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Agronomic Performance Of S_1 Maize Lines Derived From A Bi-Parental Cross Under Infested And Striga Free Environments

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Abstract

Striga hermonthica, causes up to 100% yield loss in maize production in sub-Saharan Africa. Developing Striga resistant maize cultivars could be a major component of integrated Striga management strategies. This study aims at assessing the agronomic performance of S_1 breeding lines in improving maize for *Striga* resistance. Two hundred S_1 lines have been evaluated under artificial infestation *Striga* and Striga-free conditions in Benin for two years during 2018 and 2019 growing seasons using alpha-lattice design (51 x 4) with two replicates. Twelve agro-morphological and *Striga* adaptive traits have been assessed. The tested lines have displayed high genetic variability for most agronomic and *Striga* adaptive traits. The S_1 lines exhibited high grain yield

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than their parents with averages of 2,552.72±593 kg ha^{-1} and 2,965.67±635.86 kg ha^{-1} under *Striga* artificial infestation and *Striga*-free conditions, respectively. Grain yield has displayed high positive and significant genetic and phenotypic correlations with ears per plant and high negative correlations with days to 50% silking, ears aspect, and *Striga* damage rating at 8 and 10 weeks after planting (WAP). Useful traits like ears per plant, days to 50% silking, ears aspect, number of emerged *Striga* plants and *Striga* rating at 10 WAP could assist for indirect selection under *Striga* conditions. Based on the selection index, a total of 15 S_1 lines have been identified as top ranking and can be used as sources of resistance or tolerance genes to *Striga* and further improvement in maize breeding in future.

Keywords: Recurrent Selection, *Striga Hermonthica*, Benin, Maize

Introduction

Maize, (*Zea mays*, L) is one of the most important cereal crops grown in Sub-Saharan Africa (SSA). This crop is gaining momentum compared to other cereals, both in terms of production volume and used for human consumption and animal feed (Sangaré *et al.*,2018). In Benin, 1,470,250 ha of maize has been produced with an average yield of 1.07 t/ha (MAEP, 2020). With such performance in yield, Benin has the lowest productivity among the West African countries producing maize (FAO, 2020). Among the major constraints affecting maize productivity in this country, drought, low soil fertility and parasitic weeds known as *Striga hermonthica* are the most widespread stresses affecting maize production (Batamoussi *et al.*,2014; Badu-Apraku and Fakorode, 2017; Amogou *et al.*,2018). *S. hermonthica* is a root hemiparasitic plant that invades its host and extracts water added to essential nutrients from it. Consequently, the host becomes stunted, wilted, chlorotic, poorly yielded, and in severe cases, dies (Gurney *et al.*,1999; Stanley *et al.*,2020). In Benin, particularly in the northern part and under unfavorable environmental conditions, grain yield losses due to *S. hermonthica* range from 60 to 90% in maize genotypes (Kim *et al.*,2002; Toukourou *et al.*,2004). In severe cases the Northern part conditions such as low soil fertility, erratic rainfall patterns and low-input conditions, the grain yield losses can be as high (100%) for susceptible maize cultivars (Menkir *et al.*,2006; Badu-Apraku *et al.*,2010a). An integrated approach including use planting of resistant varieties, in combination with other control measures (fertilizer, crop rotation, intercropping with legumes) is considered as a viable approach to control *Striga spp.* for better maize yields in SSA (Kanampiu *et al.*,2018).

The extent to which *S. hermonthica* affects the growth of its host varies tremendously with level of host plant resistance/tolerance, infestation severity, and the prevailing environmental conditions (Kamara *et al.*,2020). Resistance to *Striga* denotes the capability of the host plant to induce the germination of Striga seeds but prevents the parasite from impacting the roots of the maize plants or kills the attached parasite (Badu-Apraku *et al.*,2020a). Under *S. hermonthica* infestation, the resistant genotype supports considerably Striga plants and produces a greater yield than the susceptible genotype (Ejeta *et al.*,1992; Haussmann *et al.*,2001). In contrast, a *Striga* tolerant genotype allows high Striga infestation as a susceptible genotype (DeVries, 2000), but produces more dry matter and shows fewer damage symptoms (Kim *et al.*,1994). Striga damage in maize is used as the indicator of tolerance while emerged *Striga* plants are an indicator of resistance (Adewale *et al.*,2020). Therefore, the development of maize genotypes that combine outstanding levels of resistance and tolerance are a promising breeding strategy which has been recommended for *Striga* resistance breeding in several studies (Kim,1991; Pierce *et al.*,2003). Efforts have been deployed at the International Institute of Tropical Agriculture (IITA), to develop maize genotypes, including inbred lines, S_1 lines, hybrids, etc. combining both Striga tolerance and resistance in collaboration with National Agricultural Research Systems (NARS) in SSA countries, including Benin National Maize Programme. These new materials need to be evaluated for adaptation and maize yield improvement under environmental stress.

