Variance components and heritability of traits related to Striga asiatica resistance and compatibility to *Fusarium oxysporum F.Sp. Strigae* in maize

Admire I. T. Shayanowako, Hussein Shimelis, Mark D. Laing, Learnmore Mwadzingeni*

Corresponding Author Learnmore Mwadzingeni
African Centre for Crop Improvement, University of KwaZulu-Natal, P/Bag X01, Scottsville 3209, Pietermaritzburg, South Africa;
Tell: +27623117075; E-mail: MwadzingeniL@ukzn.ac.za

Abstract
Genetic gain in breeding maize for yield and yield components and *Striga* resistance is dependent on the magnitude of genetic variation and heritability. The objective of this study was to determine variance components and heritability of yield and yield-related traits and *Striga asiatica* (L.) Kuntze resistance in maize involving a bio-control agent *Fusarium oxysporum* f.sp. *strigae* (*FOS*). Eighteen selected and genetically diverse maize populations were evaluated across nine testing environments in three sites under three levels of *FOS* treatment during the 2016/2107 growing season using an alpha lattice design with two replications. Variance components, heritability estimates and correlations among *S. asiatica* traits, grain yield and yield components of maize were calculated to provide a selection guide. Significant differences ($P<0.01$) were observed among maize genotypes, test environments, level of *Striga* infestation and their interactions. *FOS* treatment decreased *S. asiatica* parasitism in maize, and enhanced yield and its component traits. Moderate to high broad sense heritability values ($H^2>0.5$) were recorded for ear aspect (0.58), cob length (0.60), grain yield t ha^{-1} (0.61), grain yield plant^{-1} (0.65), cob diameter (0.83), 100 kernel weight (0.91); *Striga* counts (0.71) and *Striga* damage rating (0.75). Grain yield t ha $^{-1}$ and its components were negatively correlated with *Striga* parameters under *FOS* treatments. Yield-related traits such as cob length, cob diameter, and 100 kernel weight were important in indirect selection for *FOS* compatible and *Striga* resistant maize genotypes. *FOS* could serve as an effective bio-control agent against *S. asiatica* in maize production using compatible genotypes

KeyWords: *FOS*, heritability, maize, phenotypic variance, *S. asiatica* resistance, yield components

Introduction

Striga infestation is a major impediment to maize production and productivity in sub-Saharan Africa (SSA). An estimated area of 40 million hectares of land under maize production is parasitized by *Striga* species, causing yield losses valued at US$ 1 billion annually (Mugo et al., 2006). Erratic and low rainfall conditions, poor soils fertility and lack of production inputs increase the severity of the parasite on maize largely grown by smallholder farmers. *S. hermonthica*, *S. asiatica* and *S. aspera* are the three main *Striga* species causing significant yield losses in cereal crops in SSA. *S. asiatica* predominantly occurs in the southern African region where it causes severe yield losses in maize (Gurney et al., 2002).

Maize genotypes with considerable resistance to *S. hermonthica* are being developed by the International Institute of Tropical Agriculture (IITA) and other national breeding programs. This has been a significant milestone in provision of low cost and effective *Striga* control option for resource poor maize farmers in SSA. These genetic resources may serve as useful parents for breeding programs. However, improved and *Striga* resistant cultivars are limited in the southern Africa region. Further, host resistance currently being achieved is not sufficient to withstand high parasite infestation due to partial resistance to *Striga* in maize genotypes (Hearne, 2009).

A potentially low-cost control option to supplement the present partial resistance in maize against *Striga* is the use of a biocontrol agent referred to as *Fusarium oxysporum f.sp. strigae* (*FOS*). *FOS* has been evaluated for inundative control of *Striga* (Nzioki et al., 2016). It produces natural phytotoxins with bio-herbicidal effects that affect the parasitic weed through multiple target site inhibition (Watson et al., 2007). *FOS* can be an effective and integrated approach to supress resistant *Striga* plants emerging following continuous use of several herbicides with single site mode of action such as acetolactate synthase inhibitors (Gressel, 2009). The fungal pathogen forms a symbiotic association with most cereal crops including maize (Elzein et al., 2010; Shayanowako et al., 2017) and sorghum (Rebeka et al., 2013; Mrema et al. 2017). Total control of all developmental stages of *S. asiatica* was reported in sorghum seeds coated with *FOS* in a manner that mimics the imazapyr seed coating technology (Elzein et al., 2006). Venne et al. (2009) reported a 90% reduction in *S. hermonthica* emergence following coating maize seed with *FOS*. In addition, *FOS* is reported to proliferate highly in the rhizosphere ensuring continuous control of *Striga*.

