Variability and host specificity of witchweed [*Striga hermonthica* (Del.) Benth.] populations on millet [*Pennisetum glaucum* (L.) R. Br.]

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ABSTRACT

Field surveys and greenhouse experiments were conducted during season 2009/10 in the Sudan to investigate variability and host specificity of witchweed [*Striga hermonthica* (Del.) Benth.] populations. Field surveys were conducted in *S. hermonthica* endemic areas in Gadarif, Gezira and Kordofan to collect seeds from *Striga* plants growing under their respective hosts. A total of fifteen *S. hermonthica* populations were collected. Twelve *S. hermonthica* populations, one each, were collected from under sorghum and three *S. hermonthica* populations, one each, were collected from under millet. A greenhouse experiment was undertaken at the horticulture nursery, Faculty of Agricultural Sciences, University of Gezira, Wad Medani, Sudan, to test the infectivity of seeds of witchweed populations on millet, cultivar Ashana, which is known for its differential response and to study virulence of parasitism on this cultivar. The fifteen *S. hermonthica* populations were arranged in a randomized complete block design with three replicates. Growth and harvest attributes on the parasite and crop were measured. Data were collected and transformed as necessary to $\sqrt{x+0.5}$ and subjected to the analysis of variance procedure. Means were separated for significance using Duncan's Multiple Range Test (at $p \leq 0.5$). The greenhouse experiment showed that emergent *S. hermonthica*, capsules per plant and shoot dry weight were highest on the respective host. It is noteworthy that some of the *Striga*, sorghum populations, displayed limited emergence on millet and produced seeds. *S. hermonthica* populations significantly reduced growth and yield of millet. However, the magnitude of the damage attained, by each population was highest on the respective host. These findings suggest the existence of inter-crop specialization. Moreover, the results confirmed the existence of two strains of *S. hermonthica*, one specific to sorghum and the other to millet. These findings showed clearly the complexity of obtaining millet cultivars with high and durable resistance across locations.

INTRODUCTION

Witchweeds (*Striga* spp.), member of the family Orobanchaceae (Olmostead *et al*.,2001), are obligate root parasitic plants that attack agronomically important cereals and legumes (Anonymous, 1993). *Striga* is the major biotic constraint to cereals production, especially in the non-fertile semi-arid region of sub-Saharan Africa (Haussmann *et al*., 2000). The parasite negatively affects the lives of over 300 million people (Kim *et al*., 2002). In extreme cases, severe infestation of *Striga* results in complete loss of the crop and the abandonment of otherwise productive fields (Butler, 1995). The increasing seriousness of the *Striga* problem is directly related to increased land-use intensity to produce sufficient food for the increasing human populations (Berner *et al.*, 1996). In the Sudan, *Striga hermonthica* (Del.) Benth. is the most serious biotic problem to cereal production. It attacks sorghum (*Sorghum bicolor* [L.] Moench), millet (*Pennisetum glaucum* [L.] R. Br.), maize (*Zea mays* L.), sugarcane (*Saccharum officinarum* L.) and rice (*Oryza sativa* L.) (Abbasher *et al.*,1998). Musselman and Hepper (1986) believed, on the basis of common occurrence on wild grasses, that *S. hermonthica* has Sudan as centre of origin. The parasite constitutes a major threat to sorghum production and hence a direct threat to food security as sorghum constitutes the main staple food crop for the majority of the Sudanese people in rural areas (Zahran,2008). The impact of *Striga* is compounded further by its predilection for attacking crops already under moisture and nutrient stress, conditions that prevail throughout the semi-arid tropics. Moreover, available evidence strongly suggest that the problem is worsening (Ejeta and Butler, 1993).

The most promising and culturally acceptable methods for *Striga* management today are crop rotation with non-host trap crops and planting of tolerant cultivars (Christopher *et al.,* 2002). Resistant cultivars, due to paucity of resistance genes, are limited in number (Ejeta *et.al.*,1992). Furthermore, resistance is temporally and spatially unstable. Instability of resistance is attributed to existence of strains and physiological variants of the parasite. Furthermore, differential effects arising from variability according to size of the parasite seed bank and soil fertility cannot be ruled out. Without good knowledge of the nature of the specificity and physiological variability within *S. hermonthica* population, its interactions with host genotypes, its relationships with resistance mechanisms, total exploitation of host plant resistance may not be possible (Ali *et al.*,2007). Several experiments were undertaken to study host specificity in *S. hermonthica*. However, little work has been done on the biological basis of host specificity, physiological and genetic variability within *S. hermonthica* populations and it's interaction with selected hosts in Sudan. Therefore, this experiment was conducted to study the interactions between *Striga* populations and millet cv. Ashana as manifested in i) *Striga* emergence, ii) *Striga* growth and reproduction, iii) underground attachment iv) millet growth attributes and v) millet yield attributes.