Phenotypic recurrent selection is one of the main breeding methods used for selecting segregating populations derived from crosses between highly elite genotypes selection (Ceballos et al.,2012; De Oliveira *et al.*,2018). This method has been used in several maize breeding programmes to improve resistance or tolerance of maize to abiotic or biotic stress (Kamara *et al.*,2003, Menkir and Kling, 2007; Badu-Apraku *et al.*,2012). Recurrent selection has been successfully used to improve grain yield and other agronomic traits in maize populations under Striga-infested conditions (Menkir *et al.*,2004; Badu-Apraku, 2010). The goals of recurrent selection are to improve the mean performance of a population and to maintain some level of genetic variability in the population. Progress in selection is based on the trait heritability and the types of genetic variation controlling the trait in the particular population (Durrishahwar *et al.* 2008). Keeping in view the grain yield losses due to Striga and the role of S_1 line recurrent selection in addressing this problem, the current study was conducted to identify some S_1 lines with greater genetic potential in improving maize germplasm for Striga resistance. Therefore, the objectives of this study have been to (i) assess the performance of S_1 lines for Striga resistance and agronomic traits (ii) understand the interrelationships of traits associated with Striga resistance/tolerance in S_1 lines of maize and (iii) identify high performers S_1 lines for further improvement. The hypothesis

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tested in the study is that there is adequate genetic variation among maize S_1 lines for Striga resistance/ tolerance that can be improved by selection.

Materials and Methods

Study Sites

The experiments have been conducted at Angaradébou (11° 20' N, 2° 43' E, 256 m above sea level) and Ina (09° 57' N, 2°43' E and at 371 m above sea level). These sites are located in Sudan and Sudan-Guinean zones of Benin, respectively. The mean monthly rainfalls at Angaradébou during the cropping periods (June to November) of 2018 and 2019 were 138.4 mm and 165.0 mm, respectively as well as mean temperatures of 28.18°C and 28.14°C. At Ina, the mean monthly rainfalls were 176.88 and 152.78 mm, respectively during the 2018 and 2019 cropping seasons, and temperatures were 27.44°C and 27.58°C. Minimum and maximum temperatures were respectively (28.2 and 28.13°C), (27.44 and 27.57°C) during the cropping seasons of 2018 and 2019, respectively (Table 1).

Table 1. Monthly temperatures and rainfalls for two growing years (2018 and 2019) at Angaradébou and Ina, Benin

Location/ Month	2018 Temperature (°C)			2019 Temperature (°C)			2018	2019
	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Rainfall (mm)	
Angaradébou								
June	23.4	33.1	29.6	23.5	32.5	29.11	200	175
July	22.5	31.4	27.9	22.7	31	26.85	131	264
August	22.1	30	27.1	22.3	29.6	26.95	270	308.5
September	22.4	30.7	27.5	23.2	31	27.75	216.5	186.5
October	21.3	34.5	28.9	23.2	34.3	29.75	13.0	56.0
November	18.7	35.8	28.3	18.8	36	28.4	0	0
Ina								
June	23.3	31.1	27.7	22.2	31.6	27.9	263	112.9
July	22.2	29.8	27.0	21.8	29.9	26.8	244.5	247.1
August	21.6	28.2	25.9	21.7	29.4	26.5	298.1	309.3
September	21.6	29.3	26.5	21.2	30.1	26.6	198.1	158.6
October	22.2	32.5	28.4	22.0	32.3	28.2	57.6	88.8
November	21.6	34.9	29.3	21.9	34.8	29.4	0	0

Plant Materials

This study used 200 intermediate maturity (105-110 days) S_1 maize lines derived from the biparental cross (TZISTR1108 x 5057). The two intermediate white maize parental inbreds used in the present study have varied significantly in their responses under artificial Striga infestation. The inbred line TZISTR1018 is a *Striga hermonthica* resistant line which was derived from *Zea- diploperenis* (a wild relative of the modern maize plant with resistance to *S. hermonthica*), while 5057 is highly susceptible to the parasite.

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TZISTR1018 is a progeny of cross between IITA developed tropical maize germplasm and *Zea diploperennis*, a wild progenitor of *Zea mays* L (Menkir, 2006; Menkir *et al.*,2006). For the development of the S_1 lines, crosses have been made between TZISTR1018 and 5057, to obtain F1 progenies at IITA, Ibadan, Nigeria. Resulting F_1 have been selfed to generate an F_2 segregating population. From the F_2 bulk seeds, over 300 S_1 lines have been, thereafter, developed. From these 300 lines, 200 S_1 lines have been randomly selected alongside with the two parents. The two parents and two inbred lines with known resistance (9450) and tolerance (9030) reactions to *S. hermonthica* have been included as benchmarks to assess the performance of the S_1 lines.

