p	38.38	1.77	17.37	52.30	0.165
SUWAN × TZSTR 190	0.50	1.33	1.42	2.67	53.25	58.42	95.75	166.95	83.98	10.39	57.73	2.96	23.01	66.00	0.189
SUWAN × TZSTR 193	2.17	0.67	2.67	3.67	54.00	60.83	97.92	126.69	63.86	8.39	46.43	2.28	17.00	50.10	0.131
SUWAN × TZEI 114	0.42	1.25	2.17	3.42	53.92	58.67	94.88	175.95	78.81	12.06	5276	2.68	21.52	59.30	0.170
SUWAN × SAMMAZ 14	0.42	1.75	1.58	2.92	52.83	58.83	96.00	183.65a	86.83	12.18	62.61	3.19	25.62	70.00	0.172
SUWAN × SAMMAZ 16	0.50	0.33	1.50	2.25	52.67	59.67	96.75	177.76	82.98	13.18	58.20	2.85	23.14	66.30	0.183
SUWAN × SAMMAZ 17	1.08	2.75	2.42	2.92	54.00	61.92	94.17	143.10	89.17	8.93	39.07	2.06	16.30	48.10	0.134

Table 4 *(continue)*

SOV	SCT7	SCT10	SDM7	SDM10	DTFT	DTFS	DTFM	PLHT	EHT	CLHT	CWPP	GYPH	HGWT	SHGP	HIDX
Checks															
GWG111	0.58	0.92	3.00	4.42	53.00	59.29	96.71	158.93	68.08	9.89	38.86	1.89	19.46	58.50	0.156
5005	0.17	0.58	1.25	2.00	53.50	59.75	95.92	174.99	94.15	15.67	71.46	3.36	24.96	65.20	0.197
GWG888	0.67	1.33	2.17	4.17	52.25	59.58	92.33	128.90n	58.31	10.13	45.54	2.23	17.79	49.30	0.155
Mean	0.77	1.12	1.74	2.74	52.83	58.73	93.56	160.01	77.93	10.58	52.34	2.57	21.79	63.74	0.184
LSD	0.14	0.16	0.82	0.97	1.44	0.18	0.33	19.43	12.36	2.17	13.87	0.71	0.51	17.07	0.061
CV	236.29	203.69	77.78	85.01	4.95	6.88	4.76	22.76	28.02	42.95	56.21	59.20	39.57	35.54	48.47
											1.18				

SCT7= *Striga* count at 7weeks, SCT10= *Striga* count at 10weeks, SDM7=*Striga* damage at 7 weeks, SDM10=*Striga* damage at 10 weeks, DTFT=Days to 50% tasselling, DTFS=Days to 50% Silking, DTFM=Days to 50% maturity, PLHT=Plant height, EHT=Ear height, CLHT=Cob length, CWPP= Cob weight/plant, GYPH=Grain yield/ha, HGWT=100 grain weight, SHGP=Shelling%, HIDX=Harvest index

Table 5
General combining ability effect for the combined season for twenty-two characters

Parents	SCT7	SCT10	SDM7	SDM10	DTFT	DTFS	DTFM	PLHT	Non-In	EHT	CLHT	CWPP	GYPH	HGWT	SHGP	HIDX
TZSTR 190	-0.10	-0.08	-0.10*	-0.28**	0.00	0.01	0.38	-4.52	-3.42	-1.03	-3.18	-8.72	-141.82	-0.79	6540.24	-194.87
TZSTR 193	0.09	-0.01	0.01	0.01	-0.01	0.10	-0.19	4.62	-7.16**	-8.12	-1.86	1.13	-680.10	-1.61	13164.16	321.80
TZEI 114	0.01	0.01	0.03	0.07	0.01	-0.25*	-0.15	2.81	-3.79*	1.15	-2.34	1.18	716.21	0.01	-8965.63	307.10
SAMMAZ 14	0.17*	0.09	0.04	0.17**	-0.03	-0.25*	-0.20	-1.83	1.25	-2.80	-0.44	-7.17	-1733.83	-0.13	792.44	432.65
SAMMAZ 16	-0.07	-0.03	-0.01	-0.04	0.02	0.39*	0.28	5.47	3.75*	3.48	3.05	18.09*	3368.37	3.54	4958.05	317.09
SAMMAZ 17	-0.04	0.04	0.02	0.03	-0.03*	0.06	0.08	-11.24	6.81**	9.15	2.23	-3.50	-1524.39	2.42	-11014.16	-479.68
SUWAN	-0.06	-0.02	0.02	0.03fd	0.05**	-0.07	-0.20	4.69	2.57	-1.83	2.54	-1.00	-4.45	-3.44	-5475.10	-704.09

