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Screening for resistance to *Striga gesnerioides* and estimation of yield loss among Cowpea (*Vigna unguiculata* (L.) Walp.) progenies in the Upper East Region of Ghana

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Parasitic weed *Striga gesnerioides* (Willd.) is one of the major constraints of cowpea production. Host-plant resistance seems to be efficient and economical in controlling the pest. The objectives of this study were to evaluate recombinant inbred lines developed between IT97K 499-35 (*Striga* resistant parent,) and Sanzi (*susceptible* parent), by Single Seed Descent (SSD), for *Striga* resistance in Northern Ghana. The study also evaluated the promising *Striga gesnerioides* resistant lines and susceptible checks for yield loss due to *Striga* infestation. The studies involved a field and pot screening under artificial inoculation. Twenty-seven (27) recombinant inbred lines (RILs) out of the 251 RILs screened were resistant to *Striga gesnerioides*. The percentage reduction in the grain yield and dry biomass were lower in the resistant RILs (0.55 to 3.08% and 1.11 to 7.7%, respectively) than the susceptible ones (28.45 to 58.88% and 47.29 to 61.71%, respectively). The negative effect of *Striga* infestation on cowpea grain yield and dry biomass can then be reduced when resistant genotypes are used.

Key words: Cowpea, *Striga gesnerioides,* recombinant inbred lines, yield loss.

INTRODUCTION

Cowpea *Vigna unguiculata* (L.) Walp.) is an important crop in the semi-arid tropics including parts of Asia, Africa, Southern Europe, Southern United States, Central and South America (Singh, 2005; Timko et al., 2007a). It

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is an affordable source of quality protein for rural and urban dwellers in Africa (Ajeigbe et al., 2012; Dube and Fanadzo, 2013). The dry grain protein concentration oscillates from 21 to 33% (Abudulai et al., 2016). It is well adapted to hectic environments where several crops fail to grow well (Bisikwa et al., 2014; Ddamulira et al., 2015). According to FAO, cowpea was cultivated on about 12.08 million hectare in Africa in 2016 with a total production of 5.83 million hectare in West Africa, predominantly in Nigeria, Niger, Burkina Faso, Mali and Senegal (FAOSTAT, 2018). Currently, cowpea yields are estimated around 300 to 500 kg ha^{-1} on farmer's field in Sub Saharan Africa (SSA) while its yield potential is up to 3000 kg ha^{-1} in optimum growing conditions (Tanzubil et al., 2008).

Cowpea production is mostly affected by major constraints. Parasitic plants are a major constraint to today's agriculture with most crop species being potential hosts (Westwood et al., 2010). *Striga gesnerioides*, is a key threat to cowpea production throughout West and Central Africa (Omoigui et al., 2017). It is one of the greatest devastating parasitic weed in most parts of the world. It is an obligate root parasitic flowering weed that belongs to the Orobanchaceae family (Parker, 2012). Out of about 30 *Striga* species which have been identified, *Striga gesnerioides* is the only *Striga* species that is virulent to dicots (Mohamed and Musselman, 2008). *Striga gesnerioides* is a major limitation to cowpea production in Africa (Timko et al., 2007b), causing considerable yield losses (Aggarwal and Ouédraogo, 1989). The extent of the damage in cowpea due to *S. gesnerioides* could be up to 70% depending on the extent of damage and level of infestation (Alonge et al., 2004). On susceptible cultivars, yield losses can reach up to 100% when *S. gesnerioides* population is over 10 emerged shoots per plant (Kamara et al., 2008). Omoigui et al. (2009) reported that yield losses caused by *Striga* in dry savannah of SSA are estimated in millions of tons annually and the prevalence of *Striga* infested soils is steadily increasing. Methods including improved cultural practices and the use of chemicals to control *S. gesnerioides* are available but most of them are ineffective whilst others are not affordable for small-scale farmers of Sub Saharan Africa (Singh et al., 1997; Timko et al., 2007b). The long viability of the seeds and the subterranean nature of the initial stages of parasitism make the control of the parasite by conventional approaches challenging (Berhane, 2016). In general, *S. gesnerioides* control is difficult to achieve due to the close association with its host (Lane et al., 1997). The identification of sources of *S. gesnerioides* resistance and their incorporation into breeding schemes would be a useful approach to combat the damage caused by the parasite in cowpea fields (Omoigui et al., 2017).