There is a need to select maize genotypes that can provide an enabling rhizosphere for the proliferation of the fungus that supress *Striga* damage. A compatible host will release exudates that trigger virulence genes of the biocontrol agent (Handelsman and Stabb, 1996). Success in achieving this association is dependent on the presence of genetic variation and heritability of *FOS* compatibility, *Striga* resistance, yield and yield-related traits of genotypes.

The magnitude of variance components and heritability of a trait is one of the most useful estimators of expected gain from selection. In genetic analysis of maize, Badu-Apraku et al. (2007a) reported heritability values of 0.4 for *Striga* counts and damage rating, while Menkir et al. (2007) reported heritability values of 0.43, 0.65 and 0.70 for *Striga* damage, emergence rating and grain yield, respectively. Heritability estimates for yield, yield-related traits and *Striga* resistance under *FOS* are influenced by differences in test environments and populations. Rebeka et al. (2013) and Mrema et al. (2017) reported that differences exist in the level of genotype by *FOS* interactions. Thus, there is need to ascertain the influence of *FOS* on heritability of *Striga* resistance traits, grain yield and yield components of maize under the prevailing environments of *Striga* infestation. It is also essential to increase the spectrum of selection indices by testing the association between complementary traits such as *Striga* plant vigor, *Striga* plant height and yield components of maize (Adetimirin et al., 2000). Therefore, the objective of this study was to determine variance components and heritability of yield, yield-related traits and *S. asiatica* resistance in maize under *Striga* infestation with and without *FOS* treatment for resistance breeding or integrated *Striga* management.

Materials and Methods

Plant materials and study site

Eighteen genetically diverse maize populations obtained from the African Centre for Crop Improvement (ACCI), Agriculture Research Council (ARC), National Plant Genetic Resources Centre (NPGRC)/South Africa and the International Institute of Tropical Agriculture (IITA)/Nigeria were used in this study. *Table 1* presents a list and sources of the maize genotypes used in the study. The IITA genotypes served as resistant and susceptible checks. Experiments were conducted during the 2016/2017 summer cropping season at three sites including the University of KwaZulu-Natal (UKZN)'s Ukulinga Research Farm (29.6627° S, 30.4050° E), Baynesfield Estate (29.7652° S, 30.3414° E) and at UKZN's Controlled Environment Facilities. Fields of at least 15 years of continuous maize mono-cropping system with sporadic occurrence of *S. asiatica* were used at Ukulinga Research Farm and Baynesfield Estates. Greenhouse conditions at the Controlled Environment Facilities were maintained at temperature and humidity ranges of 30°C/20°C and 50%/55%, respectively.

F. oxysporum inoculum preparation and seed coating

Pure *FOS* chlamydospores from cultures grown on potato dextrose agar (PDA) were kindly supplied by the Plant Health Products (Pty) Ltd, Kwazulu-Natal, South Africa. Rice medium was used to mass-produce

Table 1 - List and sources of maize genotypes evaluated in the study.

E. No	Genotype	Source	Attributes	E. No	Genotype	Source	Attributes
1	NC QPM	NPGRC/South Africa	Commercial QPM	10	Obatanpa	CSIR/Ghana	QPM
2	Colorado	NPGRC/South Africa	Commercial	11	ZM1523	CIMMYT/Zimbabwe	Drought tolerant
3	N.Choice	NPGRC/South Africa	Commercial	12	ZM1623	CIMMYT/Zimbabwe	High yielding
4	Shesha	NPGRC/South Africa	Commercial	13	Land8	ACCI/South Africa	Early mature
5	B/king	NPGRC/South Africa	Commercial	14	HYB9022	IITA/Nigeria	Striga resistant
6	M/Pearl	NPGRC/South Africa	Commercial	15	HYB8338	IITA/Nigeria	Striga susceptible
7	Kep	NPGRC/South Africa	Commercial	16	TZB-SR	IITA/Nigeria	Striga susceptible
8	ZM1421	CIMMYT/Zimbabwe	Drought tolerant	17	STR-SYN-W1	IITA/Nigeria	Striga resistant
9	ZM1423	CIMMYT/Zimbabwe	Drought tolerant	18	Z-DPLO-DTC1	IITA/Nigeria	Striga resistant