SCT7= *Striga* count at 7weeks, SCT10= *Striga* count at 10weeks, SDM7=*Striga* damage at 7 weeks, SDM10=*Striga* damage at 10 weeks, DTFT=Days to 50% tasselling, DTFS=Days to 50% Silking, DTFM=Days to 50% maturity, PLHT=Plant height, EHT=Ear height, CLHT=Cob length, CWPP= Cob weight/plant, GYPH=Grain yield/ha, HGWT=100 grain weight, SHGP=Shelling%, HIDX=Harvest index

some crosses that recorded high performance and *Striga* resistance had the combination of two *Striga* susceptible parents, such as TZEI 114, SUWAN, and SAMMAZ 14. The result of this present study also showed that most of the crosses that showed susceptibility were reciprocal hybrids, thereby suggesting that the choice of the donor and pollen receptor parents remains vital in the study of resistance to *Striga* in the maize plant. This is in agreement with the findings of Antoine et al. (2017). However, Kang et al. (1999), reported a contrary view in his work on where he asserted that the reciprocal effect is not important in the inheritance of rind puncture resistance in maize.

Genetic Component

General Combining Ability Effect for **Striga** *Resistance in Combined Season*

The estimates of general combining ability effects pooled over two seasons for all the characters are presented in Table 5. The results revealed TZSR 190 had the highest significant general combining ability estimate amongst the parental lines for traits where negative values are required like *Striga* damage and SAMMAZ 16 had the highest significant positive combining ability estimate where positive values are required like cob weight and other yield components. TZSR 190 also exhibited the highest negative value, though not significantly different from other parents for *Striga* count in both 7 and 10 weeks after planting, which is desirable. SAMMAZ 17 had the highest negative value for days to 50% tasselling, with SUWAN showing the highest positive significant value. TZEI 114 and SAMMAZ 14 had the highest significant negative GCA value of -0.25 each, while SAMMAZ 16 had the highest significant positive value of 0.39. It is interesting to note, however, that the parental varieties TZSR 190 and SAMMAZ 16 that performed well in *Striga* characters, yield, and their components are the best general combiners for *Striga* resistance, yield and yield components. Similar result was reported by Kim et al. (1998); Menkir (2006); Sangaré et al. (2018); Vivek et al. (2010) . Olaoye and Bello (2009), concluded that low GCA could probably be due to high tolerance of the parental varieties to *Striga* emergence.

Specific Combining Ability Effects of Crosses for **Striga** *Resistance in Season*

The specific combining ability effects of the crosses for *Striga* resistance characters, growth characters, yield and yield components for the 21 crosses in a glasshouse trial are presented in Table 6. Out of the 21 crosses, only two hybrid SAMMAZ 14 × SUWAN and TZSR 193 × TZEI 114 showed a negative SCA effect of -0.29 and -0.23 for *Striga* count at 7 weeks after planting. SAMMAZ 16 × SUWAN showed the highest non-significant negative SCA of -0.21 for *Striga* count at 10 weeks, while SAMMAZ 17 × SUWAN had the highest non-significant positive SCA value of 0.27. This shows that cross SAMMAZ 14 × SUWAN and TZSR 193 × TZEI 114 produce low strigolactones to stimulate *Striga* germination.

Similarly, TZSR 193 × TZEI 114 had the highest significant negative SCA (-0.29) for *Striga* damage at 7 weeks, followed by SMMAZ 14 × SUWAN (-0.26), while TZSR 193 × SUWAN had the highest significant positive SCA effects of 0.32. TZEI 114 × SAMMAZ 16 showed the highest significant negative SCA effect of -0.26, followed by TZSR 193 × TZEI 114 (-0.24), while SAMMAZ 16 × SAMMAZ 17 showed the highest highly significant positive SCA effect of 0.30 at 10 weeks. Crosses TZSR 193 × TZEI 114 and SAMMAZ 14 × SUWAN show high resistance to *Striga* infestation as they combine low *Striga* emergence and no visible *Striga* damage. Interestingly, the two crosses are a combination of a good general combiner (resistant) and a poor general combiner (susceptible) parental variety for *Striga* resistance. A similar finding was reported by Akaogu et al., (2017). TZSR 190 × TZEI 114 shows the only significant negative SCA effect of -0.07 for days to 50% tasselling while SAMMAZ 17 × SUWAN showed the highest highly significant negative SCA effects for both days to 50% silking and days to 50% maturity making the early flowering and maturity Cross hybrids which most desirable in maize especially in the savanna ecological region or areas with short rainfall. This is also in line with the reports by Akaogu et al. (2020) and Badu-Apraku et al. (2016).