MATERIALS AND METHODS

Collection of *S. hermonthica* seeds

Field surveys were conducted during the rainy season of 2008/09 (mid-September to mid-October) in *S. hermonthica* endemic area in Gadarif, Gezira and Kordofan area i.e. eastern, central and western Sudan, respectively. Field surveys were conducted to collect seeds from *Striga* plants growing under their respective hosts (sorghum and millet). A total of fifteen *S. hermonthica* populations were collected. Twelve *S. hermonthica* populations, one each, were collected from under sorghum in Galabat, Sumsum, Gadarif, Butana, El Fau (Gadarif area); Hasaheisa, Abu-Haraz, Hag-Abdalla, Barakat and Wad-Rabia (Gezira area); Um-Rawaba and El-Rahad (Kordofan area).Three *S. hermonthica* populations, one each, were collected from under millet in Kadugli, Khour-Tagat and El Obied (Kordofan area). The seeds were surface sterilized by sodium hypoclorite, (NaOCl) 1% solution, for 3 min with continuous agitation. The NaOCl solution was obtained by dilution of commercial sodium hypochlorite (bleach).

Subsequently, the seeds were thoroughly washed with sterilized distilled water for several times. Floating seeds were discarded and the remaining seeds were stored, for 7 months, at room temperature till used.

Greenhouse experiments

An experiment was undertaken in a greenhouse of horticulture nursery, Faculty of Agricultural Sciences, University of Gezira, Wad Medani, Sudan, to study the interactions between *Striga* populations and millet cv. Ashana as manifested in i) *Striga* emergence, ii) *Striga* growth and reproduction, iii) underground attachment iv) millet growth attributes and v) millet yield attributes. Plastic pots 10 cm internal diameter and 18 cm high, with drainage holes at the bottom, were filled with Gezira soil and river silt mixed in the ratio 1:1. *Striga* seeds (30 mg) were added to the soil, in each pot, and hand-mixed in the top 6 cm layer of each pot. The soil was kept moist for 7 days prior to planting the test plants. Millet cultivar Ashana was sown in each pot (5 seeds / pot). The pots were kept free from weeds, irrigated and the seedlings were thinned to 2 plants per pot, 7 days after emergence. Treatments were arranged in a randomized complete block design with three replicates. *Striga* plants were counted 45 days after planting and subsequently at 15 days intervals. At harvest, number of capsules /plant and *Striga* dry weight were determined. Crop height was measured and number of leaves and internodes were counted at 60, 90 and 120 days after emergence. Crop shoots were cut at ground level. Roots were retrieved from soil and washed. The shoots and roots were dried in a forced drought oven at 105^0C for 24 h and weighed.

Statistical analysis

Data were collected, transformed as required to $\sqrt{x+0.5}$ and subjected to the analysis of variance procedure. Means were separated using Duncan's Multiple Range Test at $p \leq 0.5$.

RESULTS

The experiment was designed to study the interactions between *S. hermonthica* populations and millet cv. Ashana. Measurements employed in the study consist of growth attributes of both *Striga* and millet.

***Striga* emergence (plant/pot)**

Striga populations from Butana and El Fau, Gadarif area, Hasaheisa, Abu-Haraz and Wad-Rabia, Gezira area, displayed no emergence throughout the season on millet (Table 1). *Striga* populations from Galabat and Gadarif, Gadarif area, and from Hag-Abdalla, Barakat, Gezira area, Um-Rawaba and El-Rahad, Kordofan area, displayed very low emergence. However, *Striga* collected from under millet at Kadugli, El Obied and Khour-Tagat displayed comparable emergence. Among all populations, *Striga* from Sumsum displayed the highest emergence. Average *Striga* seedlings per pot were 3, 4, and 4 at 60, 75, and 90 days after crop emergence, respectively (Table 1).

***Striga* growth and reproduction attributes**

At harvest, *S. hermonthica* populations exhibited considerable variations in number of capsules per plant and shoot dry weight (Table 2).

Number of capsules /plant

At harvest, *Striga* populations collected under sorghum from Butana, El Fau, Hasaheisa, Abu-Haraz and Wad-Rabia displayed no emergence (Table 2). *Striga* populations collected from Sumsum, Galabat and Gadarif produced 15–19 capsules per plant. *Striga* collected from Barakat and Hag-Abdalla, on the other hand, produced 14 and 12 capsules per plant, respectively. *Striga* populations collected from western Sudan, irrespective of host, produced considerable number of capsules. Those collected under sorghum from Um-Rawaba and El-Rahad produced 13 and 18 capsules per plant, respectively, while those obtained from under millet at El Obied, Kadugli and Khour-Tagat produced 20, 17 and 17, respectively. In general, *Striga* populations collected from Kordofan area displayed the highest number of capsules per plant, while, those collected from Gezira area displayed the lowest number of capsules per plant (Table 2).