The objective of this study was to evaluate the field performance of 251 recombinant inbred lines (RILs) under *S. gesnerioides* infestation in Northern Ghana and to assess yield loss due to *Striga* infestation.

MATERIALS AND METHODS

The experiments were conducted from July 2015 to April 2016 at the Manga Station of Council for Scientific and Industrial Research-Savannah Agricultural Research Institute (CSIR-SARI). Manga near Bawku in the Upper East Region is geographically located within latitude 11.02° and longitude 0.27°, with an altitude of 224 m above sea level. The area is situated in the Sudan Savanna agro-ecological zone of Ghana. The mean rainfall of the area during the period of the experiment was approximately 44.33 mm. The average annual temperature was about 29.44°C, the highest being observed from March to April 2016. The relative humidity (RH) of the location fluctuated significantly, dropping in the dry season and rising during the rainy season with an average humidity of 55.4%. The study was conducted in two stages. The first stage was carried out in the field and the second stage in pots experiment.

Planting materials

Two hundred and fifty one recombinants inbred lines (RILs) at F_8 generation (F_8) (Table 1) derived from a cross between two cowpea lines, 'Sanzi' (susceptible to *Striga*) and 'IT97K-499-35' (resistant to *Striga*) (Omoigui et al., 2009), were used in the study.

Field experiment

The field study was carried out under rain fed conditions (between July and September) and under irrigation during the dry season. In a preliminary screening, each of the RILs and the parents (Sanzi and IT97K-499-35) were planted in a 2-meter single row plot without any replication on a field known to be a *Striga* hot spot. During this preliminary screening, data collected included days to 50% flowering, presence or absence of *Striga* plants, number of *Striga* per plants, total number of *Striga* per plot and *Striga* height. The presence or absence of *Striga* was recorded by visual observation on the different plots from thirty five (35) days after planting (DAP) up to maturity.

Pot experiment

Pot experiment was carried out to confirm the resistance or otherwise of the sixty-nine (69) the RILs that were identified as *Striga* resistant in the field experiment (Table 2). The pots were filled with top soil and then artificially infested with 5 g of *Striga* seeds. The top most, (1/3) portion of the soil per pot was mixed with the 5 g of *Striga* seeds. The infested pots were watered and allowed to condition before planting of the cowpea seeds. The pots were arranged in a randomized complete block designs with three replications. Thirty five days after planting (DAP), the pots were monitored on daily basis to check for *Striga* emergence. At maturity, the early pods were harvested on single plant basis to get some seeds from each plant. This was followed by gently washing the soil off the roots of the plants to confirm or otherwise that there were no *Striga* attachment to the roots of those that did not record *Striga* emergence.

Yield loss assessment due to *Striga* infestation

Twelve RIL's were selected based on their good agronomic traits on the field (white seed coat, big size and early maturity). The 12

Table 1. List of recombinant inbred lines (RILs) used in field experiment.

Genotype				
3	97	181	244	12B
9	98	182	245	12C
11	100	183	249	130A
14	106	184	252	131B
15	108	186	255	134B
21	110	187	257	141A
23	113	188	260	141B
25	119	190	261	144A
28	121	191	262	144B
29	124	195	263	150A2
35	125	199	265	150B
37	126	200	266	154 A
44	128	202	268	155A1
45	129	205	270	155A2
46	135	208	275	155B*
47	136	209	276	158A
48	143	210	277	158B
49	145	212	278	160B
54	148	213	279	165A
55	149	214	280	165B*
56	151	215	104A	166A1
62	152	217	104B	166B
64	153	220	105A	168A
68	157	221	105B	168B1
73	161	223	107A	168B2
74	162	224	107B	16A
79	164	225	109A	170A
80	167	226	109B	170B
81	169	227	112A	171A
84	175	230	112B	171B
90	176	235	114A	174A
93	177	238	114B	174B
94	180	240	12A	178A
178B1	229B	248B	40A1	70B
178B2	22A	251A	40A2	72A
179A	22B	251B	40B	72B
179B	232A	254A	40C1	7B
179C	232B	254B	40C2	7C
192A	234A	256A	42A	85A
192B	234B	256B	42B	86B
197A	234C	258A	43A	89B
197B	237A	258B	43B	8A
19B	237B	259*	51A	92C
1A	239C	269B	51B	95A
1B	242A	273A	59A	95B
201A	242B	273B	59B	96A
201B	242C	282A	63A	96B
211A	246B	282B	63B	Apagbaala
216A	247A	30A	65A	IT 97k-499-35
216B	247B	33A	65B	Sanzi
229A	248A	33B	70A	

Table 2. List of recombinant inbred lines (RILs) used in pots experiment.