From the result of Table 6, none of the crosses exhibited a significant SCA effect for plant height; however, TZSR 193 × SAMMAZ 16 had the highest negative SCA of -25.63, which makes it the shortest plant, which is desirable against lodging. TZSR 190 × SAMMAZ 17 had the highest significant positive SCA effects of 23.77 for ear height at maturity, preventing cob damage by rodents. This was also reported by Badu-Apraku et al. (2011). SAMMAZ 16 × SUWAN had the highest significant positive SCA of 13.90 for cob length at maturity. This cross hybrid may be considered in *Striga* free environment for high yielding performance, as cob length has been reported by Ahmad (2018) as a good attribute for yield in maize. The result of Table 6 also showed that in cob weight, TZSR 190 × SUWAN had the highest positive SCA effect of 34.91, while TZSR 193 × SUWAN exhibited the highest negative SCA effects (-39.47). SAMMAZ 14 × SUWAN showed the highest highly significant positive SCA effects of 14741.06 for grain yield per hectare and 100 grain weight (34.13), making it the best high yielding hybrid as it incorporates high grain weight, which is desirable for commercialization. This report affirms the findings of Amiruzzaman et al. (2013) and Ali et al. (2017). SAMMAZ 14 × SAMMAZ 17 had the highest highly significant positive SCA effects of 101769.91 and 4202.70 for shelling percentage and harvest index which also a desirable character in grain maize production as plant utilize assimilates for grain production whereas SAMMAZ 16 × SUWAN which had the highest highly significant negative SCA effects of -81701.81 for shelling percentage will be good for forage maize production for animal feeds. This finding is in agreement with the report by Aminu and Izge (2012).

Table 6
Specific combining ability effect for the combined season for twenty-two characters in maize