Experimental design and field infestation with *S. hermonthica*

The S_1 lines have been evaluated in alpha-lattice design (51 x 4) with two replicates. Each line has been planted under infested and non-infested adjacent bands, which is 1.5 m apart, using a criss-cross arrangement described by Pearce (1976). On each strip, each line has been planted on a row of 3 m length with 0.75 m inter-row spacing and 0.25 m intra-row spacing. For each S_1 line, the infested row has been planted directly to the non-infested row in adjacent bands to accurately assess yield losses due to *S. hermonthica* damage (Kling *et al.*,2000).

The field has been treated with ethylene gas two weeks before planting to remove *S. hermonthica* seeds from the soil through suicidal germination. *S. hermonthica* seeds used for artificial infestation were collected from farmers' sorghum fields in the previous planting years. Two maize seeds have been planted in a 6 cm deep hole injected with 8.5 g of sand mixed with Striga seeds. The mixture contained approximately 3,000 germinable Striga seeds. Two weeks after planting, all maize plants have been thinned to one plant per hill to attain a population density of 53,333 plant. ha^{-1}. Fertilizer has been applied to planting at the rate of 30 kg/ha of nitrogen, 60 kg. ha^{-1} each of phosphorus and potassium, and an additional 30 kg. ha^{-1} nitrogen has been applied four weeks later as top-dressing fertilizer. Weeds other than Striga have been removed from plots manually throughout the planting season.

Field data collection

Data have been recorded for anthesis and silking days, plant height, ear aspect, and ear per plant, grain yield in both Striga-infested and Striga-free conditions while plant aspect has been recorded in Striga free condition (Table 2).

Table 2. List of the assessed maize agro-morphological traits alongside used codes and their descriptions

S/N	Traits	Code	Traits description	Unit
1	Days to anthesis	DAYAT	The number of days from planting to the time when 50% of the plants had another shedding pollen.	count

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2	Days to silking	DYSK	The number of days from planting to the time when 50% of the plants had emerged silks.	count
3	Anthesis silking interval	ASI	The interval in days between dates of silking and anthesis	count
4	Plants height	PLHT	The distance from the base of the plant to the height of the first tassel branch.	cm
5	Ears aspect	EASP	It was scored on a scale of 1-5. where 1= clean. uniform. large and well-filled ears and 5 = rotten small partially filled ear	Scale
6	Plants aspect	PASP	It was recorded only on a scale of 1-5. where 1 = excellent plant type and 5 = poor plant type.	Scale
7	Ears per plant	EPP	Total number of ears with at least one fully developed grain divided by the number of harvested plants.	Count
8	Emerged Striga plants	CO 1 & 2	Number of emerged Striga plants per plot at 8 and 10 weeks after planting [WAP].	Count
9	Striga damage rate	RAT 1 & 2	It is scored on a scale of 1-9. where 1= no visible host plant damage symptom and 9 = all leaves are completely scorched and finally dead plants. Taken at 8 and 10 WAP (Kim et al.,1994).	Scale
10	Grain yield	G.Y	Calculated from grain weight of harvested ears per plot adjusted to 150 g grain kg^{-1} moisture content (Badu-Apraku et al.,2020a).	kg/ha

Data analysis

The data recorded on ear aspect, plant aspect, emerging Striga counts and Striga damage severity scores have been subjected to logarithm transformation (Feng *et al.*,2014). Data collected on grain yield, ears per plant, Striga damage as well as Striga emergence counts have been tested for normality using Shapiro–Wilk's (W) test (Wang *et al.*,2018) before running the analysis of variance (ANOVA). ANOVA has been conducted across research environments using the general linear model procedure (PROC GLM) implemented in the Statistical Analytical System (SAS), version 9.4 (Vargas *et al.*,2013). The statistical model used for combined analysis is as follows:

$Y_{ijkg} = \mu + E_i + R_{j(i)} + B_{k(ij)} + G_g + EG_{ig} + \varepsilon_{ijkg}$, where Y_{ijkg} is the observed measurement for the g^{th} genotype grown in the environment i, in the block k, in replicate j; μ is the grand mean; E_i is the main effect of environment; $R_{j(i)}$ is the effect of replicate nested within environment; $B_{k(ij)}$ is the effect of block nested within replicate j by environment i; Gg is the effect of genotypes (S_1 lines and checks); EGig is the interaction effect between genotype and environment, and εijkg the error term.

Phenotypic and genetic correlation coefficients have been calculated among the traits, using the adjusted means of the S_1 lines in META-R (Alvarado *et al.*,2016). Broad sense heritability (H^2) estimates have been

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calculated from phenotypic variance (σ^2_p) and the genetic variance (σ^2_g) (Hallauer *et al.*,2010).The tested genotypes have been classified as either resistant or susceptible to Striga using a selection index that involved grain yield, ears per plant, Striga damage, and number of emerged Striga plants (Badu-Apraku and Fakorode, 2017). The final ranking and outstanding lines were identified using wasb function implemented in the metan package (Olivio, 2020) whereby different traits have been assigned as by increasing or decreasing. The genetic gain (GG) made up of the selected genotypes was evaluated for the overall population as well as for the best used checks for each trait. $GG(\%) = (X - X0) * H^2/X0GG(\%) = (X - X0) * H^2/X0$; where X (mean of the selected S_1 lines); H^2 (broad sense heritability) and X_0 (Overall grand mean and the best checks).