Genotype				
23	162	270	197A	33B
25	184	275	197B	40A1
28	188	279	19B	40A2
35	191	280	1A	40B
46	195	104A	1B	40C1
47	200	12C	201A	72A
73	210	155A1	201B	72B
80	212	155A2	211A	89B
97	213	155B*	22A	96A
100	214	165A	22B	96B
151	249	16A	251B	Apagbaala
152	257	178A	256A	IT97K-499-35
153	260	178B1	259*	Sanzi
157	265	179B	30A	

Table 3. Characteristics of germplasm used to determine yield losses by *Striga gesnerioides* infestation.

Genotype	Days to maturity	Growth habit	Seed color	Seed texture
Parent				
IT97k-499-35	69	Erect	White	Smooth
Sanzi	67	Spreading	Brown	Rough
Resistant RILs				
16A	60	Erect	White	Rough
19B	65	Erect	White	Rough
35	68	Erect	White	Rough
155A2	61	Erect	White	Rough
191	68	Erect	White	Rough
Susceptible RILs				
12B	61	Erect	White	Rough
22A	55	Erect	White	Rough
25	62	Erect	White	Rough
112A	62	Erect	White	Rough
211A	57	Erect	White	Rough

consisted of five *Striga* resistant lines, five *Striga* susceptible lines and the two parents (IT97K-499-35 and Sanzi) as checks (Table 3).

The experiment was designed as a split plot with four replications. The *Striga* treatments (infested and no infestation) were the main plots while the 12 lines were the sub plots. The soil used to fill the pots were steam sterilised at 100°C to get rid of all *Striga* seeds. A metallic barrel was used for the sterilization of the soil. A wire mesh was fitted at 1/3 of the length of the barrel from the bottom. This served as a separator between the soil and the water. The setup was placed on fire. Water was poured in the barrel to fill up to the level where the wire mesh is fitted, jute sack was then laid over the wire mesh before filling the remaining two thirds with soil. The soil was covered with jute sack. The steam generated from the boiling water was allowed to pass through the soil for an hour and half to heat up the soil up to 100°C. The fire was put off upon attaining the 100°C to allow the soil to cool down. The soil was then scooped and spread on a plastic sheet to allow it to further cool down under shade before filling the plastic pots.

Forty-eight pots were infested with 5 g with *S. gesnerioides.* The other forty-eight pots were not infested with *Striga* seeds. All the pots were watered to field capacity and allowed to drain for 24 h before planting. The pots were irrigated as when it is needed and kept weed-free through hand pulling. Monitored spray was done against insects. From thirty-five days after planting, *Striga* emergence was recorded on daily based on visual observation. The other agronomic data collected included first day of flowering, days to 50% flowering, plant height, number of peduncles per plant and days to maturity.

The post-harvest data collected included dry pod weight, grain weight, number of seeds per pod, hundred seed weight as well as fresh and dried biomass weight. The dried biomass was obtained after drying in an oven for 24 h to a constant weight.

Yield loss assessment due to *Striga* infestation was estimated using the formula:

$$YL = \frac{yield\ in\ uninfested\ pot - yield\ in\ infested\ pots}{yield\ in\ uninfestded\ pot} \times \mathbf{100}$$

YL: Yield losses.

Statistical analysis

All field data collected were subjected to analysis of variance (ANOVA) using the GenStat analytical software (version 12.1.0.3338). Varietal means were compared using least significant difference at 5% level of probability (LSD 5%).

RESULTS

Cowpea RILs reaction to natural *Striga gesnerioides* in the field screening

The result showed that sixty-six (66) RILs out of the 251 (26.29%) used for this trial were resistant. (Table 4). *Striga* plants emerged from the soil of the plots containing susceptible RILS.

Reaction of cowpea RILs to artificial *Striga gesnerioides* in pot experiments

The results of artificial inoculation showed that 27 RILs were found to be resistant (no *Striga* emergence or *Striga* attachment) whiles 39 were susceptible (having *Striga* emergence or *Striga* attachment at the roots level) (Table 5). The number of days to flowering and maturity varied from 35 to 55 and 60 to 86, respectively.

