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Identification of new maize inbred lines with resistance to *Striga hermonthica* (Del.) Benth.

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Abstract: *Striga hermonthica* is a noxious, obligate hemi-parasite of cereal grasses that causes severe grain yield loss in susceptible maize cultivars in Africa. The development of host plant resistance is one of the most practical *Stiga* control strategies. In this study experiments on 36 maize inbred lines were conducted in pots and in field during the two rainy seasons of 2009 at Kibos and Alupe stations in Kenya. This study was carried out in order to determine the variation in *Striga* emergence, and the correlation between the attachments of the parasite to the roots. Significant differences ($P < 0.001$) were detected among the inbred lines for grain yield under *Striga*-free environment. The *Striga* damage rating (SDR) was significant ($P < 0.05$) among the inbred lines. A highly significant and negative correlation coefficient was observed between grain yield and *Striga* damage rating ($r = - 0.67$). Positive correlation coefficients were observed between grain yield and ear aspect ($r = 0.46$) and plant aspect ($r = 0.75$), respectively. For the experiment in pots, highly significant differences ($P < 0.01$) were observed among the inbred lines for *Striga* resistance traits. *Striga* attachments were found to be correlated with the number of emerged *Striga* plants. A significant correlation was found between *Striga* attachments and *Striga* counts in pots at the 10th week after planting (WAP) ($r = 0.25$) and the 14th WAP ($r = 0.31$). Inbred lines JI-30-19 and OSU231//56/44-6-4-17-3 were identified as the most resistant lines as they consistently performed well in both *Striga*-free and *Striga*-infested environments. These inbred lines could be used for breeding *Striga*-resistant maize varieties.

Keywords: maize inbred lines, resistance, *Striga hermonthica*, Kenya

Introduction

Maize (*Zea mays*) is one of the major staple food crops in sub-Saharan Africa. The demand for this cereal in the world is expected to increase to about 504 million tons by 2020, thus surpassing the demand for both wheat and rice (IFPRI, 2000). Among the most serious biotic constraints to maize production in the land holdings of resource-poor farmers is the root hemiparasitic weed *Striga hermonthica*. The parasite decimates maize, pearl millet, sorghum and upland rice in Africa wherever it exists. *Striga* is an obligate parasite which has a deleterious effect on its host as well as robbing it of

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water and nutrients (Amusan *et al*., 2008). This root-attaching parasite affects over 100 million people (Kanampiu and Friesen, 2003; Berner *et al*., 1995)

Grain yield losses in maize from *S. hermonthica* infestation in Africa range from 20 to 80 % (Berner *et al*., 1995), but can sometimes reach 100 % in susceptible maize cultivars under severe field infestation (Ransom *et al*., 1990; Haussmann *et al*., 2000). The development of host plant resistance and tolerance is one of the most feasible and effective *Striga* control strategy, and is a potentially practical option for reducing yield loss from *S. hermonthica* for farmers who lack the financial means to use high-input management practices and other options to control *Striga* in maize fields (Doggett, 1988; Ramaiah *et al*., 1991).

The International Institute for Tropical Agriculture (IITA) has developed artificial field infestation techniques that impart uniform infestation with the parasite and accurately identify cultivars resistant to *S.hermonthica* from diverse germplasms (Kim, 1991). The IITA has also developed many maize inbred lines, hybrids and populations with improved field tolerance and resistance to *Striga* (Kim, 1994; Badu-Apraku *et al*., 2007). Tolerant germplasm supports a number of emerged *Striga* plants which may ultimately flower and set seeds, resulting in an increase in the *Striga* seed bank in the soil. This therefore calls for further screening towards high *Striga* resistance levels, as *Striga*-resistant varieties reduce the seed reproduction of the parasites and contribute to the depletion of the soil seed bank (Haussmann, 2000). To obtain resistant germplasm, a good source of resistance was obtained from elite tropical germplasms as well as from populations obtained from local maize collections in Africa and an accession of *Zea diploperennis* as donor parents (Berner *et al*., 1995). Subsequently resistant inbred lines with high resistance levels were developed through intensive screening of the germplasm in the field.