† E. No, Entry number; QPM, quality protein maize, CIMMYT, International Maize and Wheat Improvement Centre; IITA, International Institute of Tropical Agriculture; NPGRC, National Plant Genetic Resources Centre; ACCI, African Centre For Crop Improvement

FOS chlamydospores. A 500g sample of pealed white rice was placed in a 1L glass beaker and soaked for an hour in sterile double distilled water. The rice was transferred into a Sterilin autoclavable bag, which was then heat sealed to exclude contaminates and autoclaved at 121 °C for 15min and left to cool at room temperature for a day. The medium was re-autoclaved and left to cool under laminar airflow before opening. Small cubes of *FOS* inoculum were aseptically cut from the *FOS* cultures on PDA and immersed into the Sterilin bag, which was gently massaged to ensure even inoculum distribution. It was then heat-sealed and incubated at 28⁰C for 10 days. The bag containing fully colonized rice was then split open under lamina air flow and the medium was washed with doubled distilled water and filtered through a cheese cloth to collect a spore-rich fluid, which was centrifuged at 10000G for 10 min to collect the spore pellets in 500ml centrifuge tubes. Maize seed was coated with *FOS* as described by Elzein et al. (2006). Seeds were first surface sterilized by spraying them with 70% ethanol and soaking them in 1% sodium hypochlorite solution for 30 minutes, washed twice in double distilled and dried under laminar air flow. A thin film coat of a mixture of 40% Arabic gum and fresh spores was then applied on each seed and left to dry. Enumeration to estimate amount of *FOS* conidia on each seed was done through serial dilutions on randomly selected seed samples showing an average of 5.833×10^{-5} colony-forming units per seed

Experimental design and trial management

The selected 18 maize populations were evaluated using a 9 x 2 alpha lattice design with 2 replications. *FOS* treatments were applied on maize seed prior to planting. Three treatments were compared comprising of maize genotypes grown without *Striga* infestation and without *FOS* treatment (control), maize genotypes with *Striga* and without *FOS* treatment, and maize genotypes with *Striga* and with *FOS*. In the field trials, maize seeds were planted in 2 rows of 2.5 meters length each with a spacing of 0.75 meters between rows and 0.25 meters between plants. Under glasshouse conditions, each plot consisted of 6 pots of 5L capacity filled with composited pine bark medium with two replications. Prior to planting, the *Striga* seeds were mixed with fine sand at a ratio of 1 : 99 (seed : sand) so that each tablespoon scoop would deliver more than 5000 viable *Striga* seeds (Berner et al., 1997). The sand-*Striga* mixture was preconditioned by drenching in water and incubating for a week at room temperature. A scoop of the mixture was put on each station and covered with a bit of soil before placing the maize seed on top during planting to ensure uniformity of *Striga* seeds in each planting station. Standard agronomic practices recommended for maize production were followed. Hand weeding was routinely done to remove all other weeds except *Striga*.

Data Collection

Striga parameters

Data on *Striga* emergence counts were collected 8 and 10 weeks after planting denoted as SEM 8 and SEM 10, respectively. *Striga* damage was also recorded 8 and 10 weeks after planting and was designated as SR 8 and SR 10, respectively, using a rating scale of 1 to 9 as described in Table 2 (Adetimirin et al., 2000).

Table 2 - Damage rating score and symptom description.