Evaluation of *Striga* promising lines in yield loss

Genotypes varied significantly in terms of days to 50% flowering and maturity under both infested and not infested (Table 6). Days to flowering and maturity varied from 41 to 55 and 63 to 73 days after planting. Under *Striga* infestation, the genotype 191 was the earliest to flower at 44 days after planting (Table 6). Under no *Striga* infestation, the genotypes 25 and 112A flowered earlier than the rest of the genotypes (41 and 43 days). 155A2 flowered 50 days after planting. The remaining genotypes were considered as medium maturity cultivars based on the days to flowering (43 to 49 days).

Under *Striga* infestation, all the resistant lines significantly ($P<0.001$) flowered and matured almost at the same time as in no *Striga* infested pots whiles the susceptible lines delayed in flowering and maturity (Table 6).

The resistant genotype 19B for instance flowered at 48 DAPS and matured at 65 and 66 days DAP in the non-infested and *Striga* infested pots, respectively.

The susceptible genotype 12B flowered at 48 days after planting under no *Striga* infestation and 55 DAP under *Striga* infestation. The days to maturity were 65 and 73 days non-infested and *Striga* infested pots respectively ($P< 0.001$).

Seed yield and dry biomass per hectare

The analysis of variance revealed significant differences between the progenies under *Striga* infestation and no *Striga* infestation (Table 9)

Among the RILs, 16A, under no infestation produced the highest grain yield (754.2 kg ha^{-1}) followed by 25 (473.3 kg ha^{-1}) and 19B (470.1 kg ha^{-1}) (Table 7). The genotype, 155A2, a resistant cultivar recorded the lowest grain yield (320.1 kg ha^{-1}). The cultivar 16A which recorded the highest yield under no infestation (754.2 kg ha^{-1}) also recorded the significant yield under *Striga* infestation. (750 kg ha^{-1}). Ironically, the susceptible cultivar 25, one of the highest grain producers under no *Striga* infestation (436.1 kg ha^{-1}) also had one of the lowest grain yield under the infestation (338.6 kg ha^{-1}). In general, the reduction in grain yield was higher in the susceptible progenies than the resistant ones.

Dry biomass yield showed significant differences among the *Striga* infested ($P < 0.001$) and non-infested conditions. The mean values of dry fodder yield were 1507 kg ha^{-1} under no *Striga* condition and 1126 kg ha^{-1} in the infested conditions. The progenies with the highest dry biomass under no infestation conditions were 155A2 and 12 B with 2234 and 1901 kg ha^{-1}, respectively. The lowest fodder yield was recorded for the cultivar 25 with yield of 876 kg ha^{-1}. The dry biomass yields for the other genotypes ranged from 1076 to 1812 kg/ha.

Under the *Striga* infestation condition, the genotype 155A2 still recorded the highest fodder likewise in the no infestation. The dry fodder yield of genotype 12B drastically dropped from 1901 kg ha^{-1} in the non-infested condition to 1002 kg ha^{-1} under the infested condition. The genotype 16A also recorded good production of fodder in both infested (1813 kg ha^{-1}) and no infested condition (1898 kg ha^{-1}).

Plant height and number of pods per plant

The number of pod per plant was significantly different in both infested ($P < 0.001$) and non-infested environment. The analysis of variance indicated a significant difference for the plant height in both infested and non-infested environments.

The resistant plants were taller than the susceptible RILs under *Striga* infested condition (Table 8). The resistant parent IT97k-499-35 was the tallest plant (35.61 cm) followed by 16A and then 191 with plant heights of 31.63 and 31.53 cm, respectively. The susceptible cultivars 12B recorded the shortest plants height with 15.74 cm, in the no *Striga* infested pots. *Striga* susceptible

Table 4. Reaction of cowpea RILs derived from a cross of IT97K-499-35× Sanzi to *Striga gesnerioides* infestation in field trial (Manga Station, 2016).