An ideal maize inbred line with the desired levels of resistance under field conditions should allow the emergence of only a few parasitic plants and show very low parasitism and little loss in grain yield (Kim, 1991; Kim, 1994). Such an inbred line would probably have low levels of *Striga* emergence stimulants, resulting in a low emergence. It is therefore of paramount importance to understand the relationship between the number of emerged *Striga* plants in the field, and the attachment of the germinated *Striga* seeds to host roots. The aim of this study was therefore to identify new maize inbred lines with good levels of *Striga* resistance by screening maize inbred lines from diverse sources (IITA and Kenyan germplasm) under artificial infestation in pots and field trials. The study sought firstly to confirm the efficacy of the IITA-sources of resistance under conditions in eastern Africa, and secondly to explore the possible presence of field resistance in germplasm obtained from Kenyan sources.

Materials and Methods

Field experiment

A total of 36 maize inbred lines from various sources, which included the Kenya Agricultural Research Institute (KARI), International Maize and Wheat Improvement Center (CIMMYT) and International Institute for Tropical Agriculture (IITA) (Table 1), were used in this study. The inbred lines were first planted at Kiboko site ($37^0$75’E, 2^0 15’S) in a seed increase nursery for adaptation during short rainy season of 2008. The inbred lines were evaluated on-station at Kibos (0^o4'S, 34^o48'E) and Alupe (0^o29'N, 34^o 2'E) under both artificial *Striga* infestation and in *Striga*-free environments during the long rainy season and the short rainy season of 2009. Artificial infestation was conducted in a specially developed field facility in order to screen large numbers of breeding lines. Plants were artificially infested with *S. hermonthica* seeds. *Striga* seeds were added to each plot to ensure that each maize plant was exposed to a minimum of 2,000 viable *Striga* seeds. These seeds were added in a sand/seed mixture and placed in an enlarged planting hole at a depth of 7–10 cm directly below the maize seed.

Table 1 Maize inbred lines tested under both *Striga*-free and *Striga*-infested conditions.

Entry	Genotype	Source	Entry	Genotype	Source
1	OSU231//56/44-6-4-17-3	KARI	19	JI-30-17	KARI (MUGUGA)
2	TESTR 152	IITA	20	TESTR 139	IITA
3	JI-30-19	KARI (MUGUGA)	21	CML444-IR	CIMMYT
4	JI-30-1-19	KARI (MUGUGA)	22	DT//56/4-6-1-15-2	KARI (MUGUGA)
5	F1-14-14-24-4-5-4	KARI (MUGUGA)	23	CML395	CIMMYT
6	CML444	CIMMYT	24	JI-30-21	KARI (MUGUGA)
7	F1-14-79-4-1-3	KARI (MUGUGA)	25	JI-30-7	KARI (MUGUGA)
8	TESTR 153	IITA	26	JI-30-8	KARI (MUGUGA)
9	JI-30--4	KARI (MUGUGA)	27	TESTR 149	IITA
10	JI-30-18	KARI (MUGUGA)	28	TESTR 132	IITA
11	JI-30--3	KARI (MUGUGA)	29	CML202IR	CIMMYT
12	TESTR 156	IITA	30	MGA19-4-1	KARI (MUGUGA)
13	CML204-IR	CIMMYT	31	TESTR 136	IITA
14	EARLY-N-POP-7-13-5-1	KARI (MUGUGA)	32	TESTR 151	IITA
15	JI-30-22	KARI (MUGUGA)	33	E11-133/7/44-6-3-17-3-2	KARI (MUGUGA)
16	TESTR 150	IITA	34	TESTR 133	IITA
17	JI-30-16	KARI (MUGUGA)	35	CML206//56/44-6-3-7-1	KARI (MUGUGA)
18	JI-30-7	KARI (MUGUGA)	36	CML395-IR	CIMMYT

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The genotypes were planted in 5m single row plots, with a spacing of 75cm between rows and 25 cm between hills with two seeds per hill, and later thinned to one plant per hill to give a population of approximately 53,333 plants per hectare. The experimental design used was an alpha lattice (0, 1) design with 2 replicates. Di-ammonium phosphate (18-46-0) was applied during planting at 50 and 128 kg N and P_2O5/ha, and top dressing was done using calcium ammonium nitrate (CAN) at 50 kg N/ha. Normal crop husbandry was carried out; weeding was done three weeks after planting and thereafter hand pulling was done only to remove other types of weed other than *Striga*.