Shoot dry weight (g)

Striga collected from under sorghum at Butana, El Fau, Gadarif area, Hasaheisa, Abu-Haraz and Wad-Rabia, Gezira area, displayed no emergence (Table 2).

Table 1. Effects of *S. hermonthica* population on emergence of *Striga* plants / pot.

		No. of emerged *Striga* plants / pot		
		Days after emergence of millet		
Area	Location	60	75	90
Gadarif	Galabat*	0.33 b (0.88)	0.67 ab (1.05)	1.00 bc (1.23)
	Sumsum*	2.67 a (1.77)	3.00 a (1.81)	4.33 a (2.19)
	Gadarif*	0.33 b (0.88)	0.33 b (0.88)	1.00 bc (1.23)
	Butana*	0.00 b (0.71)	0.00 b (071)	0.00 c (0.71)
	El Fau*	0.00 b (0.71)	0.00 b (071)	0.00 c (0.71)
	Hasaheisa*	0.00 b (0.71)	0.00 b (071)	0.00 c (0.71)
Gezira	Abu-Haraz*	0.00 b (0.71)	0.00 b (071)	0.00 c (0.71)
	Hag-Abdalla*	0.67 b (1.05)	1.00 ab (1.17)	1.33 b (1.34)
	Barakat*	0.33 b (0.88)	0.33 b (0.88)	1.00 bc (1.23)
	Wad-Rabia*	0.00 b (0.71)	0.00 ab (0.71)	0.00 c (0.71)
Kordofan	Um-Rawaba*	0.67 b (1.05)	0.67 b (1.00)	1.33 b (1.34)
	El-Rahad*	1.33 ab (1.34)	1.67 ab (1.44)	2.00 b (1.56)
	Kadugli**	0.67 b (1.05)	1.00 ab (1.17)	1.67 b (1.46)
	Khour-Tagat**	0.33 b (0.88)	0.33 b (0.88)	1.33 b (1.34)
	El Obied**	1.00 ab (1.23)	1.33 ab (1.43)	1.67 b (1.46)
SE ±		(0.203)	(0.244)	(0.175)
CV %		(22.1)	(30.6)	(13.3)

*, **= *Striga* populations collected from under sorghum and millet, respectively.

Numbers between parentheses are transformed data $\sqrt{x} + 0.5$.

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test ($P \leq 0.05$).

Population from Galabat, Sumsum, Gadarif, Hag-Abdalla, Barakat and Um-Rawaba displayed low and comparable shoot dry weight (0.04 – 0.23g/ plant). *Striga* populations from El-Rahad, Kadugli, El Obied and Khour-Tagat displayed the highest shoot dry weight (0.39 – 0.45g per plant) (Table 2). At harvest none of the populations showed underground *Striga* seedlings.

Table 2. Number of capsules per plant and shoot dry weight of *S. hermonthica* as influenced by population and millet, cv. Ashana.

Area	Location	Number of capsules / plant	Shoot dry weight (g / plant)
Gadarif	Galabat*	17.3 c	0.05 c
	Sumsum*	19.0 a	0.09 bc
	Gadarif*	15.3 de	0.08 bc
	Butana*	0.0 h	0.00 c
	El Fau*	0.0 h	0.00 c
Gezira	Hasaheisa*	0.0 h	0.00 c
	Abu-Haraz*	0.0 h	0.00 c
	Hag-Abdalla*	12.3 g	0.22 c
	Barakat*	14.3 ef	0.23 b
	Wad-Rabia*	0.0 h	0.00 c
Kordofan	Um-Rawaba*	13.0 fg	0.04 c
	El-Rahad*	18.3 ab	0.39 a
	Kadugli**	17.0 c	0.42 a
	Khour-Tagat**	16.7 cd	0.42 a
	El Obied**	20.0 a	0.45 a
	SE ±	0.576	0.576
	CV %	15.7	15.7

*, **= *Striga* populations collected from under sorghum and millet, respectively.

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test (P ≤ 0.05).

Effects of *S. hermonthica* populations on millet growth attributes

Regardless of *S. hermonthica* population, millet average height, number of leaves and number of internodes increased with time. Generally, *S. hermonthica*, populations collected from different locations, resulted in significant differences in plant growth across all assessment periods (Tables 3, 4 and 5).

Plant height (cm)

At 30 days after crop emergence, *S. hermonthica* population collected from Gadarif and Butana, Gadarif area, resulted in the shortest millet plants (34.67 and 33.67 cm, respectively) (Table 3). Millet infected by *Striga* from Galabat, Sumsum and El Fau showed significantly less reduction in millet height. Millet infested by *Striga* populations collected from Abu-Haraz and Hag-Abdalla, Gezira area, displayed comparable height (42.33– 41.33 cm, respectively). Millet infested by *Striga* collected from Hasaheisa, Barakat and Wad-Rabia displayed a significant reduction in height compared to those collected from Abu-Haraz. Millet infested by *S. hermonthica* populations collected from Um-Rawaba and El-Rahad, Kordofan area, showed heights of 48 and 50 cm, respectively. Among the regions, *S. hermonthica* populations collected from under millet at El Obied, Khour-Tagat and Kadugli displayed the shortest millet plants (25, 27 and 28 cm, respectively) (Table 3).