RILs	Field trial	RILs	Field trial	RILs	Field trial
1A	R	72B	R	179B	R
1B	R	73	R	184	R
12C	R	80	R	188	R
16A	R	89B	R	191	R
19B	R	96A	R	195	R
22A	R	96B	R	197A	R
22B	R	97	R	197B	R
23	R	100	R	200	R
25	R	104A	R	201A	R
28	R	151	R	201B	R
30A	R	152	R	210	R
33B	R	153	R	211A	R
35	R	155A1	R	212	R
40A1	R	155A2	R	213	R
40A2	R	155B*	R	214	R
40B	R	157	R	249	R
40C1	R	162	R	251B	R
46	R	165A	R	256A	R
47	R	178A	R	257	R
72A	R	178B1	R	259*	R
260	R	55	S	109A	S
265	R	56	S	109B	S
270	R	59A	S	110	S
275	R	59B	S	112A	S
279	R	62	S	112B	S
280	R	63A	S	113	S
IT 97k-499-35	R	63B	S	114A	S
3	S	64	S	114B	S
7B	S	65A	S	119	S
7C	S	65B	S	121	S
8A	S	68	S	124	S
9	S	70A	S	125	S
11	S	70B	S	126	S
12A	S	74	S	128	S
12B	S	79	S	129	S
14	S	81	S	130A	S
15	S	84	S	131B	S
21	S	85A	S	134B	S
29	S	86B	S	135	S
33A	S	90	S	136	S
37	S	92C	S	141A	S
40C2	S	93	S	141B	S
42A	S	94	S	143	S
42B	S	95A	S	144A	S
43A	S	95B	S	144B	S
43B	S	98	S	145	S
44	S	104B	S	148	S
45	S	105A	S	149	S
48	S	105B	S	150A2	S
49	S	106	S	150B	S

Table 4. Contd.

51A	S	107A	S	154 A	S
51B	S	107B	S	158A	S
54	S	108	S	158B	S
160B	S	202	S	245	S
161	S	205	S	246B	S
164	S	208	S	247A	S
165B*	S	209	S	247B	S
166A1	S	215	S	248A	S
166B	S	216A	S	248B	S
167	S	216B	S	251A	S
168A	S	217	S	252	S
168B1	S	220	S	254A	S
168B2	S	221	S	254B	S
169	S	223	S	255	S
170A	S	224	S	256B	S
170B	S	225	S	258A	S
171A	S	226	S	258B	S
171B	S	227	S	261	S
174A	S	229A	S	262	S
174B	S	229B	S	263	S
175	S	230	S	266	S
176	S	232A	S	268	S
177	S	232B	S	269B	S
178B2	S	234A	S	273A	S
179A	S	234B	S	273B	S
179C	S	234C	S	276	S
180	S	235	S	277	S
181	S	237A	S	278	S
182	S	237B	S	282A	S
183	S	238	S	282B	S
186	S	239C	S	Sanzi	S
187	S	240	S	Apagbaala	S
190	S	242A	S		
192A	S	242B	S		
192B	S	242C	S		
199	S	244	S		

R, Resistant; S: Susceptible; flow: Flowering, mat: Maturity.

genotypes were shorter compared to the resistant RILs.

Among the progenies, the highest mean number of pods per plant (10 pods) was recorded in the susceptible genotype, 22A, under no *Striga* infestation, but produced 7 pods under *Striga* infested condition. However, for the resistant RIL 19B, the mean number of pods was not affected when grown on Striga infested soils.

Grain yield and dry biomass loss due to *Striga gesnerioides*

In general the grain and biomass yield loss were higher in the susceptible lines compared to the resistant RILs. For the resistant RILs the dry grain yield losses ranged from 4.5 kg ha^{-1} (0.55%) to 14.5 kg ha^{-1} (3.08%) (Table 9). In the susceptible genotypes, grain yield losses oscillated from 134.7 kg ha^{-1} (28.45%) to 262.5 kg ha^{-1} (58.88%).

The highest grain yield loss (58.88%) was recorded for the susceptible RIL 12B followed by the susceptible line 22A which registered 37.9% grain yield loss. Grain yield losses for the resistant progenies were found to be between 0.55% for the cultivar 16 A to 3.08% for the genotype 19B. The resistant line 16A also showed a lower yield loss (0.55%) than the resistant parent (1.51%).

Table 5. Reaction of cowpea RILs derived from a cross of IT97K-499-35× Sanzi to *Striga gesnerioides* infestation in field trial and pot experiment (Manga station, 2016).