Data were recorded from each plot on agronomic traits which included: grain yield, days to 50 % anthesis, days to 50 % silking, anthesis silking interval (calculated as the difference between days to 50 % anthesis and days to 50 % silking), plant height and ear height. Reaction to two major diseases gray leaf spot caused by *Cercospora zeae-maydis* and Northern leaf blight caused by *Exserohilum turcicum* was recorded using a scale of 1-5, where 1 = no disease and 5 = severely diseased. The *Striga* damage rating was recorded using a scale of 1 - 9 (where 1 - 3 = no damage, 4 - 6 = extensive leaf blotching, wilting and some stunting, and 7 - 9 = complete scorching). The *Striga* count data was recorded by counting the number of *Striga* plants emerged per plot starting at 8 weeks and then after every two weeks up to 14 weeks after planting (WAP).

Pot experiment

The 36 maize inbred lines were planted in pots 20cm in diameter and 30cm in height. The pots were filled with sandy soils up to 25cm from the bottom. The *Striga* inoculum was applied in each pot using a tablespoonful to ensure about 2000 viable *Striga* seeds per pot. An enlarged hole was made in the sand in each pot and the maize seeds were placed directly on top of the inoculum. Four maize seeds were sown in each pot and later thinned to two to ensure a uniform stand. The data recorded included *Striga* counts at 10, 12 and 14 WAP, flowering *Striga* plants at 12, 14 and 15 WAP and *Striga* plants setting seeds at 12, 14 and 15 WAP. *Striga* attachment was recorded after washing the maize roots of each plant and later counting individual attachments.

Statistical analysis

Striga count per square meter was calculated and the data transformed using $log_{10}(X + 1)$, where X = count per meter squared. An adjustment of grain yield to 15 % moisture content was done after harvesting. The data were then subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) procedure of SAS (SAS, 2003) for individual locations and across locations. Means were separated using Duncan's Multiple Range Test at $p < 0.05$. Least significant differences (LSD 0.05) values based on analysis of variance were also calculated to allow pair-wise multiple comparisons among means.

Results

Field experiments

Striga-free environment

Grain yield was highly significant ($P < 0.001$) among the inbred lines evaluated. The mean grain yield was 1.4 t/ha and the range was 0.1 to 4.3 t/ha. Inbred line OSU231//56/44-6-4-17-3 gave the highest grain yield while CML395-IR gave the lowest yield. Among the top 10 inbred lines in terms of grain yield, seven were from KARI, one was from CIMMYT and two were from IITA (Table 2). Highly significant ($P < 0.01$) differences were observed in days to 50 % anthesis, days to 50 % silking, plant aspect, plant height and ear height.

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Table 2 Performance of selected maize inbred lines under *Striga*-free conditions across sites.

Genotypes	Grain yield (t/ha)	Days to 50 % anthesis (days)	Days to 50 % silking (days)	Plant height (cm)	Ear height (cm)	*E. turcicum* (score 1-5)	Plant aspect (score 1-5)
OSU231//56/44-6-4-17-3	4.3	64.3	70	200	102.5	2.4	3.5
TESTR 152	4.1	70.0	76	145	80.0	2.5	3.8
JI-30-19	4.0	65.8	74	184	101.3	2.4	4.0
JI-30-20	3.9	68.5	77	199	102.5	2.5	3.5
F1-14-14-24-4-5-4	2.4	68.0	75	190	102.5	2.1	3.3
CML444	2.3	74.3	81	135	77.5	2.5	2.8
F1-14-79-4-1-3	2.2	67.3	72	195	113.8	2.6	3.5
TESTR 153	1.9	68.5	71	169	93.8	3.0	3.3
JI-30--4	1.6	69.3	73	111	73.8	2.3	2.5
JI-30-18	1.5	78.3	81	146	87.5	2.0	2.8
JI-30--3	1.5	75.8	81	136	75.0	2.4	3.0
TESTR 156	1.4	71.5	77	146	72.5	2.4	2.5
CML204IR	1.4	77.8	86	134	83.8	2.4	3.5
EARLY-N-POP-7-13-5-1	1.4	74.8	84	133	83.8	2.5	2.8
JI-30-22	1.3	75.8	81	138	87.5	2.1	3.8
TESTR 151	0.4	80.0	82	165	87.5	3.1	2.5
E11-133/7/44-6-3-17-3-2	0.2	73.5	87	159	92.5	2.0	2.0
CML206//56/44-6-3-7-1	0.1	75.0	85	150	90.0	2.1	2.5
CML395-IR	0.1	88.8	92	87	62.5	2.3	2.0
TESTR 133	0.1	73.3	80	93	60.0	3.0	2.3
Mean	1.4	73.8	79.6	140.3	80.9	2.6	2.6
CV (%)	30.5	7.7	8.9	25.5	22.6	16.3	20.9
LSD(0.05)	1.94	8.10	11.13	50.19	25.61	0.58	1.12
Significance(GxE)	***	***	***	***	***	***	***