At 60 days after crop emergence, for Gadarif area populations, *Striga* collected from Galabat and Gadarif had significantly reduced millet height in comparison to populations collected from other sites within the same region (Table 3). *Striga* population from Sumsum was less suppressive to crop growth. *Striga* populations from Butana and El Fau were the least suppressive to millet and they resulted in about equal effects on millet height. Among populations collected from Gezira area, *Striga* from Wad-Rabia reduced millet height significantly in comparison to populations collected from other sites within the region. Millet infested by *Striga* populations collected from Hasaheisa, Abu-Haraz and Hag-Abdalla displayed comparable height (116.3 and 118.3 cm). *Striga* population from Barakat was invariably the least suppressive to the crop and showed an average height of 123.3 cm. For Kordofan area populations, *Striga* collected from El-Rahad was the least suppressive to millet growth followed by population from Um-Rawaba. Among all populations, irrespective of site or region, *Striga* collected from under millet resulted in higher reduction in millet height (Table 3).

At 90 days after crop emergence, *Striga* populations from Galabat, Sumsum and Gadarif, Gadarif area, resulted in comparable height (117- 120 cm) (Table3). Populations from Butana and El Fau showed significantly lower reduction in height. For the Gezira area populations, *Striga* seeds collected from Wad-Rabia caused the highest reduction in millet height (116 cm). *Striga* populations collected from Hasaheisa, Abu-Haraz and Hag-Abdalla effected about equal suppression and millet height was 126.3 to 128 cm. *Striga* population collected from Barakat was the least suppressive among populations collected from Gezira area. For Kordofan area, *Striga* population from El-Rahad caused the least reduction in millet height, followed by population from Um-Rawaba. *S.hermonthica* populations collected from under millet effected the highest reductions in millet height. *Striga* population from El Obied was the most suppressive as millet height was 90.7 cm. *Striga* populations from Kadugli and Khour-Tagat reduced millet height to 98 and 99 cm, respectively (Table 3).

Table 3. Effects of *S. hermonthica* populations on millet height (cm)

		Mean height (cm)		
		Days after emergence		
Area	Location	30	60	90
Gadarif	Galabat*	42.33 c	107.0 f	117.0 ef
	Sumsum*	43.00 c	112.0 e	120.0 e
	Gadarif*	34.67 f	108.0 f	118.7 ef
	Butana*	33.67 f	117.0 cd	127.0 cd
	El Fau*	43.33 c	115.0 d	124.3 d
Gezira	Hasaheisa*	39.67 de	117.3 cd	127.0 cd
	Abu-Haraz*	42.33 c	118.3 c	128.0 c
	Hag-Abdalla*	41.33 cd	116.3 cd	126.3 cd

Kordofan	Barakat*	37.67 e	123.3 b	135.3 b
	Wad-Rabia*	39.67 de	106.3 f	116.0 f
	Um-Rawaba*	48.00 b	125.0 b	135.0 b
	El-Rahad*	50.33 a	130.0 a	140.3 a
	Kadugli**	28.33 g	87.7 g	98.0 g
	Khour-Tagat**	27.33 g	90.0 g	99.0 g
	El Obied**	25.00 h	80.0 h	90.7 h
	SE ±	0.778	0.855	1.004
	CV %	8.2	3.5	4.4

*, **= *Striga* populations collected from under sorghum and millet, respectively.

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test (P ≤ 0.05).

Number of leaves

At 30 days after crop emergence, *Striga* populations collected from Galabat, Sumsum and Gadarif, Gadarif area, were the most suppressive and showed comparable number of leaves per plant (5–6) (Table 4). *Striga* populations from Butana and El Fau were significantly less suppressive. *Striga* collected from Gezira area effected about equal suppression in number of leaves per plant (7). Among *Striga* populations collected from Kordofan area, *Striga* from Um-Rawaba and El-Rahad were significantly less suppressive than those from other sites within the region and they achieved the same number of leaves. However, *Striga* populations collected from under millet were significantly more suppressive and achieved comparable number of leaves (Table 4).

At 60 days after crop emergence, *Striga* collected from Galabat and Butana were the most suppressive compared to those collected from other sites within the region (Table 4). Millet infested by *Striga* populations collected from Sumsum, Gadarif and El Fau displayed comparable number of leaves per plant. *Striga* populations collected from Gezira area effected about equal suppression in number of leaves per plant. Among *Striga* populations collected from Kordofan area, populations from Um-Rawaba and El-Rahad were significantly less suppressive than those from other sites within the region. However, *Striga* populations collected from under millet were significantly more suppressive.