Crosses	SCT7	SCT10	SDM7	SDM10	DTFT	DTFS	DTFM	PLHT	EHT	CLHT	CWPP	GYPH	HGWT	SHGP	HIDX
TZSTR 190 × TZSTR 193	-0.20	0.04	-0.02	-0.14	-0.02	0.43	0.76	26.48	-11.09	5.33	25.38	4540.85	22.32	-3625.30	928.86
TZSTR 190 × TZEI 114	0.14	0.24	0.03	0.05	-0.07*	0.87	0.62	-15.17	-1.65	4.02	12.40	446.51	31.00*	33528.48	1282.53
TZSTR 190 × SAMMAZ 14	0.07	-0.09	0.13	0.21*	-0.02	-0.30	-0.77	2.29	0.80	-5.69	-10.28	-3965.35	-14.76	-32321.52	53.39
TZSTR 190 × SAMMAZ 16	0.13	0.08	0.01	-0.04	-0.02	-0.97*	-1.24	-10.74	-0.60	-0.63	-22.15	-882.58	-14.86	4060.07	-117.55
TZSTR 190 × SAMMAZ 17	0.02	0.16	0.00	-0.13	0.02	-0.06	-0.19	6.11	23.77*	2.57	25.88	9022.57*	11.11	14303.50	1507.31
TZSTR 190 × SUWAN	-0.07	0.09	-0.14	0.19	-0.02	0.63	0.73	-11.49	-11.04	7.34	34.91*	12667.30**	13.88	55480.92	1595.20
TZSTR 193 × TZEI 114	-0.23	0.06	-0.29**	-0.24*	0.02	0.70	1.22	-12.28	3.49	-1.58	7.41	7026.81	13.86	41073.11	2701.55*
TZSTR 193 × SAMMAZ 14	0.00	0.33	0.02	0.13	0.00	0.81	1.25	17.81	0.66	6.05	10.84	-5783.26	3.24	21315.33	974.88
TZSTR 193 × SAMMAZ 16	-0.09	0.07	-0.03	0.15	0.05	-0.42	-0.69	-25.63	8.20	-2.85	2.75	-570.26	-15.55	13567.90	-2218.20
TZSTR 193 × SAMMAZ 17	0.05	0.10	-0.11	0.12	-0.06	-0.77	-0.58	-9.34	1.36	-0.36	2.94	6607.28	-3.69	-17745.49	545.63
TZSTR 193 × SUWAN	0.47**	-0.19	0.32**	0.15	0.01	-1.12**	-1.64**	-10.13	-8.86	-4.61	-39.47**	-9377.66*	-21.84	-21013.84	-2014.67
TZEI 114 × SAMMAZ 14	0.25	0.09	0.06	0.02	-0.02	-0.13	-0.31	11.57	14.51	3.63	17.35	706.19	-18.07	-43135.16	-1877.11
TZEI 114 × SAMMAZ 16	-0.19	-0.01	-0.13	-0.26*	0.00	0.50	0.85	-8.14	6.17	4.91	12.53	12142.30**	8.79	55564.89*	2550.15
TZEI 114 × SAMMAZ 17	0.07	0.00	-0.06	-0.14	0.06	0.82	1.05	19.66	-14.49	5.60	4.71	-254.95	13.69	54340.07	1131.50
TZEI 114 × SUWAN	0.03	0.11	0.11	0.08	-0.03	-0.31	-0.19	18.48	-5.09	-4.22	32.58*	706.98	17.18	31633.72	-64.92
SAMMAZ 14 × SAMMAZ 16	0.15	-0.06	0.09	0.04	-0.05	0.51	0.75	-5.39	-14.18	-4.22	-11.19	-1918.40	13.32	-26671.56	937.76
SAMMAZ 14 × SAMMAZ 17	-0.01	0.12	0.05	-0.06	0.06	0.76	0.96	-21.41	-15.09	3.98	34.84*	5896.87	23.70	101769.91**	4202.70**
SAMMAZ 14 × SUWAN	-0.29	-0.04	-0.26**	-0.09	-0.01	0.91*	1.31*	6.70	2.50	5.23	23.23	14741.06**	34.13**	40520.07	1799.49
SAMMAZ 16 × SAMMAZ 17	0.15	-0.19	0.13	0.30**	-0.03	0.07	-0.24	7.28	-10.32	-4.71	-2.23	-9769.54*	-10.99	-42529.00	-1797.43
SAMMAZ 16 × SUWAN	0.17	-0.21	-0.12	-0.09	-0.04	0.34	0.21	19.24	6.94	13.90*	-35.08*	-5934.68	-4.45	-81701.81**	-1930.37
SAMMAZ 17 × SUWAN	-0.05	0.27	0.14	-0.08	0.01	-1.20**	-1.82**	-15.88	21.09	-11.23*	-35.04*	-7726.83	-32.04*	-39921.89	-2280.63

SCT7= *Striga* count at 7weeks, SCT10= *Striga* count at 10weeks, SDM7=*Striga* damage at 7 weeks, SDM10=*Striga* damage at 10 weeks, DTFT=Days to 50% tasselling, DTFS=Days to 50% Silking, DTFM=Days to 50% maturity, PLHT=Plant height, EHT=Ear height, CLHT=Cob length, CWPP= Cob weight/plant, GYPH=Grain yield/ha, HGWT=100 grain weight, SHGP=Shelling%, HIDX=Harvest index

Reciprocal Effect for Combine Analysis in Maize

An average of 7 hybrids showed a significant reciprocal effect value for *Striga* characters, as shown in Table 7. Hybrid SAMMAZ 17 × SAMMAZ 14 shows the highest significant negative recip. effect for *Striga* count at 7 weeks, while SAMMAZ 14 × TZSR 193 had the highest significant positive recip. Effect. TZEI 114 × TZSR 190 showed the highest significant negative recip. effect for *Striga* count at 10 weeks, while SUWAN × SAMMAZ 14 exhibited the highest significant positive recip. effect. For *Striga* damage at 7 and 10 weeks, SAMMAZ 17 × SAMMAZ 14 exhibited the highest significant negative recip. effect while SAMMAZ 16 × SAMMAZ 14 and SAMMAZ 14 × TZSR 193 had the highest significant positive recip. effect respectively.

From Table 7, SUWAN × SAMMAZ 16 has the highest significant negative recip. effect of -3.18 for days to 50% maturity, while SAMMAZ 14 × TZSR 190 has the highest positive significant recip. effect value of 1.56. For plant height at maturity, most of the hybrids showed negative recip. effect. SAMMAZ 16 × TZEI114 had the highest significant negative recip. value of -27.61, followed by SAMMAZ 16 × TZSR 193 with -20.26 while SUWAN × TZSR 190 exhibited the only significant positive recip. value of 21.85. For cob length, only SAMMAZ 16 × TZSR 193 and SAMMAZ 17 × TZSR 190 showed significant positive recip. effect of 14.00 and 7.08 respectively while SUWAN × TZEI 114 had the highest significant negative recip. effect of -15.38.