Results

Phenotypic variation and agronomic performance of the S_1 lines and the parental lines

From the combined analysis of variance (ANOVA), under Striga-infested condition, significant differences in mean squares of genotypes have been observed for all traits, except anthesis silking interval, and environment had significantly affected all measured traits. Similarly, means squares for genotype × environment interaction (GEI) effects were significant for grain yield and several other measured traits, except plant height and Striga adaptive traits (Table 3). However, GEI effects for all characters in non-infested conditions have been not significant, except phenological traits.

Mean performance of progenies (S_1 lines) and their parents (TZISTR1108 and 5057) under Striga artificial infestation and Striga non-infestation are shown in Table 4. Under Striga conditions, progenies had higher mean values for grain yield (2,552.27 kg ha^{-1}), ears per plant (0.74) and plant height (102.85 cm). For Striga damage and number of emerged Striga plants, S_1 lines had the lowest mean values at 8 WAP while parental line TZISTR1108 had the lowest mean values at 10 WAP. Similar results have been observed for all the traits, except ears aspect under Striga-free conditions. In general, the S_1 lines and the resistant parental line (TZISTR1108) have shown higher and similar mean values for most of all the traits, while the susceptible parental line (5057) had the lowest means. The lowest heritability (0.43) has been observed for ear aspect and the highest (0.77) has been for days to 50% anthesis under Striga artificial infestation. Under Striga non-infested conditions, low heritability (0.27) has been observed for anthesis and silking interval while the highest (0.79) has been obtained for grain yield (Table 4).

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Interrelationships among measured traits

Genetic (lower diagonal) and phenotypic (upper diagonal) correlation coefficients between agronomic traits of maize genotypes evaluated under artificial Striga infestation are presented in Figure 1.

Grain yield displayed positive and significant genetic and phenotypic correlations with ear per plant (r_g=0.86***and r_p= 0.66***) and plant heights (r_g=0.65***and r_p= 0.35***), but negative correlations with days to 50% anthesis (r_g= -0.59***and r_p= -0.57***), days to 50% silking(r_g=-0.74***and r_p= -0.66***), anthesis silking interval (r_g= -0.70***and r_p= -0.57***), ear aspect (r_g= -0.96***and r_p= -0.64***), and Striga damage rating at 8 WAP (r_g= -0.77***and r_p= -0.64***), and 10 WAP (r_g= -0.80***and r_p= -0.66***). Furthermore, positive and significant genetic correlations were observed between grain yield and number of the emerged Striga plants at 8 WAP (r_g= 0.18*) and 10 (r_g= 0.20*) WAP (Figure 1). Similarly, Striga damage at 8 and 10 WAP recorded positive and significant genetic and phenotypic correlations with anthesis-silking interval (r_g= 0.83*** and r_p= 0.34***; r_g=0.68*** and r_p=0.38***) and ear aspect (r_g=0.55*** and r_p= 0.46***; r_g=0.66*** and r_p=0.49***), but displayed negative correlations with plant heights (r_g= -0.86*** and r_p= -0.34***; r_g= -0.98***and r_p= -0.39***). Striga damage at 8 WAP and Striga damage at 10 WAP (r_g= 0.97***and r_p= 0.75***) showing positive significant genetic and phenotypic correlations. However, negative and significant genetic correlations were observed between emerged Striga plants at 10 WAP and Striga damage rating at 8 and 10 WAP (r_g =-0.23**and -0.21*), as well as phenotypic correlation with Striga damage rating at 8 WAP (r_p = -0.18*). In general, genetic correlations for all the traits measured have been higher than phenotypic correlations, except between days to 50% anthesis and days to 50% silking.

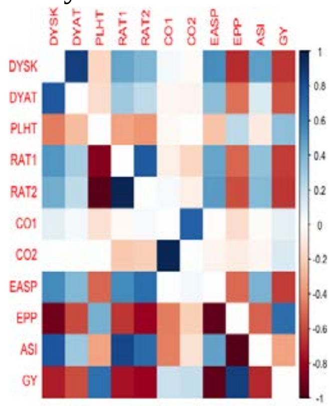

Figure 1. Genetic (lower diagonal) and phenotypic (upper diagonal) correlation coefficients between agronomic traits evaluated under artificial Striga infestation

DAYAT: days to anthesis, DYSK: days to silking, PLHT: plant height, RAT1: Striga damage at 8 WAP, RAT 2: Striga damage at 10 WAP, CO1: number of emerged Striga plant per plot at 8 WAP, CO2: number of emerged Striga plant per plot at 10 WAP, EASP: ear aspect, EPP: ear per plant, ASI: anthesis silking interval and GY: grain yield