SN	Genotype	Field trial status	Pot trial status	50% flow. (days)	50% mat. (days)
1	23	R	R	38	63
2	35	R	R	43	67
3	46	R	R	53	66
4	151	R	R	37	65
5	162	R	R	62	80
6	184	R	R	56	78
7	191	R	R	38.5	73
8	249	R	R	60	81
9	257	R	R	56	70
10	279	R	R	37	66
11	280	R	R	58	70
12	12C	R	R	56	72
13	155A1	R	R	53	65
14	155A2	R	R	36	60
15	16A	R	R	35	60
16	178A	R	R	71	86
17	19B	R	R	44	64
18	1A	R	R	69	72
19	201A	R	R	73	86
20	22B	R	R	50	63
21	251B	R	R	58	66
22	40A1	R	R	58	72
23	40A2	R	R	41	66
24	40B	R	R	43	62
25	40C1	R	R	63	76
26	89B	R	R	65	81
27	96B	R	R	61	85
28	IT97K-499-35	R	R	46	68
29	25	R	S	49	66
30	28	R	S	65	85
31	47	R	S	60	79
32	73	R	S	66	75
33	80	R	S	53	78
34	97	R	S	58	79
35	100	R	S	51	63
36	152	R	S	66	74
37	153	R	S	57	73
38	157	R	S	55	72
39	188	R	S	51	65
40	195	R	S	57	71
41	200	R	S	69	84
42	210	R	S	58	70
43	212	R	S	67	80
44	213	R	S	54	69
45	214	R	S	50	62
46	260	R	S	55	76
47	265	R	S	64	70
48	270	R	S	60	78
49	275	R	S	52	62
50	104A	R	S	63	86

Table 5. Contd.

51	155B*	R	S	58	69
52	165A	R	S	44	62
53	178B1	R	S	53	68
54	179B	R	S	71	88
55	197A	R	S	63	78
56	197B	R	S	42	60
57	1B	R	S	62	80
58	201B	R	S	41	68
59	211A	R	S	54	68
60	22A	R	S	42	60
61	256A	R	S	58	74
62	259*	R	S	62	67
63	30A	R	S	55	68
64	33B	R	S	49	68
65	72A	R	S	51	67
66	72B	R	S	53	70
67	96A	R	S	51	73
68	Apagbaala	S	S	49	71
69	sanzi	S	S	39	66

R: Resistant; **S**: Susceptible; **flow**: Flowering; **mat**: Maturity.

Table 6. Mean days to flowering and maturity of cowpea RILs on no infestation and *S. gesnerioides* infested plots (Manga Station, 2016).

Genotype	Days to flowering		Days to maturity	
	No infestation	Infestation	No infestation	Infestation
Parents				
IT97k-499-35	49	48	68	69
Sanzi	46	49	66	73
R. progenies				
16A	47	48	68	70
19B	48	48	65	66
35	47	46	65	66
155A2	50	51	67	67
191	44	44	62	63
S. progenies				
12B	48	55	65	73
22A	43	47	69	73
25	41	45	62	67
112A	43	48	63	68
211A	46	51	67	73
Mean	45.81	48.38	65.56	68.75
LSD (5%)	3.641	2.089	3.75	2.833
CV (%)	5.5	3	4	2.9

Values represent means of four replications.

Dry biomass losses for the susceptible progenies ranged from 889 kg ha^{-1} (47.29%) to 664 kg ha^{-1} (61.71%) for the cultivars 12B and 112A, respectively.

Similarly for the dry grain yield, the resistant RILs did

Table 7. Mean grain weight and dry biomass of cowpea RILs under no infestation and *Striga gesnerioides* infested plots.

Genotype	Grain yield (kg/ha)		Dry biomass (kg/ha)	
	Uninfested	Infested	Uninfested	Infested
Parent				
IT97k-499-35	554.2	545.8	1812	1779
Sanzi	488.8	302.8	1251	557
R. progenies				
16A	754.2	750	1898	1813
19B	470.1	455.6	1627	1548
35	397.4	389.7	1099	1036
155A2	320.1	313.2	2234	2209
191	390.3	385.4	1424	1314
S. progenies				
12B	445.8	183.3	1901	1002
22A	436.1	270.8	1567	810
25	473.3	338.6	876	379
112A	389.3	259	1076	412
211A	481.1	340.3	1317	656
Mean	466.7	377.9	1507	1126
LSD (5%)	95.79	116.1	336	170.1
CV (%)	14.3	21.4	15.5	10.5

Values represent means of four replications

Table 8. Mean plant height, number of pods per plant of cowpea RILs under no infestation and *S. gesnerioides* infested plots.