Rating	Symptom description
1	Normal plant growth with no visible symptoms
2	Small and vague purplish-brown leaf blotches visible
3	Mild leaf blotching with some purplish-brown necrotic spots
4	Extensive blotching and mild wilting with slight but noticeable stunting and reduction in ear and tassel size
5	Extensive leaf blotching, wilting and some scorching with moderate stunting; ear and tassel size reduction
6	Extensive leaf scorching with mostly grey necrotic spots. Some stunting and reduction in stem diameter, ear size and tassel size
7	Definite leaf scorching, with grey necrotic spots, and leaf wilting and rolling with severe stunting and reduction in stem diameter, ear size, and tassel size, often causing stalk lodging, brittleness, and husk opening at a late-growing stage
8	Definite leaf scorching with extensive grey necrotic spots and conspicuous stunting, leaf wilting, rolling, severe stalk lodging, brittleness, reduction in stem diameter, ear size and tassel size
9	Complete scorching of all leaves, causing premature death or collapse of host plant and no ear formation

Source- (Adetimirin et al., 2000)

Maize parameters

Anthesis-to-silking interval (ASI) was recorded as the number of days from 50% silk emergence to 50% anthesis. Ear aspect score (EASP) was recorded using a 1 to 5 rating scale; where 1= well-formed cob with good kernel set and 5= ears poorly formed with poor kernel set. Given the negative impact of *Striga* on individual plants and total yield performances both grain yield $plant^{-1}$ (GYP) and grain yield t ha^{-1} (GYD) were recorded. Cob diameter (CD), cob length (CL), kernels row^{-1} (KR), 100 kernel weight (100KWT), were also recorded. Grain yield (t ha^{-1}), grain yield (plant $^{-1}$) and 100 kernel weight were adjusted to 12.5% moisture content. Grain yield per plant was converted to grain yield in t ha^{-1} using the following formula adapted from Lauer (2002);

GYD=Field weight kg*10000m2*100–MOI*Shelling%1000kg*Plot area m2*100–12.50%

Where GYD = calculated grain yield per ha; MOI = measured grain moisture content at harvest; Shelling % = average shelling % for normal ears when 80% of the field is ready for harvest.

Data analysis

Combined analysis of variance and variance components among recorded traits were estimated using the general linear model (GLM) procedure of Genstat® version 18 VSN, International (Payne, 2017). Table 3 shows partial analysis of variance and expected mean squares used to calculate variance components and heritability estimates (Shimelis and Shiringani, 2010). Broad sense heritability estimates (H^2) of each trait were computed as the ratio of genotypic variance (σ^2_g) to the phenotypic variance (σ^2_p). The phenotypic variance was calculated as:

$$\sigma^2_p = \sigma^2_g + \sigma^2_{gl}/l + \sigma^2_{gt}/t + \sigma^2_{glt}/lt + \sigma^2_e/rlt;$$

where $\sigma^2 g$ = genotypic variance, $\sigma^2 gl$ = genotype x location interaction variance, σ^2_{gt} =genotype by treatment interaction variance, σ^2_{glt} = genotype x location x treatment interaction variance, σ^2_e = environmental variance, r = replication; l = location and t = treatment. The relationships among agronomic and Striga traits were determined separately for the above three treatments.

Results

Effect of Genotypes, FOS treatments and testing environments on trait variability

Combined analysis of variance (ANOVA) for the studied traits under three test sites is summarized in Table 4. The results show significant differences ($P < 0.01$) due to genotypes, *FOS* treatments and sites. Genotype by *Striga* interaction effects were significant for anthesis-to-silking interval, *Striga* damage rating eight weeks after plating, cob length, 100 kernel weight and grain yield. *Striga* emergence and damage rating were lower under *FOS* treatments than untreated controls. Hence, grain yield t ha^{-1} of *FOS* treated genotypes was higher than untreated and *Striga* infested groups. *FOS* reduced the damage severity of *Striga* on maize and its effect on the parasite was more pronounced on certain genotypes.

Table 3 - Partial analysis of variance and expected mean squares among 18 selected maize populations evaluated at three localities under *Striga* infestation and *Fusarium oxysporum f.sp. strigae* (*FOS*) treatment.