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Table 3. Mean squares for grain yield and other measured traits for S_1 maize lines, evaluated under Striga-infested and non-infested conditions at Angaradébou and Ina, Benin in 2018 and 2019

Source of Variation	df	GY	EPP	EASP	DYAT	DYSK	ASI	PLHT	PASP	CO1	CO2	RAT1	RAT2
Striga artificial infestation conditions													
Environment (E)	3	5710030.85***	3.98***	389.58***	1737.01***	734.79***	121.46***	12690.56***		587.13***	1464.40*	97.10***	530.76***
Block(E*Replicate)	400	211518.66***	0.08***	1.47***	10.18***	14.13***	0.99^{ns}	1256.07^{ns}		33.78***	176.89***	0.69***	1.39***
Replicate(R)	4	317892.36***	0.356***	10.64***	61.99***	43.31***	0.94^{ns}	692.34^{ns}		131.52**	439.61**	5.10***	17.85***
Genotype (G)	203	392701.06***	0.125***	1.91***	16.31***	20.95***	1.16^{ns}	1198.45^{ns}		32.06*	144.82*	0.87***	1.79***
G x E	609	137650.9**	0.079***	1.31**	4.67*	7.39**	0.81^{ns}	1193.29^{ns}		27.24^{ns}	114.06^{ns}	0.38^{ns}	0.66^{ns}
Error	812	112128.6	0.058	0.667	3.913	5.82	5.018	1222.54^{ns}		25.0322	113.951	0.354	0.636
CV(%)		11.24	15.45	12.56	07.60	0.14	0.78	16.45		17.42	12.03	15.45	16.34
Non-infested condition													
Environment (E)	3	10152860.1***	4.18***	325.46***	2038.97***	1433.71***	47.18***	2087.62***	121.48***				
Blk(E*Repetition)	400	391620.9***	0.17***	0.46***	14.65***	11.46***	1.97^{ns}	481.73***	0.34***				
Repetition(E)	4	3211805.2***	0.99***	5.67***	175.95***	91.41***	4.62*	4557.13***	0.98***				
Genotype (G)	203	793749.4***	0.153*	0.64***	20.29***	19.32***	2.59***	327.27***	0.34***				
G X E	609	212957.2ns	0.130ns	0.27ns	7.39***	6.49**	2.14*	202.75ns	0.16ns				
Error	812	192982.6	0.123	0.252	5.324	5.04	1.699	186.448	0.165				
CV(%)		13.78	11.06	10.34	5.63	9.78	0.42	18.23	10.24				

*****; **** and *** s**ignificant p-value of 0.001, 0.01 and 0.5, respectively and ns: non-significant

DAYAT: days to anthesis, DYSK: days to silking, PLHT: plant height, RAT1: Striga damage at 8 weeks after planting (WAP), RAT 2: Striga damage at 10 WAP, CO1: number of emerged Striga plant per plot at 8 WAP, CO2: number of emerged Striga plant per plot at 10 WAP, EASP: ear aspect, EPP: ear per plant, ASI: anthesis silking interval, PASP: plant aspect and GY: grain yield.CV: coefficient of variation, G x E: genotype by environment interaction

Table 4. Means, standard deviations and heritability for traits of the parents and S_1 lines under Striga artificial infestation and Striga non-infested conditions

	TZISTR1108 (Mean±SD)	S_1 lines (Mean±SD)	5057 (Mean±SD)	H^2
Striga hermonthica artificial infestation conditions				
GY	1929.62±593.50^{b}	2552.27 ±535.17^{a}	333.50±75.23^{c}	0.72
EPP	0.69±0.31^{b}	0.74± 0.22^{a}	0.05±0.12^{c}	0.59
CO1	5.18 ±2.88^{a}	4.07±2.35^{a}	29.12±9.76^{b}	0.56
CO2	13.82±4.84^{a}	17.31±11.47^{b}	43.37±14.42^{c}	0.59
RAT1	2.26±0.75^{b}	1.89±0.91^{a}	4.70±1.02^{c}	0.64
RAT2	3.56±1.41^{a}	5.01±1.49^{b}	6.87±1.46^{c}	0.72
DYAT	64.25±2.12^{a}	64.79±3.61^{a}	67.62±3.20^{b}	0.77
DYSK	67.37±2.33^{a}	68.02±2.94^{a}	76.16±7.57^{c}	0.74
ASI	2.42±1.51^{a}	3.02±2.11^{a}	9.20±7.33^{b}	0.45
PLHT	95.92±20.87^{b}	102.85±33.66^{a}	71.68±17.47^{c}	0.56
EASP	2.75±1.03^{a}	2.83±1.26^{a}	2.87±2.02^{a}	0.43
	Striga non-infested conditions			
GY	2905.19±504.24^{a}	2964.67±653.86^{a}	1481.50±385.32^{b}	0.79
EPP	0.80±0.24^{a}	0.81±0.39^{a}	0.59±0.19^{b}	0.54
PASP	2.61±0.91^{a}	2.42 0.71^{a}	3.00±0.53 ^{b}	0.64