*, **and *** indicate differences that are significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

Stem lodging and ear aspect were significant at P < 0.05. Reaction to *E. turcicum* was highly significant (P < 0.001) among the inbred lines. The worst affected inbred lines were TESTR 133, TESTR 136, TESTR 151, TESTR 153, TESTR 150 and TESTR 132. These materials have not been screened for *E. turcicum* blight disease and had *E. turcicum* scores of 3 to 4. However, inbred lines TESTR 149, TESTR 139, TESTR 152 and TESTR 156 gave a score of less than 3. Most of the inbred lines with good *E. turcicum* scores were the KARI-Muguga lines (Table 2).

Striga-infested environment

Significant differences among the inbred lines were observed (P < 0.05) for grain yield (Table 3). The mean grain yield was 2.1 t/ha and the range was 0.2 to 2.9 t/ha. Inbred lines JI-30-19, OSU231//56/44-6-4-17-3, F1-14-14-24-4-5-4, JI-30-18 and TESTR 156 were the top five best performers. They gave desirable grain yields of between 1.9 and 2.9 t/ha under artificial *Striga* infestation. Inbred line JI-30-20 gave the lowest yield (0.2 t/ha). Highly significant differences (P < 0.001) were observed for days to 50 % anthesis (AD) and days to 50 % silking (SD). The mean for AD was 68.4 days and with 65 to 86.8 days, while the mean SD was 71.2 days and the range was from 69.5 to 72.8 days. Reaction to *E.turcicum* differed significantly among the inbred lines, similarly to what was observed under *Striga*-free conditions in the present study (Table 3). Thus *Striga* infestation does not appear to interfere with the manifestation of resistance or susceptibility to *E. turcicum*.

Significant genetic (P < 0.05) variations were observed in reaction to *Striga* infection among the maize inbred lines. A mean of 5.1 for *Striga* damage rating (SDR) was observed, and the range was from 2.5 to 6.5 in a scale of 1 to 9. Inbred lines with desirable SDR scores were identified as JI-30-18, CML 202IR, JI-30-19, JI-30-20, JI-30-22, TESTR 150, JI-30-21 and JI-30-16. These inbred lines had a score of between 2.5 to 4, which is considered resistant on a scale of 1 to 9 (Kim, 1994). Inbred line OSU231//56/44-6-4-17-3 had a score of 6 although it was among the top five best in terms of grain yield. This particular inbred line could be considered tolerant as the effect of *Striga* on grain yield performance was minimal.

Table 3 Performance of selected maize inbred lines under artificial field *Striga* infestation across sites.

Genotypes	**Grain yield (t/ha)**	**Days to 50% anthesis (days)**	**Days to 50 % silking (days)**	***E. turcicum* (score 1-5)**	***Striga* damage rating (score 1-9)**	***Striga* count 8 WAP (m^2)**	***Striga* count 10 WAP (m^2)**	***Striga* count 12 WAP (m^2)**
JI-30-19	2.9	75.8	79.2	2.3	3.5	4.5	13.9	11.8
OSU231//56/44-6-4-17-3	2.4	65.0	72.7	3.0	6.0	10.7	27.9	46.7
F1-14-14-24-4-5-4	2.2	68.5	71.7	3.5	5.3	7.4	22.9	32.3
TESTR 156	1.9	73.8	80.7	3.5	5.3	3.6	5.6	9.4
JI-30-18	1.9	77.5	80.0	1.8	2.5	3.0	8.3	12.6
EARLY-N-POP-7-13-5-1	1.7	80.5	81.6	1.8	4.3	1.4	11.3	19.3
F1-14-79-4-1-3	1.7	75.5	76.2	3.5	4.5	10.9	16.4	24.1
JI-30—4	1.6	68.0	79.5	3.3	4.3	6.9	16.8	29.0
JI-30—3	1.6	78.0	79.9	2.5	4.8	3.1	9.7	15.1
CML206//56/44-6-3-7-1	1.6	76.5	78.3	1.8	4.8	2.1	11.2	21.1
TESTR 153	1.5	73.5	73.6	3.8	4.8	6.4	14.3	24.1
CML395-IR	1.2	74.6	82.3	3.0	4.3	2.2	7.8	19.8
CML202IR	1.2	75.0	79.7	2.8	3.3	2.3	9.2	14.4
JI-30-8	1.1	77.5	83.7	2.0	4.5	1.6	8.5	13.5
JI-30-16	1.1	78.3	80.5	2.0	4.0	3.9	11.3	27.4
TESTR 133	0.7	68.5	70.2	3.8	6.0	4.4	9.4	14.3
TESTR 152	0.7	85.2	90.9	2.5	5.8	4.0	9.6	11.0
CML444-IR	0.5	75.5	84.2	3.0	5.5	2.3	13.7	21.2
TESTR 132	0.4	75.5	77.8	4.0	5.0	7.1	8.6	10.0
JI-30-20	0.2	73.3	76.5	3.8	4.0	11.1	18.8	25.5
MEAN	1.2	73.8	77.5	2.8	4.5	5.9	15.2	22.3
CV (%)	27.4	8.7	9.1	24.7	30.4	23.5	24.8	29.9
LSD (0.05)	1.36	9.25	11.86	1.44	2.02	7.24	14.87	19.47
Significance (GxE)	*	***	***	**	*	**	*	**