At 90 days after crop emergence, among populations collected from Gadarif area, those from Galabat and Butana were the most suppressive (Table 4). Millet infected by *Striga* collected from Sumsum was the least affected. *Striga* populations collected from Gezira area effected about equal number of leaves. Among *Striga* populations collected from Kordofan area, *Striga* from Um-Rawaba and El-Rahad were significantly less suppressive than those from other sites within the region. On the other hand, *Striga* populations collected from under millet resulted in significant reduction in number of leaves in comparison to those collected from under sorghum, irrespective of site or region (Table 4).

Table 4. Effects of *S. hermonthica* populations on number of leaves of millet, cv. Ashana

		Number of leaves		
		Days after emergence		
Area	Location	30	60	90
Gadarif	Galabat*	5.17 efg	10.00 fg	12.00 fg
	Sumsum*	5.67 def	11.83 bcd	13.83 bcd
	Gadarif*	6.00 cde	11.00 df	13.00 de
	Butana*	6.17 bcd	10.17 ef	12.17 ef
	El Fau*	6.33 bcd	11.17 cd	13.17 cd
Gezira	Hasaheisa*	7.00 ab	11.83 bcd	13.83 bcd
	Abu-Haraz*	6.83 abc	12.00 bc	14.00 bc
	Hag-Abdalla*	7.00 ab	12.17 ab	14.17 ab
	Barakat*	6.83 abc	11.83 bcd	13.83 bcd
	Wad-Rabia*	7.33 a	11.83 bcd	13.83 bcd
Kordofan	Um-Rawaba*	6.50 abcd	13.00 a	15.00 a
	El-Rahad*	6.50 abcd	12.67 ab	14.67 ab
	Kadugli**	4.67 g	9.67 fg	11.67 fg
	Khour-Tagat**	4.83 fg	9.67 fg	11.67 fg
	El Obied**	4.67 g	9.17 g	11.17 g
SE ±		0.277	0.293	0.293
CV %		6.5	4.0	4.4

*, **= *Striga* populations collected from under sorghum and millet, respectively.

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test ($P \leq 0.05$).

Number of internodes

At 30 days after crop emergence millet infested with *Striga* collected from Galabat and Sumsum, Gadarif area, showed, significantly, the least number of internodes compared to millet infested with *Striga* populations from other sites within the region (Table 5). Millet infested by *Striga* collected from Gezira area, produced about equal number of internodes. *Striga* populations collected from under millet, reduced the number of millet internodes significantly in comparison to *Striga* populations collected from under sorghum, irrespective of site or region (Table 5).

Table 5. Effects of *S. hermonthica* populations on number of internodes of millet, cv. Ashana)

		Number of internodes		
		Days after emergence		
Area	Location	30	60	90
Gadarif	Galabat*	6.17 efg	11.00 fg	13.00 fg
	Sumsum*	6.67 def	12.83 bcd	14.83 bcd
	Gadarif*	7.00 cde	12.00 de	14.00 de
	Butana*	7.17 bcd	11.17 ef	13.17 ef
	El Fau*	7.33 bcd	12.17 cd	14.17 cd
Gezira	Hasaheisa*	8.00 ab	12.83 bcd	14.83 bcd
	Abu-Haraz*	7.83 abc	13.00 bc	15.00 bc
	Hag-Abdalla*	8.00 ab	13.17 ab	15.17 ab
	Barakat*	7.83 abc	12.83 bcd	14.83 bcd
	Wad-Rabia*	8.33 a	12.83 bcd	14.83 bcd
Kordofan	Um-Rawaba*	7.50 abcd	14.00 a	16.00 a
	El-Rahad*	7.50 abcd	13.67 ab	15.67 ab
	Kadugli**	5.67 g	10.67 fg	12.67 fg
	Khour-Tagat**	5.83 fg	10.67 fg	12.67 fg
	El Obied**	5.67 g	10.17 g	12.17 g
SE ±		0.277	0.293	0.293
CV %		5.6	3.6	3.1

*, **= *Striga* populations collected from under sorghum and under millet, respectively.

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test (P ≤ 0.05).

At 60 DAE millet showed differential response to *Striga* populations from Gadarif area (Table 5). Population from Galabat and Butana resulted in the lowest number of internodes. However, millet infested by populations from Gadarif, El Fau and Sumsum displayed higher number of internodes. Millet infested by *Striga* population from Gezira area showed relatively high and comparable number of internodes (12.83 -13.17 internodes / plant) (Table 5). Millet infested by *Striga* from El-Rahad showed comparable number of internodes to that collected from Um-Rawaba. However, *Striga* populations collected from under millet reduced the number of internodes significantly (Table 5).