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DYAT	62.85±2.11[a]	63.07±4.01[a]	66.37±2.97[b]	0.71
DYSK	66.28±2.56[a]	67.76±2.91[ab]	70.85±2.61[c]	0.73
ASI	3.42 1.51[a]	3.66±1.55[bc]	4.50±1.64[c]	0.27
PLHT	110.43±12.81[b]	124.41±18.90[a]	93.00±19.91[c]	0.57
EASP	2.97±1.02[a]	3.03±1.05[a]	3.86±0.85[b]	0.45

DAYAT: days to anthesis, DYSK: days to silking, PLHT: plant height, RAT1: Striga damage at 8 weeks after planting (WAP), RAT 2: Striga damage at 10 WAP, CO1: number of emerged Striga plant per plot at 8 WAP, CO2: number of emerged Striga plant per plot at 10 WAP, EASP: ear aspect, EPP: ear per plant, ASI: anthesis silking interval, and GY: grain yield. H: Broad-sense heritability. Means followed by the same letters for the same traits are not significantly different at the 5% level of significance according to Duncan's Multiple Range Test (DMRT)

Selection of best performing *Striga hermonthica* resistant/tolerant genotypes

Selection based index revealed the presence of 15 lines as outstanding and top ranking for all the traits evaluated across Striga infestation conditions (Figure 2 and Table 6). The selected S_1 lines had displayed higher grain yields (2,331 kg ha^{-1} and 2648 kg ha^{-1}) than all the used checks (1,745 kg ha-1 and 2,318 kg ha^{-1}) in both conditions of the study. Grain yield means of population including selected S_1 lines (1,568 kg ha^{-1} and 1,931 kg ha^{-1}) were less than the means of selected S_1 lines (2,331 kg ha^{-1} and 2,648 kg ha^{-1}) resulting in genetic gains of 1.87% and 0.92%, under Striga and Striga free-conditions, respectively. A moderated level of genetic gain has been observed for Striga adaptive and other economic traits in maize (Table 6).

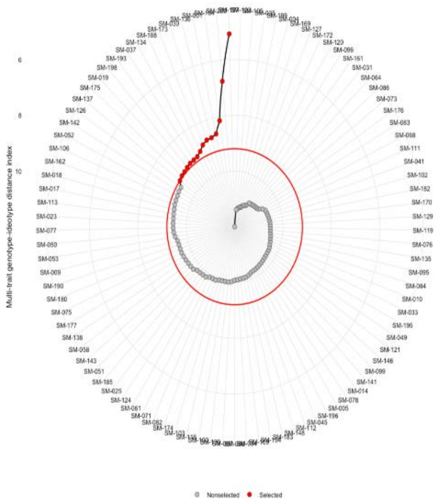

Figure 2. Best high yielding S_1 lines, with lowest Striga damage and Striga emerged plant selected using selection index

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Table 6. Grain yield and other agronomic traits of selected S_1 lines and best used checks under Striga-infested and Striga-free environments in Benin in 2018 and 2019