SAMMAZ 17 × TZSR 190 had the highest significant positive recip. of 12258.23 for grain yield per hectare, followed by SAMMAZ 16 × TZSR 190 (8915.56) and SAMMAZ 16 × TZSR 193 (8876.31) and SAMMAZ 14 × TZSR 190 (8362.71) while SUWAN × TZEI 114 had the highest significant negative recip. effect of -13121.18, followed by SUWAN × SAMMAZ 17 (-8997.10) and SAMMAZ 16 × SAMMAZ 14 with -8444.20. SUWAN × SAMMAZ 16 had the highest significant positive recip. value of 33.06 for 100 grain weight, followed by SAMMAZ 16 × TZSR 193 (23.56) and SAMMAZ 16 × TZSR 190 (23.24).

The above analysis showed that reciprocal hybrid SAMMAZ 17 × SAMMAZ 14, TZEI 114 × TZSR 190 and SAMMAZ 17 × TZSR 190 are good potential *Striga* resistant hybrids as they produce low strigolactone stimulant for *Striga* and non-visible *Striga* damage. It is interesting to note that most of the *Striga* resistant parental varieties are the donor parents in the hybrid combination, hence indicating that the choice of donor and receptor parents is vital in the development of *Striga* resistant hybrid. This is in line with the submissions of Chukwu et al. (2016) and Olaoye and Bello (2009).

In summary, this study provides valuable insights into the genetic mechanisms underlying Striga resistance, yield performance, and other agronomic traits in maize. The significant genotype-by-environment interactions highlight the need for location-specific breeding strategies, while the observed maternal effects and non-additive gene influences underscore the complexity of trait inheritance. The identification of high-yielding, Striga-