At 90 days after crop emergence, *Striga* populations collected from Gadarif area, at Galabat and Butana, were the most suppressive (Table 5). Millet infested by *Striga* populations collected from Sumsum, Gadarif and El Eau displayed comparable average number of internodes per plant. For the Gezira area populations, *Striga* effected about equal number of internodes per plant. For Kordofan area populations, *Striga* collected from Um-Rawaba and El-Rahad were significantly less suppressive than those from other sites within the region However, *Striga* populations collected from under millet were significantly most suppressive (Table 5).

Effects of *S. hermonthica* populations on millet yield attributes

At harvest, *S. hermonthica* populations collected from different locations, induced significant variations in millet root dry weight, shoot dry weight and root: shoot ratio.

Root dry weight (g)

At harvest millet infested by *Striga* populations from Butana and El Fau, Gadarif area, showed root dry weight of 3.5 and 3.67 g / plant, respectively (Table 6). Millet infested by *Striga* from Galabat, Gadarif and Sumsum, on the other hand showed significantly low root dry weight. Millet infested by *Striga* populations collected from Hasaheisa, Hag-Abdalla and Barakat, Gezira area, displayed comparable root dry weight (4 - 4.27 g / plant). *Striga* population collected from Abu-Haraz and Wad-Rabia reduced millet root dry weight significantly (Table 6). Millet infested by *S. hermonthica* populations collected from Um-Rawaba and El-Rahad, Kordofan area, showed lower root dry weight (3.73 and 3.4 g per plant, respectively) in comparison to millet infested by *Striga* populations collected from under millet. *Striga* populations collected from Kadugli, Khour-Tagat and El Obied showed significantly the highest root dry weight (4.97 - 6.07 g / plant) (Table 6 and Plate 1).

Table 6. Effects of *S. hermonthica* populations on root, shoot dry weight and root: shoot ratio of millet, cv. Ashana

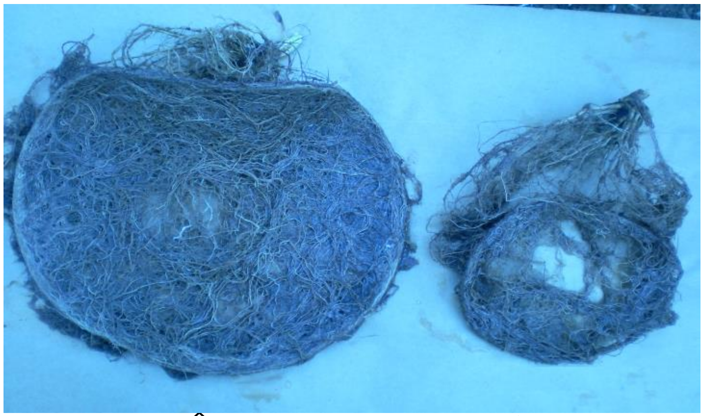
Area	Location	Dry weight (g/plant)		Root: Shoot ratio
		Root	Shoot	
Gadarif	Galabat*	2.07 j	17.10 a	0.12 c
	Sumsum*	2.47 ij	16.07 ab	0.15 c
	Gadarif*	2.93 hi	15.07 bc	0.19 c
	Butana*	3.50 fg	15.90 ab	0.22 c
	El Fau*	3.67 efg	15.17 bc	0.24 bc
Gezira	Hasaheisa*	4.10 de	14.00 cd	0.29 bc
	Abu-Haraz*	3.47 fg	13.00 de	0.27 bc
	Hag-Abdalla*	4.27 d	12.17 ef	0.35 abc
	Barakat*	4.00 def	10.27 g	0.39 abc
	Wad-Rabia*	3.60 efg	11.20 fg	0.32 abc
Kordofan	Um-Rawaba*	3.73 defg	9.77 g	0.60 abc
	El-Rahad*	3.40 gh	14.57 bcd	0.23 bc
	Kadugli**	5.53 b	7.00 h	0.79 ab
	Khour-Tagat**	4.97 c	7.40 h	0.67 abc
	El Obied**	6.07 a	7.10 h	0.85 a
SE ±		0.170	0.546	0.166
CV %		3.9	12.5	37.7

*, **= *Striga* populations collected from under sorghum and millet, respectively.

Means in the same column followed by the same letter(s) are not significantly different according to Duncan's Multiple Range Test (P ≤ 0.05).

Shoot dry weight (g)

At harvest, *S.hermonthica* populations collected from Gadarif area displayed significant differential reductions in millet shoot dry weight (Table 6). *Striga* collected from Galabat, Sumsum, and Butana were the least suppressive and attained (15.9-17.1 g/ plant). *Striga* populations from Gadarif and El Fau displayed comparable shoot dry weight. *Striga* populations from Barakat and Wad-Rabia, Gezira area, resulted in the lowest shoot dry weight in comparison to those from the other sites within the region. Populations from Hasaheisa, Abu-Haraz and Hag-Abdalla were significantly less suppressive. *Striga* populations collected from Um-Rawaba and El-Rahad, Kordofan area, were significantly less suppressive than those from other sites within the region. *Striga* collected from under millet at Kadugli, Khour-Tagat and El Obied affected the highest reductions in shoot dry weight.