Source of variation	Degrees of Freedom	Expected mean square
Genotype (g)	g-1	$\sigma^2 e + r\sigma^2 gtl + rt\sigma^2 gl + rl\sigma^2 gt + rtl\sigma^2 g$
FOS treatment (t)	t-1	-
Site (l)	l-1	-
gt	(g-1)(t-1)	$\sigma^2 e + r\sigma^2 gtl + rl\sigma^2 gt$
gl	(g-1)(l-1)	$\sigma^2 e + r\sigma^2 gtl + rt\sigma^2 gl$
gtl	(g-1)(t-1)(l-1)	$\sigma^2 e + r\sigma^2 gtl$
tl	(t-1)(l-1)	-
Replication (r)/site	l(r-1)	-
Replication * block (b)	(r-1)(b-1)	-
Error	tl(g-1)(r-1)	$\sigma^2 e$

r, number of replication; σ2e, environmental variance; $\sigma^2 g$, genotypic variance; $\sigma^2 gl$, genotype by location interaction variance; $\sigma^2 gt$, genotype by treatment interaction variance; $\sigma^2 gtl$, genotype by treatment by location interaction variance.

Variance components and heritability of maize and Striga asiatica parameters

Variance components and heritability estimates of 8 maize traits and 4 *S. asiatica* parameters using 18 maize genotypes evaluated in three test sites, with three *FOS* treatment conditions are presented in Table 5. Ear aspect, cob length, cob diameter, 100 kernel weight, grain yield plant^{-1}, grain yield t ha^{-1}, *Striga emergence* counts eight weeks after planting, *Striga emergence* counts 10 weeks after planting, *Striga* damage rating eight weeks after planting and *Striga* damage rating 10 weeks after planting recorded moderate to high broad sense heritability's ($H^2 > 0.5$). Heritability estimates of $H^2 < 0.5$ were recorded for kernels row^{-1} and anthesis-to- silking interval, respectively.

Correlation of maize and Striga asiatica parameters

Correlation coefficients (r) describing the magnitude of the relationship among measured traits are summarized in Table 6. Significant correlations ($P < 0.05$) were observed between grain yield t ha^{-1} and SEM 10 (r=-0.20) under *Striga* infestation without *FOS*. Under *FOS* treatments, grain yield t ha^{-1} was significant and negatively correlated with SEM 8 (-0.294) and SR 8 (-0.26). Grain yield plant^{-1} was significantly correlated with SEM 8 (-0.5), SEM 10 (-0.3) and SR 8 (-0.39) with *FOS* treatment. Under *Striga* infestation without *FOS* treatment, grain yield plant^{-1} was only significantly correlated with SR 8 (-0.21). Anthesis-to-silking interval showed significant and positive correlation (r > 0.5, $P < 0.01$) with SR 8 under *Striga* treatments. Conversely, association between anthesis-to- silking interval and SEM 8 was non-significant under *FOS* treatment. Association between most secondary traits with *Striga* traits were significant and negative, with and without *FOS* treatments. Ear aspect showed significant and positive correlation with *Striga* emergence count and *Striga* damage rating with and without *FOS* treatments. Association of ear aspect and *Striga* traits with SEM 8, SEM 10 and SR 8 under *FOS* was weak and non-significant for SR 10. Ear traits such as cob diameter, cob length, and kernels row^{-1} were significantly correlated with *Striga* parameters under *FOS* treatments. Significant correlations were detected between *Striga* traits SEM 8, 10 and SR 8, 10 with and without *FOS* treatments (Table 6).

Discussion

Recent studies on biological control of *Striga* using *FOS* showed a significantly reduced level of *Striga* parasitism when sorghum genotypes were compatible to the fungi (Mrema et al., 2017; Rebeka et al., 2013). Selection for host compatibility might benefit from knowledge of trait expression under *FOS* treatment and *Striga* infestation. The present study examined the influence of *FOS* and determined components of genetic variation and heritability values among diverse maize populations selected for *S. asiatica* resistance breeding. The success of any breeding program is dependent on the presence of broad genetic diversity. Hence significant genotypic differences ($P < 0.01$) observed in this study indicate the potential of selecting useful maize populations for *Striga* resistance breeding programs (Table 4). *FOS* has improved the

Table 4 - Mean squares and significant tests after combined analysis of variance for maize and Striga parameters when evaluating 18 maize genotypes in three locations, under *Striga* infestation and *Fusarium oxysporum f.sp. strigae (FOS)* treatment.