*, **and *** indicate differences that are significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

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Data on *Striga* counts was highly significant ($P < 0.001$) 12 weeks after planting (WAP). Genetic variations among the inbred lines were observed in *Striga* counts at the 8, 10 and 12th WAP. The mean *Striga* count at 12 WAP was 22.3 *Striga* plants per m^2, and the range was from 2.9 to 46.7 *Striga* plants per m^2 (Table 3). Inbred lines TESTR 139, TESTR 151, TESTR 152, TESTR 132, TESTR 150, TESTR 136, TESTR 156, TESTR 149, JI-30-21 and JI-30-19 gave the least number of *Striga* plants per m^2.

Further assessment on the resistance of the maize inbred lines was done by examining the relationship between the yield performance and the *Striga* resistance traits. This was investigated through use of a simple linear correlation coefficient in a combined analysis for the two sites. A highly significant ($P < 0.001$) and negative correlation was observed between grain yield and SDR (r = -0.67***). A positive but not significant correlation coefficient between grain yield and *Striga* counts was observed (Table 4). A positive and significant correlation coefficient was observed between ears per plant (EPP) and grain yield (r = 0.39** and days to 50 % anthesis (r = 0.33**) while a negative and significant correlation between EPP and anthesis silking interval (ASI) (r = -41**) was observed. *Striga* counts at 8 WAP was highly correlated to *Striga* counts at 10 WAP (r = 0.81***) and the 12WAP (r = 0.77***) (Table 4).

Table 4 Correlation between grain yield, agronomic traits, and *Striga* resistance traits under *Striga*-infested conditions across sites.

Traits	YLD	AD	SD	ASI	PH	EH	EPP	GLS	RUST	TURC	EA	PA	SDR	STR8	STR10
YLD	1.00														
AD	-0.23														
SD	-0.38*	0.76***													
ASI	-0.13	-0.12	0.37*												
PH	0.35	-0.40**	-0.38**	-0.15											
EH	0.58***	-0.40**	-0.47***	-0.32*	0.43**										
EPP	0.39**	0.33**	-0.03	-0.41**	-0.10	0.20	1.00								
GLS	0.34**	-0.09	-0.08	-0.14	0.06	0.39**	0.14	1.00							
RUST	0.14	-0.16	-0.15	-0.25	0.03	0.29	0.26	0.33**	1.00						
TURC	-0.26	-0.47	-0.20	0.17	0.22	0.01	-0.57***	0.17	0.12						
EA	0.46***	0.11	0.21	0.18	-0.08	-0.30	-0.44	-0.32*	-0.25	0.28	1.00				
PA	0.75***	-0.36**	-0.57***	-0.10	0.33*	0.59***	0.31	0.22	0.11	-0.07	-0.20				
SDR	-0.67***	-0.16	-0.06	0.25	-0.05	-0.49***	-0.24	-0.24	-0.16	0.28	0.16	-0.28	1.00		
STR8	0.17	0.04	0.19	0.37*	0.11	0.12	-0.17	-0.11	-0.15	0.04	0.18	0.01	0.22	1.00	
STR10	0.27	-0.13	-0.04	0.27	0.24	0.23	-0.17	-0.11	-0.14	-0.01	0.21	0.13	0.15	0.81***	1.00
STR12	0.21	-0.15	-0.01	0.35*	0.15	0.18	-0.17	-0.21	-0.24	-0.08	0.22	0.12	0.15	0.77***	0.95***