	Yield (kg/ha)		EPP		DYSK(day)		ASI(day)		EASP(1-5)		PLHT(cm)		STRRAT(1-9)		STRCO		BI
	SI	SF	SI	SF	SI	SF	SI	SF	SI	SF	SI	SF	8WAP	10WAP	SI	SI	
Selected S_1 lines																	
SM_200	3006	3040	0.77	0.86	67	66	2.6	2.9	2.7	2.6	118	126	2.2	3.4	14.5	26.7	11.9
SM_30	2868	3783	0.83	1.03	64	66	4.1	3.5	2.6	3.1	106	137	1.9	3.7	15.9	22.2	10.8
SM_50	2361	2594	0.99	1.00	66	68	3.9	5.1	3.0	3.1	86	100	2.5	3.3	15.5	26.4	7.8
SM_64	2350	2589	0.74	0.70	68	66	2.6	3.2	2.9	2.9	98	107	2.1	3.8	14.2	18.5	7.7
SM_9	2333	2389	0.99	0.77	65	67	2.7	4.2	3.4	3.7	88	98	2.2	4.0	18.5	22.6	7.1
SM_136	2218	2521	0.93	1.00	67	68	2.6	3.0	3.2	2.9	90	97	2.4	3.7	12.9	20.6	7.1
SM_198	2464	2242	0.58	0.63	66	68	4.0	4.1	3.6	2.9	98	109	1.8	4.7	13.4	24.1	6.7
SM_23	2238	2724	1.10	0.91	66	66	3.0	3.8	2.7	2.9	86	104	2.6	3.7	16.1	24.4	6.6
SM_51	2539	3310	0.77	0.72	67	65	4.4	3.3	2.4	4.3	97	112	2.8	4.0	15.6	24.2	6.3
SM_53	2200	2235	1.14	0.77	67	65	2.6	4.4	3.2	2.5	100	114	2.4	3.6	18.5	33.3	5.9
SM_188	1904	2322	0.99	0.73	70	72	3.9	6.0	3.3	3.8	107	114	2.5	3.8	10.2	15.5	5.8
SM_175	2256	2553	1.15	0.73	63	66	2.8	5.1	3.4	3.0	104	114	2.7	4.3	13.2	31.6	5.7
SM_137	2216	2797	0.98	1.12	63	63	1.5	2.7	2.9	2.3	85	103	2.5	4.1	16.5	22.5	5.7
SM_143	1929	2681	0.93	0.93	68	68	4.5	6.0	2.9	3.7	88	105	2.5	3.6	12.8	13.0	5.6
SM_142	2085	1946	1.00	0.71	69	68	5.2	4.6	3.4	3.0	96	122	2.6	4.1	13.0	18.5	5.6
Mean	2331	2648	0.93	0.74	66	67	3.4	4.1	3.0	3.1	97	111	2.4	3.8	15	23	
Inbred (best checks)																	
TZISTR1108	1930	2925	0.69	0.80	67	66	2.4	3.4	2.7	2.9	96	110	3.2	4.6	6	16	4.7
9030 (Tolerant)	1821	2170	1.1	0.95	70	69	3.1	3.2	3.1	3.3	95	103	2.8	4.2	18	32	5.8
9450 (Resistant)	1485	1859	0.44	0.78	70	66	3.0	3.5	3.1	3.3	94	111	2.2	3.5	9	18	2.7
5057 (Susceptible)	334	1482	0.05	0.59	76	71	9.2	4.5	2.8	3.8	72	93	4.7	6.8	29	43	-18.6
Mean	1309	2109	0.57	0.78	71	68	4.4	3.6	2.9	3.3	89	79.25	2.7	4.7	16	27	
Grand Mean	**1563**	**1931**	**0.7**	**0.8**	**69**	**68**	**3.3**	**3.2**	**3.8**	**3.91**	**93**	**104**	**3**	**5**	**16**	**37**	
GG(%)	**1.87**	**0.92**	**0.42**	**0.11**	**-0.11**	**-0.08**	**0.11**	**0.24**	**-0.12**	**-0.33**	**0.05**	**0.21**	**-0.13**	**-0.17**	**-0.24**	**-0.26**	

SI: Striga artificial infestation condition, SF: Striga-free conditions, BI: Base Index, WAP: week after planting, STRAT: Striga damage rate, STRCO: Striga emergence count, PLHT: plant height, EPP: ear per plant, DYSK: days to 50% silking, EASP: ear aspect, and ASI: anthesis silking interval. GG: genetic gain

Discussion

The identification of gene source resistance to *Striga* is a prerequisite to speed up the Striga resistance improvement of elite's maize varieties adopted by farmers. In this study, maize S_1 lines have been screened, assessed association among traits, identified new sources of Striga resistance or tolerance and we discussed the implications of our findings on breeding for Striga resistance in maize. The significant mean squares obtained for environments (E), Genotype (G) and G × E interaction for most of the measured traits, indicated that there is adequate genetic variability for resistance/tolerance to Striga among the S_1 lines. The observed significance among the S_1 lines for the measured traits in the present study have shown the potential for selection of improved grain yield and related traits under Striga-infested conditions. This could be attributed to the differences in the genetic backgrounds of the parental lines. Differential responses of maize genotypes under Striga infestation have been reported by earlier researchers (Badu-Apraku *et al.*,2010c; Akinwale *et al.*,2013). G × E interaction has been significant for grain yield, ears per plant, days to 50% anthesis and days to 50% silking, but was not significant for all remaining traits. Significant G×E variances observed for grain yield indicated that this trait is highly affected by the G×E interaction, which could be attributed to variation in climatic conditions across the two years in each location. These results are similar with the findings of Konaté *et al.* (2017) who reported the lack of significant G×E for Striga damage ratings at 8 and 10 WAP. In previous studies significant G×E have reported for Striga damage ratings at 8 and 10 WAP and grain yield related traits (Makumbi et al.,2015; Kanampiu et al.,2018; Oyekale *et al.*,2021). The difference in the results of this study and those of the previous authors suggests that the environments where the genotypes have been evaluated, and their genetic background might be different.