Source of variation				***Maize traits***						***Stiga traits***		
	ASI	EASP	CD	CL	KR	KWT	GYP	GYD	SEM8	SEM10	SR8	SR10
Genotype (g)	1.5934**	0.6418***	0.69703***	12.074***	45.02***	342.95***	1.3812***	4.1161***	7.677***	17.691***	3.8277***	3.7198***
FOS tre-atment (t)	64.6138***	2.5507***	0.99168***	144.593***	575.21***	253.25***	11.1034***	148.6934***	19.892**	66.202***	8.2081***	20.6133***
Site (l)	45.878***	25.7502***	7.95377***	634.321***	3103.53***	1375.55***	40.6517***	120.0171***	7.421*	41.655***	21.0252***	25.2877***
gt	1.1346*	0.1468ns	0.07858ns	4.024*	12.2ns	36.52*	0.3138ns	1.1698*	1.028ns	2.315ns	1.2341*	1.3455ns
gl	0.6446ns	0.2443*	0.08171ns	4.136*	22.18*	20.6ns	0.4145**	1.2648**	2.545ns	5.017ns	0.6601ns	0.862ns
glt	0.6374ns	0.1609ns	0.07272ns	2.594ns	10.25ns	23.92ns	0.2091ns	0.6285ns	1.045ns	2.587ns	0.4853ns	0.6819ns
tl	15.8767***	4.3535***	0.37289**	48.257***	261.44***	309.7***	4.8654***	26.3066***	24.672***	35.27***	13.2823***	1.6181ns
Replication (Rep)	0.0123ns	0.1516ns	0.01528ns	0.223ns	0.01ns	0.69ns	0.0258ns	0.0481ns	4.031ns	1.94ns	2.9167*	3.3376*
Rep*block	2.2284*	0.2523ns	0.25179*	11.482*	50.43*	6ns	0.2881ns	0.5217ns	16.623***	30.217***	2.9293*	5.218**
Error	0.742	0.1618	0.08171	2.499	12.91	23.42	0.229	0.7011	2.134	4.267	0.6683	0.8244

, **, and *, significantly different at P < 0.05; P < 0.01; P < 0.001, respectively. ns, non-significant,; ASI, Anthesis-silking-interval; SEM 8, Striga emergences counts 8 weeks after planting; SEM 10, Striga emergences counts 10 weeks after planting; SR.8, Striga damage rating 8 weeks after planting; SR 10, Striga damage rating 10 weeks after planting; EASP, Ears Aspect; CL, cob length; CD, cob diameter; KR, Kernel row-1; 100 KWT, 100 kernel weight; GYP, grain yield-1; GYD, Grain yield t ha -1.*

resistance of maize to *S. asitica* shown by significant differences ($P<0.01$) among *FOS* treated maize genotypes. Pronounced differences in resistance and tolerant symptoms on the host genotypes observed under greenhouse and field conditions was probably due to genotype by test environment interactions.

Development of *Striga* resistant and *FOS* compatible maize genotypes can be realised given the observed significant genotype by *FOS* treatment interaction ($P>0.05$) for traits such as anthesis- to-silking interval, SR 8, cob length, 100 kernel weight, and grain yield (Table 4). (Nzioki et al., 2016) found consistent prolificacy of *FOS* across soil types and genotypes. Avedi et al. (2014) also reported lack of significant differences in response to parasitic infection among *FOS* coated and uncoated maize genotypes.

Environmental conditions determine the extent of Striga damage among the genotypes evaluated (Cochrane and Press, 1997). In this study, environmental variance (σ^2e) was more influential on trait expression than the genotypes (Table 5). Previous studies reported that σ^2e explained the largest proportion of the phenotypic variance (Badu-Apraku et al., 2007b; Hallauer, 1992; Kearsey and Pooni, 1998). Badu-Apraku et al. (2003) and Badu-Apraku (2007) also reported high σ^2e, and low σ^2g and σ^2ge. Berner et al. (1997) and Haussmann et al. (2000) recommended improvement of selection efficiency through enhancing environmental uniformity during screening by using artificial infestation techniques and increasing the number of replications over sites and seasons. Phenotypic evaluation is subject to genotype by environment interaction. It also involves high cost of field evaluations especially for Striga resistance using large genetic pools. Hence, phenotypic evaluation alone will rarely achieve optimum efficiency. Genomic approaches such as marker-assisted selection can augment phenotypic selection. Marker-assisted selection enables identification of desirable alleles in each selection generation. Also, marker assisted selection can facilitate pyramiding of genes that cumulatively contribute to Striga resistances and FOS compatibility.