*, ** and *** indicate differences that are significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.
Yld = Grain yield, AD = days to 50 % anthesis, SD = days to 50 % silking, ASI = anthesis silking interval, PH = Plant height, EH = ear height, GLS = Gray leaf spot, *Turc* = *E.turcicum*, SDR = *Striga* damage rating, STR8 = *Striga* counts 8WAP, STR10 = *Striga* counts 10WAP and STR12 = *Striga* counts 12 WAP

The *Striga* count at 10WAP was positively and highly correlated to *Striga* count at 12 WAP (r = 0.95***). Grain yield was also found to be positively correlated to ear aspect (r = 0.46***) and plant aspect (r = 0.75***). It was clear that for the more resistant genotypes, *Striga* counts peaked at week 12 and declined towards the 14th week. Therefore the assessment of resistance at 12 WAP should be considered adequate. It is noted that the decline of *Striga* plants from 12 WAP could be attributed to plants dying after the host has succumbed to infestation at the maximum level and probably dying of host maize roots.

Pot experiment

Highly significant differences were observed among the inbred lines in *Striga* counts at 10 WAP (Table 5), but not at 12 WAP. However at 14WAP the number of *Striga* plants which emerged was highly significant (P < 0.01). Flowering *Striga* plants per pot was not significant at the 12 and 14 WAP, but it was highly significant at the 15 WAP. The number of *Striga* plants setting seeds per pot was not significant at 12 WAP, although significant differences were exhibited (P < 0.05) at 14 and 15 WAP. The number of *Striga* attachments observed was not significant. The mean number of *Striga* attachments per pot was 20.71 and the range was from 0 to 74.5 *Striga* attachments per pot (Table 5). These observations were similar to those observed in the field.

A simple linear correlation between the *Striga* resistance traits was computed. *Striga* attachments were found to be significantly correlated to *Striga* counts at 10 WAP (r = 0.25**) and the 14 WAP (r = 0.31*) (Table 6). The number of *Striga* plants setting seeds at 15 WAP was also significantly correlated to the number of attachments per pot.

Table 5 *Striga* resistance traits in a pot experiment under artificial *Striga* infestation across seasons.

Genotypes	***Striga* count 10 WAP /m^2**	***Striga* count 12 WAP /m^2**	***Striga* count 14 WAP /m^2**	**Flowering *Striga* plants 14 WAP /m^2**	**Flowering *Striga* plants 15 WAP /m^2**	***Striga* plants setting seeds 14 WAP /m^2**	***Striga* plants setting seeds 15 WAP /m^2**	***Striga* attachments**
CML202IR	0.00	0.00	-0.04	0.00	0.00	0.00	0.00	0.50
CML204IR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CML395-IR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50
CML444-IR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50
TESTR 151	1.05	1.05	1.30	0.15	0.15	0.15	0.15	28.00
TESTR 149	2.50	3.05	2.60	0.00	0.00	0.00	0.00	29.50
TESTR 150	2.80	2.95	2.70	0.35	0.35	0.00	0.15	7.50
CML444	2.55	2.85	2.75	0.40	0.50	0.30	0.40	32.50
MGA19-4-1	3.15	3.05	2.75	0.30	0.30	0.00	0.25	73.50
TESTR 139	2.50	2.80	2.85	0.00	0.00	0.15	0.30	25.00
TESTR 132	4.70	510.90	2.90	185.50	0.00	0.00	0.15	5.50
JI-30—3	2.50	2.70	2.90	0.15	0.15	0.00	0.00	19.50
JI-30-19	2.75	3.05	2.90	0.00	0.15	0.30	0.40	22.50
CML395	1.75	1.75	2.95	0.50	0.55	0.40	0.45	4.00
JI-30-19	3.35	3.30	2.95	0.15	0.15	0.30	0.30	9.50
F1-14-79-4-1-3	3.20	3.30	3.35	0.55	0.65	0.15	0.50	74.50
JI-30-7	2.65	3.10	3.40	0.00	0.00	0.15	0.30	44.00
JI-30-17	3.25	3.45	3.45	0.40	0.45	0.15	0.55	23.00
JI-30—4	3.45	3.50	3.55	0.45	0.65	0.15	0.50	14.50
JI-30-8	3.70	3.70	3.60	0.65	0.90	0.00	0.15	14.50
Mean	2.29	27.73	2.34	9.48	0.25	0.11	0.23	21.55
CV (%)	29.84	30.10	14.54	29.20	27.50	20.30	24.70	19.80
LSD (0.05)	1.61	243.20	0.83	88.70	0.49	0.28	0.45	59.87
Significance	***	NS	***	NS	**	*	*	NS

*, **, *** and NS indicate differences that are significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively.