El-Obied population   Galabat population

Root: shoot ratio

At harvest, *Striga* seeds collected from Galabat, Sumsum, Gadarif, Butana and El Fau, Gadarif area, displayed comparable root: shoot ratio (0.12 to 0.24) (Table 6 and Plate 1). Sorghum infested by *Striga* populations collected from Hasaheisa, Abu-Haraz, Hag-Abdalla, Barakat and Wad-Rabia, Gezira area, displayed comparable root: shoot ratio (0.27 to0.39). For Kordofan area populations, differences in root: shoot ratios were not significant.

DISCUSSION

Striga has long been recognized as the greatest biological constraint to food production, especially in the non-fertile semi-arid region of sub-Saharan Africa (Haussmann *et al*., 2000; Ejeta, 2007). In Sudan, *S. hermonthica* is the most serious biotic problem to cereal production, it attacks sorghum, maize, pearl millet, rice and sugarcane (Abbasher *et al*., 1998).The parasite is considered to be the major threat to sorghum, the main staple food for the majority of rural Sudanese people (Zahran, 2008).

The results revealed that, *Striga* emergence was influenced by the crop, time after crop emergence and the *Striga* strain used. At 90 days after millet emergence, *S. hermonthica*, sorghum strain, showed an average number of 0 to 2 plants per pot with exceptional case of Sumsum (4plants / pot). While the millet strains showed an average of 1-2 plants per pot (Table 1). At harvest, *Striga* from sorghum showed an average number of capsules of 0-19 per plant, while millet strain showed an average of 16.7 to 20 (Table 2). At harvest, sorghum strain *Striga*, displayed an average shoot dry weight of 0–0.39 g, while millet strain achieved an average dry weight of 0.42-0.45g (Table2). However, *S. hermonthica* populations showed no underground plant. These findings are consistent with observations made by Wilson-Jones (1955) that two strains of *S. hermonthica* exist in Sudan, one prevailing in eastern and central Sudan and attacks sorghum only, while, in western Sudan, both millet and sorghum were attacked. Furthermore, the strain on millet did not attack sorghum and *vice versa*. Sorghum was usually heavily attacked by *S. hermonthica* in the clay soils of central Sudan whereas millet was particularly immune, but the reverse was true on sandy soils. Moreover, these results are in conformity with those of Doggett (1952) which suggest the existence of physiological strains of *S. hermonthica* in east Africa. It was observed that varieties of Sorghum resistant in one location became susceptible in another (Doggett,1952).Similar observations were made by Ramaiah (1987) based on his studies on S. *hermonthica* in west Africa. King and Zummo (1977) reported the existence of physiological specialization in *S. hermonthica* from West Africa following their analysis of parasite virulence on different host crops. However, *S. hermonthica* occurs on a wide range of soil types ranging from cracking heavy clays, to very light sands. Some individual strains or populations of the species may have more restricted tolerance, but this could relate more to the most suitable soils for the host rather than any direct influence on the parasite. For instance, *S. hermonthica* on millet in West Africa is associated with light sandy soils (typical of millet-growing area) while that on sorghum is more often on heavier soils (Ranson, 1960).

The close association between *Striga*, its host and the environment together with the copious seed production and ease of dissemination may maximize the risk of spread of the parasite by the ongoing climate changes (Mohamed *et al.*, 2007). It is noteworthy that *S. hermonthica* collected from under sorghum attacked millet, but its growth was terminated and few *Striga* plants emerged and set seeds (Table 2).

This behavior is intriguing and at the same time is an indicator of a serious problem. In central and eastern Sudan sorghum predominates and millet is rarely grown. However, in Eastern Sudan both crops are cultivated often in the same field. Accordingly, hybridization between the two strains may result in a progeny capable of attacking both crops. Two levels of physiological specialization, intercrop and intra-crop specialization have been suggested in *Striga* (Ramaiah and Parker, 1982). However, specificity may break down when the cropping system is changed. The change may favour evolution of a new strain that adapt itself to the newly introduced crops fostered, perhaps by selection pressure (Musselman, 1987).

It has to be noticed that *S. hermonthica* is a heterogeneous plant and is pollinated mainly by insects (Parker and Riches, 1993). Furthermore, *Striga* is known to adapt itself to cropping systems. Differences in host plant adaptation among populations of *Striga* have been reported (Ejeta *et al.*, 1992). Introduction of maize into sorghum based cropping system, initially decreases *Striga* seed population density in the soil, but the effect does not last and heavy infestations of the crop often develop. This phenomenon is most likely due to changes in genetic composition of *Striga* population and/or preferential selection. The frequent cropping of maize results in selection and gradual build-up of races which are phonologically and physiologically adapted to the crop. Analysis of this apparent contradictory phenomenon may offer a better understanding of adaptation (host specificity) and adaptability (exceptions to host specificity) of *Striga*. A similar observation was made in Ethiopia where teff (*Eragrostis tef* (Zuccagni) Trotter) previously, considered immune to *S. hermonthica* was reported to be attacked (Parker and Riches,1993). Further investigation into this phenomenon employing cross inoculations or molecular biology techniques is necessary. Such studies may improve understanding of inter and intra-crop specificity.