Table 7
Reciprocal effect for combined season in for twenty-two characters

Reciprocals	SCT7	SCT10	SDM7	SDM10	DTFT	DTFS	DTFM	PLHT	EHT	CLHT	CWPP	GYPH	HGWT	SHGP	HIDX
TZSTR 193 × TZSTR 190	0.05	0.34**	-0.01	0.09	0.01	-0.03	0.02	0.85	1.00	-1.69	-2.13	-195.51	-8.85	7403.85	681.31
TZEI 114 × TZSTR 190	-0.17	-0.31**	0.02	0.00*	-0.03	-0.11	-0.02	-2.00	8.10	3.67	2.45	894.94	4.34	8276.98	1538.62
TZEI 114 × TZSTR 193	-0.06	-0.04	-0.01	0.16	0.05	-0.06	0.01	-8.96	-4.22	-2.87	-22.99*	-2233.44	-0.30	-42693.69*	-264.99
SAMMAZ 14 × TZSTR 190	0.10	0.23*	0.11	0.02	-0.07**	1.27**	1.56**	-9.52	-18.45*	4.69	1.87	8362.71**	15.83	22978.20	1394.46
SAMMAZ 14 × TZSTR 193	0.59**	0.13	0.17*	0.35**	-0.04	0.00	-0.09	-17.80	-8.14	-7.82*	-25.24*	-4492.40	-15.33	7130.55	-542.64
SAMMAZ 14 × TZEI 114	-0.04	-0.14	-0.12	-0.14	-0.03	1.14**	1.49**	-15.48	-37.30**	-1.47	39.42**	3272.81	9.51	41588.56*	565.41
SAMMAZ 16 × TZSTR 190	0.42**	0.11	0.04	-0.05	-0.03	1.12**	1.48**	-0.24	20.64**	7.08	40.20**	8915.56**	23.24*	72815.62**	4428.81**
SAMMAZ 16 × TZSTR 193	0.13	0.07	-0.02	0.14	0.02	0.61*	1.52**	-20.26*	-1.85	14.00**	54.31**	8876.31**	23.56*	39527.68*	1776.15*
SAMMAZ 16 × TZEI 114	0.11	0.02	0.06	0.03	-0.02	-0.08	-0.09	-27.61**	1.30	0.07	30.21*	5478.83	-4.09	-4878.42	-1295.46
SAMMAZ 16 × SAMMAZ 14	0.27*	-0.21	0.22**	0.30**	0.07**	0.06	-0.01	6.62	-6.86	-1.70	-19.43	-8444.20**	-23.60*	-45824.91*	-1866.91*
SAMMAZ 17 × TZSTR 190	-0.17	0.46**	-0.23**	-0.17*	-0.04	0.62*	0.79	-17.29	-10.95	7.71*	7.95	12258.23**	3.95	37066.27*	2129.67*
SAMMAZ 17 × TZSTR 193	0.05	0.36**	0.01	-0.11	-0.06*	-1.30**	-1.51**	17.65	0.64	1.42	-15.22	-4185.46	-14.82	-29778.76	-1048.71
SAMMAZ 17 × TZEI 114	0.22*	-0.07	0.01	-0.03	0.04	0.03	0.08	-11.25	18.94*	-6.77	20.21	2724.79	-8.44	2237.40	-1384.77
SAMMAZ 17 × SAMMAZ 14	-0.49**	0.17	-0.26**	-0.40**	-0.01	0.05	0.07	-15.59	4.46	5.76	-1.47	-2503.71	4.47	-3876.08	-724.81
SAMMAZ 17 × SAMMAZ 16	0.06	0.22	-0.05	0.01	-0.01	0.04	-0.67	-19.37*	9.88	-10.36*	-43.59**	-6449.02*	-35.84**	-4351.04	-3161.59**
SUWAN × TZSTR 190	0.04	0.16	0.04	0.05	-0.01	-0.05	-0.02	21.85*	-6.98	-4.46	-14.54	1091.67	1.19	-6680.68	-1316.11
SUWAN × TZSTR 193	0.25*	-0.08	0.19**	0.23**	0.01	-0.57	-1.45**	-6.91	15.41*	-10.46*	-27.54*	-7900.61**	-30.75**	-47552.55*	-2856.59**
SUWAN × TZEI 114	-0.17	0.13	0.14*	0.15*	0.00	-1.21**	-1.53**	-19.78*	-14.32*	-15.38**	-23.35*	-13121.18**	-21.34*	-32795.91	-1404.79
SUWAN × SAMMAZ 14	-0.03	0.49**	0.11	0.00	-0.03	0.00	0.08	4.51	16.34*	-4.71	10.54	-2492.96	7.72	11722.56	-166.25
SUWAN × SAMMAZ 16	-0.17	-0.19	0.00	-0.08	0.00	0.10	0.89*	-5.81	-16.51*	5.07	43.63**	8046.14**	33.06**	54053.05**	2375.99*
SUWAN × SAMMAZ 17	0.25*	0.41**	0.14*	0.07	0.03	-1.67**	-3.18**	14.59	2.59	-10.43*	-33.74**	-8997.10**	-48.76**	-42954.50*	-3324.64**

SCT7= *Striga* count at 7weeks, SCT10= *Striga* count at 10weeks, SDM7=*Striga* damage at 7 weeks, SDM10=*Striga* damage at 10 weeks, DTFT=Days to 50% tasselling, DTFS=Days to 50% Silking, DTFM=Days to 50% maturity, PLHT=Plant height, EHT=Ear height, CLHT=Cob length, CWPP= Cob weight/plant, GYPH=Grain yield/ha, HGWT=100 grain weight, SHGP=Shelling%, HIDX=Harvest index

resistant hybrids offers a pathway for improving maize productivity in *Striga* endemic regions. These findings have important implications for maize breeding programs, as they provide a scientific basis for selecting superior genotypes, optimizing hybrid combinations, and developing resilient maize varieties suited for diverse environmental conditions.

CONCLUSION

In conclusion, the identification of hybrids with high Striga resistance and desirable agronomic traits has practical implications for improving food security in Striga-prone regions. Farmers can benefit from hybrids like TZSR 190 × SAMMAZ 16 and SAMMAZ 14 × SUWAN among others which combine Striga resistance with high yield potential. Moreover, hybrids with early maturity characters, such as SAMMAZ 14 × SAMMAZ 17, are particularly valuable for regions with short growing seasons. In addition, since *Striga* resistance genes are controlled by recessive genes, which could be cytoplasmic or non-nuclear genes as revealed in this study, identifying the donor and pollen receptor will be essential in the breeding program for *Striga* resistance. These findings can guide researchers, seed companies, and agricultural extension services in recommending suitable varieties to farmers in *Striga* endemic regions.

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