Genotype	Plant height (cm)		Mean Number of pods /plant	
	Uninfested	Infested	Uninfested	Infested
Parent				
IT97k-499-35	35.61	36.04	11.19	11
Sanzi	21.83	16.63	12	9
R. progenies				
16A	31.63	31.16	7.5	7.02
19B	29.32	29.11	8.42	8.37
35	26.1	25.87	7.9	8
155A2	24.76	24.34	7.55	7.4
191	31.53	30.35	8.32	8.25
S. progenies				
12B	15.74	12.83	7.55	4.05
22A	28.38	23.03	10.28	7.37
25	24.85	20.6	9	6.42
112A	17.79	13.8	8.47	5.92
211A	28.16	22.9	9.38	6.1
Mean	26.31	23.89	8.96	7.41
LSD (5%)	1.74	2.11	1.756	2.15
CV (%)	4.6	6.1	13.6	20.1

Table 9. Percentage dry grain and biomass loss per hectare under to *S. gesnerioides* infestation.

Genotype	Grain yield (kg/ha)			Dry biomass (kg/ha)		
	No *Striga*	*Striga*	Yield losses (%)	No *Striga*	*Striga*	Biomass losses (%)
Parents						
IT97k-499-35	554.2	545.8	1.51	1812	1779	1.82
Sanzi	488.8	302.8	38.05	1251	557	55.47
R. progenies						
16A	754.2	750	0.55	1898	1813	4.47
19B	470.1	455.6	3.08	1627	1548	4.85
35	397.4	389.7	1.93	1099	1036	5.73
155A2	320.1	313.2	2.15	2234	2209	1.11
191	390.3	385.4	1.25	1424	1314	7.72
S. progenies						
12B	445.8	183.3	58.88	1901	1002	47.29
22A	436.1	270.8	37.9	1567	810	48.3
25	473.3	338.6	28.45	876	379	56.73
112A	389.3	259	33.47	1076	412	61.71
211A	481.1	340.3	29.26	1317	656	50.18
Mean	466.7	377.9		1507	1126	
LSD (5%)	95.79	116.1		336	170.1	
CV (%)	14.3	21.4		15.5	10.5	

Values represent the means of four replications.

not show any significant biomass losses. With regard to the biomass losses, the cultivar 155A2 performed better in both *Striga* infested (2209 kg ha^{-1}) and non-infested (2234 kg ha^{-1}) then to the resistant parent IT97K-499-35, and also recorded the least biomass loss (1.1%) (Table 9).

DISCUSSION

Field screening for cowpea genotypes resistant to *Striga gesnerioides*

The field study recorded high emergence of *Striga gesnerioides* per plot (243 shoots) of the susceptible lines and this is similar to observations in other studies (Carsky et al., 2003; Kamara et al., 2008). The high *Striga* emergence observed on the Striga Susceptible lines was an indication that the site was really a hot spot for *S. gesnerioides* and the field had been infested with high concentration of *Striga* seeds over the years. However, a rigorous screening of the 66 genotypes in artificially infested soils in pot experiments revealed that only 10.75% were truly resistant to *Striga*. A susceptible genotype could be heavily infested underground without any *Striga* emergence as a results of several factors. According to Kim et al. (2002), one of the major limitations of screening under natural infestation is the variability in *Striga* seeds dissemination and cultivars escaping infestation. *Striga* sp. seeds need warm stratification for a certain time at a right temperature (approximately 30°C) before the seeds start responding to germination stimulants (Matusova et al., 2004). The high interference such as soil and climatic factors observed in the field makes the field screening less accurate (Baptiste et al., 2013).

Pot screenings

Field screening under artificial infestation is not always practical due to the fact that it can cause *Striga* seeds spreading to novel regions and it is moreover not consistent because breeders do not have any control of the parasite density and distribution (Haussmann et al., 2000). Pot screening has been operative as an alternative technique to confirm uniform infestation of *Striga* seeds.

After the pot experiment, the number of resistant lines was reduced from sixty-six (66) RILs to twenty seven (27) RILs after the pots experiment. This is essentially due to the high level of infestation (five grams of *Striga* seed per pot), the uniformity and a better control of the environment. A previous study done by Baptiste et al. (2013), confirmed the reliability of the pot screening compared to field screening.