Expression of field resistance to *Striga* in maize is controlled by minor genes that are inherited quantitatively (Kim, 1994). Thus, low to moderate heritability values are expected for traits like *Striga* counts, *Striga* damage rating, maize yield and its components. Traits with low heritability values are difficult to improve using direct selection. Indirect selection based on highly heritable component traits and marker-assisted selection facilitates accumulation of desirable genes. Badu-Apraku (2007) reported low heritability value ($H^2<50$) for *Striga* counts and damage rating, and high heritability estimate ($H^2>50$) for anthesis-to-silking interval.

The negative correlation observed between grain yield and *Striga* counts and grain yield and *Striga* damage rating scores under *FOS* treatments (Table 6) indicate that grain yield response of a genotype is subject to its resistance to *Striga* parasitism. However, the low phenotypic correlations observed between grain yield and *Striga* traits under *Striga* and *FOS* treatments suggest that the traits can probably be selected for separately (Badu-Apraku et al., 2006; Badu-Apraku et al., 2017). The results also show that secondary traits are important in selection for host resistance and *FOS* compatibility under *Striga* infestation.

Table 5 - Variance components for maize and Striga traits when evaluating 18 maize genotypes in three locations, under Striga infestation and Fusarium oxysporum f.sp. strigae (FOS) treatment.

	Maize Traits																*Striga Traits*							
Components	**ASI**		**EASP**		**CD**		**CL**		**KR**		**KWT**		**GYP**		**GYD**		**SEM8**		**SEM10**		**SR8**		**SR10**	
	Var	*%*	*Var*	*%*	*Var*	*%*	*Var*	*%*	*Var*	*%*	*Var*	*%*	*Var*	*%*	*Var*	*%*	*Var*	*%*	*Var*	*%*	*Var*	*%*	*Var*	*%*
σ^2g	0.04	4.12	0.02	0.39	0.5	13.82	0.04	0.49	1.43	8.43	21.46	45.6	0.06	18.11	0.15	15.03	0.58	17.55	1.54	23.9	0.27	23.59	0.28	22.52
σ^2gt	0.09	10.56	0.01	0.29	0.33	9.08	0	0.03	2.21	13.01	0	0	0.04	11.21	0.11	10.43	0.09	2.76	0	0	0.13	11.02	0.06	4.45
σ^2gl	0	0	0	0.04	0.25	6.88	0.01	0.1	0.42	2.46	2.55	5.41	0.01	4.02	0.07	7.06	0.48	14.54	0.66	10.31	0.08	6.68	0.05	4.16
σ^2gtl	0	0	0	0	0.09	2.48	0	0	0	0	0.12	0.25	0	0	0	0	0	0	0	0	0	0	0	0
σ^2e	0.76	85.32	0.16	3.17	2.43	67.73	0.08	1.03	12.9	76.1	22.94	48.74	0.22	66.66	0.69	67.48	2.14	65.15	4.24	65.79	0.68	58.71	0.86	68.87
Total	0.89	100	0.2	100	3.59	100	0.13	100	16.95	100	47.07	100	0.34	100	1.02	100	3.29	100	6.44	100	1.16	100	1.25	100
σ^2p	0.11		0.03		0.83		0.05		3.02		23.6		0.09		0.25		0.89		1.99		0.38		0.37	
(H^2)	0.33		0.58		0.6		0.83		0.47		0.91		0.67		0.61		0.65		0.77		0.72		0.77	

σ^2, Variance;Var, variance; g, Genotype; t, FOS treatment; l, site; e, Error; p phenotype; H^2, Broad-sense heritability; ASI, Anthesis-silking-interval; SEM 8, Striga emergences counts 8 weeks after planting; SEM 10, Striga emergences counts 10 weeks after planting; SR 8, Striga damage rating 8 weeks after planting; SR 10, Striga damage rating 10 weeks after planting; EASP, Ears Aspect; CL, cob length; CD, cob diameter; KR, Kernel row^{-1}; 100KWT, 100 kernel weights; GYP, Grain yield^{-1}; GYD, Grain yield t ha^{-1}

Table 6 - Pearson's correlation coefficients (r) describing association of 12 phenotypic traits of 18 maize genotypes evaluated at three locations, under *Striga* infestation (upper diagonal) and *Fusarium oxysporum f.sp. strigae (FOS)* treatment (lower diagonal).