Table 6 Correlation between *Striga* resistance traits in a pot experiment.

Traits	1	2	3	4	5	6	7	8	9
1. *Striga* count 10 WAP									
2. *Striga* count 12 WAP	0.33*								
3. *Striga* count 14 WAP	0.92***	0.04							
4. Flowering *Striga* plants 12WAP	0.34*	0.99***	0.06						
5. Flowering *Striga* plants 14WAP	0.32*	0.10***	0.03	0.99***					
6. Flowering *Striga* plants 15WAP	0.50***	-0.21	0.57***	-0.17	-0.21				
7. *Striga* setting seeds 12 WAP	0.33*	0.99***	0.03	0.99***	0.99***	-0.23			
8. *Striga* setting seeds 14 WAP	0.15	-0.14	0.25	-0.10	-0.14	0.36**	-0.10		
9. *Striga* setting seeds 15 WAP	0.41**	-0.07	0.47***	-0.06	-0.07	0.53***	-0.07	0.73***	
10. *Striga* attachments	0.25**	-0.13	0.31*	-0.15	-0.13	0.20	-0.14	0.12	0.31*

Discussion

A broad range of genetic variation in *Striga* resistance traits was exhibited in this study particularly in the number of *Striga* plants emerged and the number of *Striga* plants attached. Similar results were reported by Amusan *et al*., (2008). Under *Striga* infested conditions, the days to 50 % flowering for the most susceptible inbred lines was delayed by about 5 days and some maize inbred lines did not reach days to 50 % silking. Cases of delayed flowering while testing several maize cultivars under different nitrogen levels were also reported by Kim *et al*., (1997). Our results also agree with these results in which some inbred lines never silked leading to reduction in yield due to lack of fertilization. The delay in flowering is a common observation in maize subjected to stresses other than *Striga*, for example drought stress.

The ear aspect of the tolerant and resistant inbred lines was significantly superior compared to that of the susceptible inbred lines. The usefulness of the ear aspect in the assessment of host plant response to *Striga* infection was also reported by other workers (Kim *et al*., 1997). The inbred line JI-30-19 exhibited the best ear aspect and also gave the highest grain yield. The number of ears harvested from the maize inbred lines tested in this study proved to be a major component of grain yield under *Striga* infestation as was previously reported by Kim, (1991).

Most of the inbred lines with field resistance to *Striga* had significantly fewer attached parasites as opposed to the susceptible inbred lines. These results were consistent with previous observations reported in maize (Kim, 1999; Amusan *et al*., 2008). *Striga* emergence in some moderately susceptible inbred lines was found to be similar to *Striga* emergence in some resistant and tolerant lines, as was observed in inbred lines tested in the field (Table 4). Previous results from several studies have shown that *Striga* emergence counts from tolerant maize cultivars and from moderately susceptible cultivars were not significantly different. This discredits the use of *Striga* emergence counts as the only criterion to distinguish genetic control of *Striga* tolerance in maize (Kim, 1994; Kim and Adetimirin, 1997). This is probably because resistance may often be confounded by tolerance existing in the same germplasm.

A significant and negative correlation has been shown between grain yield and *Striga* damage rating (SDR) (Kim and Adetimirin, 1997; Amusan *et al*., 2008). Similar observations were made in the present study where a significant ($P < 0.001$) and negative correlation was recorded between grain yield and SDR ($r = - 0.67$***). However there was no significant correlation between grain yield and *Striga* counts as would have been expected.

In the present study, the observed significant and positive correlation between the attached and emerged *Striga* plants with the *Striga* damage rating and reduction in grain yield of the maize plants indicated that the possibility exists of selecting maize inbred lines with low SDR scores and *Striga* emergence, and with higher grain yields under *Striga* infection.