The increased number of susceptible recombinant inbred lines found among the 66 could also be implied that these genotypes though showed no emerged seedlings of *Striga* had *Striga* attached to their roots. According to Ba (1983), some cowpea genotypes stimulate the *Striga* to germinate and penetrate their root tissues, but the *Striga* fails to grow more.

After both field and pot screening for *Striga* resistance, and taking into consideration farmers preferred traits, the genotypes 16A, 19B, 35, 155A2 and 191 were identified as promising *Striga* resistant lines.

Striga infestation delayed the flowering and maturity of susceptible cowpea genotypes. The susceptible genotypes also experienced huge reduction in grain yield and dry biomass in the *Striga* infested environment compared to when they were grown under no *Striga* environment. The study also confirmed that *Striga* infestation induces stunted growth hence the significant reduction of plant height at 50% flowering recorded for the susceptible genotypes. It also had an effect on the production of number of pods per plant. These data corroborated with previous studies (Press, 1995; Alonge, 1999; Gworgwor et al., 1991), which produced similar results. The stunted growth of genotypes, 12B, 22A, 25, 112A and 211A, could be attributed to the competition between the host and *Striga* for resources. The reduced vegetative growth of the susceptible varieties resulted in reduced leaf area, photosynthetic capacity and therefore affected flowering, podding and seed production (Alonge, 1999). According to Press (1995), the lower biomass accumulation by the susceptible genotypes could be the result of competition among the host and the weed for solutes, as well as carbon, water and minor rate of photosynthesis in the leaves of *Striga* infested plant. The reduced photosynthesis might have resulted in lower number of pods per plant and translocation of photosynthates to the sink.

Graves et al. (1992), showed that the low chlorophyll content which characterizes susceptible genotypes may account for the reduced development of the susceptible cowpea genotypes causing a decrease in both grain and biomass yield. The low biomass yield could also be attributed to the reduced shoot growth of the susceptible genotypes. The same phenomenon has also been reported for cereals infected with *Striga hermonthica* and for some cowpea genotypes infected with *S. gesnerioides* (Graves et al., 1992).

The resistant cultivars showed a relatively good growth compared to the susceptible lines in the infested pots. The relative good growth and the reduced export of assimilate to the weed would have ensured sufficient biomass accumulation and seed development as suggested by Gworgwor et al. (1991) on *S. gesnerioides*. The superior growth of some genotypes like 16A, 19B, 35, 155A2 and 191 indicated the positive relationship between crop vigour and crop performance even in *Striga* infested pots.

Grain and biomass loss due to *S. gesnerioides*

This current study has shown that all the resistant cowpea cultivars (16A, 19B, 35, 155A2 and 191) exhibited lower grain and dry biomass loss compared to the susceptible ones (12B, 22A, 25, 112A and 211A) indicating that these cultivars could play an essential role in controlling *Striga* in the endemic areas.

The susceptible genotypes recorded an average yield loss of 37.66% for dry grain yield which is quite consistent with the yield loss of 31±4% with a range of 26 to 65% observed by Aggarwal and Ouedraogo (1989). According to these authors, the loss could be attributed exclusively to the genotype effect as a consequence of *Striga* direct parasitism of susceptible cowpea lines (Muleba et al., 1996). *S. gesnerioides* diverts the host nutrient into themselves via the haustorium which establishes contact with the host tissues (xylem and phloem) (Okonkwo and Nwoke 1978; Okwonkwo, 1966). Consequently, this competition among host and parasite for water, and essential metabolites could be the explanation for the yield loss (Stewart and Press, 1990). Setty and Nanjapp (1985) and Kuijt (1969), reported that the osmotic pressure of the parasite is higher in both leaf and root than its host making the *Striga* more competitive. The use of high yielding *Striga* resistant varieties coupled with good agronomic practices can therefore help to reduce the yield losses in soil infested with *Striga* in the traditional farming systems.

Conclusion

The study revealed different reactions of cowpea RILs to *S. gesnerioides* during the field and the pot experiments. Out of the 251 RILs used, 27 RILS were found resistant similar to the resistant parent (IT97K-499-35), whiles 224 RILs were susceptible.

Yield loss assessment showed that the *Striga* resistant genotypes suffered less yield loss compared to the susceptible ones and therefore resistant genotypes can be one of the best means to minimize yield loss. These genotypes that expressed complete resistance are potential lines that will serve as resistant genotypes. The latest discovery of new sources of resistance to *Striga* provides an excellent way to supply farmers with new genotypes to replace their susceptible varieties.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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