If left unmanaged, the present infested land in the Sudan, estimated to be 20% of the area under sorghum and millet, is expected to increase by several folds and the parasite is to gain access to areas where it had not been reported before (Babiker, 2007). The risk of spread of the parasite together with the difficulty of its control, once established, coupled with variability in populations of the existing physiological and ecological strains necessitate a national plan to combat the parasite through proper management. The management is to focus on containment, eradication of satellite foci and raising farmer's awareness to discourage spread of the parasite into new areas. Established

infestations should be addressed through control measures involving inputs pertaining to soil fertility, reduced infestation and measures that prevent replenishment of *Striga* seed bank. This could be done through an integrated management strategy encompassing crop rotation, water harvest, tolerant and/or resistant cultivars, hand pulling and herbicides. The technology package has to be designed in accordance with the agroecological zones and farmers technical and financial capabilities.

CONCLUSIONS AND SUGGESTIONS

- The study suggests variability and physiological specialization in *S. hermonthica* in Sudan. Furthermore, the results confirmed the existence of two host-specific strains.
- The study indicates the need for in depth research on variability in *S. hermonthica* at the molecular level. Such studies are needed to facilitate development of stable and durable resistance.

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التباين وتخصصية العائل في عشائر البُودا *Striga hermonthica* (Del.) Benth, على الدخن *Pennisetum glaucum* [L.] R. Br.

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الخلاصـة

طفيل البُودا *Striga hermonthica* (Del.)، نبات متطفل إجبارياً على الجذور ينتمي للعائلة الهالوكية (Orobanchaceae)، يُهاجم محاصيل الغلال المهمة في أفريقيا. أدى وجود السلالات الفسيولوجية، التباينات الايكولوجية وعزلات الطفيل بالإضافة للتباين في حجم مخزون التربة من البذور، إلى عقبات جدية لتطوير وسائل تحكم بسيطة وفعالة. لذا أُجريت مسوحات حقلية وتجارب بيوت محمية خلال الموسم 2009/ 2010 في السودان لبحث التباين وتخصصية العائل في البُودا. المسوحات الحقلية أجريت في المناطق الموبؤة بالبُودا في القضارف والجزيرة وكردفان، لجمع البذور من نباتات البُودا النامية على عوائلها الخاصة. جمعت اثني عشر عشيرة للبُودا، واحدة لكل، من تحت الذرة الرفيعة، وجمعت ثلاث عشائر من تحت الدخن، واحدة لكل. أجريت تجربة البيوت المحمية بمشتل البساتين، كلية العلوم الزراعية، جامعة الجزيرة، ود مدني، السودان، لاختبار تلويث بذور عشائر البودا للدخن، الصنف عشانا، المعروف باستجابته التفضيلية، ولدراسة التباين في التطفل على هذا الصنف. وُضعت الخمسة عشر عشيرة للبُودا في تصميم قطاعات عشوائية كاملة بثلاث تكرارات. تم تحديد مقاييس النمو والحصاد بالنسبة للطفيل والمحصول. حُولت البيانات عند الضرورة ($\sqrt{x+0.5}$) وأُخضعت لتحليل التباين. تمت مقارنة المتوسطات بواسطة اختبار دنكن، عندما كان الاختبار معنويا. أوضحت نتائج تجارب البيوت المحمية أن قمة انبثاق نباتات البُودا في الأصيص، الكبسولات في النبات، الوزن الجاف للمجموع الخضري، عدد نباتات البُودا تحت سطح التربة في الأصيص والعدد الكلى لنباتات البُودا في الأصيص كانت أعلى على عوائلها الخاصة. الجدير بالملاحظة أن بعض نباتات البُودا، عشائر الذرة الرفيعة، أظهرت بزوغاً محدوداً على الدخن وأنتجت بذوراً. خفضت عشائر البُودا معنوياً نمو وإنتاج الذُرة والدُخن. ولكن تحققت أعلى مستويات الضرر لكل عشيرة من البُودا على عائلها الخاص. أوضحت نتائج هذا البحث وجود التخصصية بين وداخل نوع المحصول. كما أن النتائج تؤكد وجود سلالتان للبُودا واحدة متخصصة في الذُرة الرفيعة والأخرى في الدُخن. أظهرت هذه النتائج بوضوح التعقيد في الحصول على أصناف من الدخن ذات مقاومة عالية وعريضة في المناطق المختلفة.