The results showed the progenies not likely to perform the same as their respective parents. The progenies exhibited high grain yield, as well as reduced Striga damage and emerged Striga plants at 8 WAP, whereas the parental lines showed lower grain yield and increased Striga damage and emerged Striga plants at 8 WAP. Better performance of S_1 lines than their parents may also be the result of transgressive segregation and thus developing maize populations for Striga environments could be effective. Transgressive segregation has been observed in maize populations screened under low N (Ribeiro *et al.*,2018) and Striga infestation (Mbogo *et al.*,2015; Badu-Apraku *et al.*,2020a, b). Previous studies have shown the interests of S_1 selection for improving grain yield and related traits in maize under stress conditions (Kamara *et al.*,2003; Durrishahwar *et al.*,2008; Pecina-Martínez *et al.*,2013; Ayiga-Aluba *et al.*,2015).

Moderated high heritability estimates have been observed indicating the potential for these traits to be improved through recurrent selection.The high heritability estimates for grain yield, days to 50% anthesis, and Striga damage at 8 and 10 WAP suggest that reasonable genetic gain for these traits could be expected from selection. These findings are corroborated to previous reports under artificial Striga infestation (Menkir and Meseka, 2019), but are greater than those reported by Gowda *et al.* (2021) in inbred lines of maize under Striga infestation.

Grain yield displayed significant and positive genetic phenotypic correlations with ears per plant and plant height, but negative with days to 50% anthesis, days to 50% silking, anthesis silking interval, and Striga damage ratings. Positive correlations observed mean that grain yield increases with ears per plant and plant height; which indicates that more leaves photosynthesis and heavier grain yield (Halidu *et al.*,2015). These traits are probably genetically dependent and can be included in the base index for selecting for improved grain yield in maize under Striga infestation and was in agreement with Badu-Apraku *et al.* (2007) for ear aspect as secondary trait. The significant and negative correlations observed between grain yield and Striga damage rates implied that Striga affects physiology and grain yield of infested plants, suggesting that the lower the impact of the Striga damages has been the higher grain yield. This finding occurs with that of Badu-Apraku *et* *al.* (2008, 2020b), in which they reported that the two traits are under same genetic control, and simultaneous improvement for grain yield and Striga damage rating can be obtained easily in the population. Additionally, significant and positive genetic correlations have been observed between grain yield with emerging Striga plants at 8 WAP and 10 WAP, with lack of phenotypic correlations. This result means the number of emerged Striga plants had not affected the physiology and grain yield of infested plants, suggesting that most genotypes had tolerated emergence of Striga plants. Similar findings were reported by Badu-Apraku *et al.* (2020b) and Akanvou *et al.* (1997). In contrast, Gowda *et al.* (2021) have reported significant phenotypic and negative correlation between grain yield and number of emerged Striga plants, which have indicated that increase in number of emerged Striga plants led to severe reduction in grain yield (Menkir *et al.* 2012; Adewale *et al.*,2020). This difference of findings could be attributed to the differences of genetic backgrounds of genotypes used in these studies. The observed positive and significant correlations between number of emerged Striga plants at different times (8 WAP and 10 WAP), as well as Striga damage rates, indicate that these traits can be combined into an index for selection under Striga infestation. In addition, negative and significant genetic correlations observed between number of emerged Striga plants at 10 WAP and Striga damage ratings, as well as phenotypic correlation recorded between emerged Striga plants at 10 WAP and Striga damage rating at 8 WAP, suggesting that the Striga adaptive traits at 10 WAP would be most important, and this time would be ideal for the Striga plants count and Striga damage rating during screening of maize intermediate maturity germplasm under Striga infestation conditions.

Superiority of some S_1 lines under Striga artificial infestation conditions (Table 6) shows that inherent ability for resisting/tolerating the biotic stress existed in them and can be used in maize improvement targeting Striga infested environments. The best S_1 lines identified using the selection index displayed a high average grain yield of 2,331 kg ha^{-1} and 2, 648 kg ha^{-1} under Striga and Striga free conditions, respectively. In comparing to the national maize average grain yield (1,070 kg ha^{-1}) in 2020 growing season (MAEP, 2020), the selected genotypes have shown good performances, resulting genetic gains of 0.98% and 0.61%, under Striga and Striga free-conditions, respectively. These genotypes can be used in maize population improvement for Striga resistance/tolerance.

Conclusion

In this study, the agronomic performance of 200 S_1 lines derived from a bi-parental crossunder has been assessed under *S. hermonthica* artificial infestation and non-infestation conditions. There was significant variability for most traits, especially in yield components and Striga adaptive traits. Moreover, the traits exhibited significant and strong associations have been shown and can be used in indirect selection under Striga infestation. Effective selection for superior genotypes is possible considering ears per plant, days to 50% silking, ear aspect, number of emerged Striga plants and Striga damage at 10 WAP and can be used as target traits to improve grain yield for next generation evaluation under Striga infestation. Fifteen (15) higher performers S_1 lines in resistance/tolerance to Striga have been identified. These should be used as germplasm in developing high yielding varieties targeting Striga and non-Striga environments in Benin. For the purpose of recombination and further population improvement for Striga resistance in the Benin maize breeding programme, the high performing S_1-lines in the present study could be recommended.

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