As was found in this study, the number of *Striga* attachments has similarly been shown in the past to correlate with the number of emerged parasites in the pots (Kim, 1999; Amusan *et al*., 2008). Several previous studies have revealed a strong correlation between attached *Striga* plants in pots and the number of emerged parasites in both pots and field. In the present study inbred lines TESTR 139, TESTR 151, TESTR 152, TESTR 132, TESTR 150, TESTR 136, TESTR 156, TESTR 149, JI-30-21 and JI-30-19 had significantly fewer emerged *Striga* plants compared to the susceptible lines. These results suggest the possibility of selection for field resistance to *Striga* by using both attached *Striga* and emerging *Striga* either in the pot or in the field.

Striga-resistant maize inbred lines were identified from among the diverse range of inbred lines tested. The maize inbred lines with fewer emerged *Striga* plants and low SDR scores were considered as the resistant lines, which confirm many previous studies in maize research. The IITA inbred lines were confirmed as having resistance since most of them supported very few emerged *Striga* plants. However the use of *Striga* counts as a criterion in selection for *Striga* resistance was found not to be the most appropriate. On many occasions a small number of emerged *Striga* plants caused heavy *Striga* damage in some of the inbred lines tested. A significant and negative correlation between grain yield and *Striga* damage rating was observed. The number of emerged *Striga* plants was found to be highly correlated to the number of *Striga* attachments on the maize roots. Through the use of the observed significant and positive correlation of the attached and emerged *Striga* plants with the *Striga* damage rating and reduction in grain yield of the maize plants, it is therefore possible to select maize inbred lines with low SDR scores and *Striga* emergence, and with higher yields under *Striga* infection.

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شناسایی رگه‌های خویش آمیخته ذرت مقاوم به علف هرز *Striga hermonthica*

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چکیده: علف جادوگر (*Striga hermonthica*) یک علف هرز نیمه انگلی اجباری و خطرناک در غلات است که خسارت سنگینی به ارقام حساس ذرت در آفریقا وارد می‌کند. ایجاد مقاومت در گیاهان یکی از کاربردی‌ترین روش‌های کنترل علف هرز *Striga* می‌باشد. در این تحقیق آزمایش‌ها روی ۳۶ رگه خویش آمیخته ذرت در داخل گلدان و مزرعه در طی دو فصل زراعی پر باران در سال ۲۰۰۹ در ایستگاه‌های تحقیقاتی Kibos و Alupe کنیا انجام شد. هدف اصلی تحقیق تعیین نوسانات جوانه‌زنی علف جادوگر و رابطه آن با میزان انگلی شدن ریشه‌های ذرت بود. اختلاف معنی‌دار (P<۰/۰۰۱) بین رگه‌های خویش آمیخته ذرت از نظر میزان تولید در شرایط عاری از علف هرز *Striga* وجود داشت. میزان خسارت علف جادوگر (SDR) در ارقام مختلف ذرت دارای تفاوت معنی‌دار (P < ۰/۰۵) بود. ارتباط منفی و کاملاً معنی‌داری بین میزان محصول و نرخ خسارت ناشی از علف هرز جادوگر مشاهده شد (r = -۰/۶۷). همچنین ارتباط مثبت و معنی‌داری بین میزان عملکرد دانه و اندازه بلال (r = ۰/۴۶) و وضعیت گیاه (r = ۰/۷۵) وجود داشت. در آزمایش‌های گلدانی تفاوت بسیار معنی‌داری (P <۰/۰۱) بین لاین‌های خویش آمیخته ذرت از نظر مقاومت به علف جادوگر مشاهده شد. میزان انگلی شدن ریشه ذرت با علف جادوگر با تعداد گیاهچه‌های سبز شده ارتباط معنی‌داری داشت همبستگی معنی‌داری بین تعداد مکینه‌های علف جادوگر و تعداد گیاهچه‌های سبز شده در هفته دهم (r = ۰/۲۵) و چهاردهم (r = ۰/۳۱) بعد از کشت ذرت در گلدان مشاهده شد. رگه‌های خویش آمیخته JI-C-19 و OSU231//56/44-6-4-17-3 به‌عنوان مقاوم‌ترین رگه‌ها (لاین‌ها) نسبت به علف هرز جادوگر بودند زیرا در شرایط بدون علف هرز و همچنین در حضور علف جادوگر عملکرد مشابه و قابل قبولی داشتند. این رگه‌های خویش آمیخته ذرت را می‌توان برای تهیه واریته‌های ذرت مقاوم به علف جادوگر مورد استفاده قرار داد.

واژگان کلیدی: رگه‌های خویش آمیخته، ذرت، علف هرز جادوگر، کنیا

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