	ASI	CD	CL	EASP	KR	KWT	GYP	GYD	SEM8	SEM10	SR8	SR10
ASI	1	-0.35**	-0.72**	0.69**	-0.64**	-0.47**	-0.06	0.01	0.57**	0.65**	0.75**	0.74**
CD	-0.09	1	0.44**	-0.59**	0.54**	0.17	0.50**	0.44**	-0.17	-0.18	-0.41**	-0.37**
CL	-0.30*	0.30*	1	-0.83**	0.80**	0.48**	0.27*	0.01	-0.38**	-0.42**	-0.64**	-0.58**
EASP	-0.12	-0.47**	-0.33*	1	-0.84**	-0.48**	-0.43**	0.01	0.52**	0.58**	0.72**	0.63**
KR	-0.36**	0.33*	0.791**	-0.32*	1	0.33*	0.40**	0.02	-0.39**	-0.45**	-0.66**	-0.55**
KWT	0.15	-0.23*	0.08	-0.12	-0.16	1	0.07	0.06	-0.40**	-0.51**	-0.38**	-0.36**
GYP	0.22*	0.16	-0.06	-0.47**	0.08	0.04	1	0.56**	-0.15	-0.20*	-0.21*	-0.19
GYD	0.22*	0.07	-0.44**	-0.19	-0.25	0.12	0.69**	1	-0.10	-0.11	-0.06	0.01
SEM8	0.14	-0.01	0.01	0.41**	-0.03	-0.31*	-0.50**	-0.29*	1	0.87**	0.74**	0.69**
SEM10	0.38**	-0.09	-0.24*	0.35*	-0.28*	-0.23*	-0.30*	-0.10	0.83**	1	0.73**	0.77**
SR8	0.39**	-0.32*	-0.24*	0.39**	-0.35*	-0.15	-0.39**	-0.23*	0.75**	0.77**	1	0.84**
SR10	0.56**	-0.32*	-.46**	0.24*	-0.54**	-0.10	-0.18	0.01	0.45**	0.69**	0.83**	1

, **, and *, significantly different at $P < 0.05$; $P < 0.01$; $P < 0.001$, respectively. ns, non-significant,; ASI, Anthesis-silking-interval; SEM 8, Striga emergences counts 8 weeks after planting; SEM 10, Striga emergences counts 10 weeks after planting; SR.8, Striga damage rating 8 weeks after planting; SR 10, Striga damage rating 10 weeks after planting; EASP, Ears Aspect; CL, cob length; CD, cob diameter; KR, Kernel row-1; 100 KWT, 100 kernel weight; GYP, grain yield-1; GYD, Grain yield t ha -1.*

Grain yield plant^{-1}, ear aspect, cob length, cob diameter, kernels row^{-1} and 100 kernel weight under *Striga* infestation are useful selection criteria in *Striga* resistance breeding programs. The significant positive phenotypic correlations observed between *Striga* counts 8 and 10 weeks after planting, and *Striga* damage rating 8 and 10 weeks after planting, grain yield and yield components suggest that these traits can be used to discern resistance or tolerance among genotypes with better accuracy.

Conclusion

Extensive variability for *Striga* resistance and *FOS* compatibility exists in the maize germplasm evaluated as revealed by highly significant differences recorded. Further, the biocontrol agent, *FOS*, suppressed *Striga*. High broad sense heritability estimates were recorded for *Striga* counts (0.71), *Striga* damage rating (0.75), grain yield t ha^{-1} (0.61) and most kernel traits when maize genotypes were evaluated under *FOS* treatments. Grain yield significantly and negatively correlated with *Striga* counts and *Striga* damage rating under *FOS* treatments. Recurrent selection method can be adapted to develop composite populations from genotypes exhibiting *Striga* resistance and compatibility with *FOS*. Further, use of marker-assisted selection could increase selection efficiency for effective delivery of *Striga* resistant and *FOS* compatible maize genotypes.

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