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Management of *Striga hermonthica* in Sorghum using Soil Rhizosphere Bacteria and Host Plant Resistance

MOHAMMED MAHGOUB HASSAN[1], MIGDAM EL SHEIK ABDEL GANI AND ABDEL GABAR EL TAYEB BABIKER†
Environment and Natural Resources Research Institute, National Centre for Research, Khartoum, Sudan
†Sudan University of Science and Technology Faculty of Agriculture, Sudan
[1]Corresponding author's e-mail: mohkadis@yahoo.com

ABSTRACT

Two green house experiments were carried out to investigate the potentials of native soil borne bacteria to perturb early stages of *Striga* growth. In the first experiment, 36 bacterial isolates and strains were used to study the effects of some soil borne bacteria on *Striga hermonthica* on sorghum cv. Abu Sabeen. *Striga* emergence was earlier on sorghum, which was not inoculated with bacteria. The bacterial strains *P. putida*, *Bacillus* spp. (B2) and the bacterial isolates M20, S23, S22, GSL, D8, G11, D20 and D50 reduced *Striga* incidence by 90 to 100% at peak emergence (12 week after sowing WAS) in comparison to the infested un-treated control. In the second experiment, the effects of bacterial inoculation and sorghum genotype on *Striga* incidence were investigated. Three sorghum cultivars Mugawim Buda-1 (*Striga* resistance), Arfa gadamac (*Striga* tolerant) and Abu Sabeen (*Striga* susceptible) were employed. Three bacterial strains: *P. putida*, *A. brasilense* and *Bradyrhizobium japonicum,* the bacterial isolate D46 and a combination of *P. putida* and *A. amazonas* were used to inoculate sorghum. *Striga* emergence was much earlier on Abu Sabeen, the susceptible cultivar. *Striga* incidence was invariably highest on Abu Sabeen, and lowest on Mugawim Buda1. Inoculation with bacteria delayed *Striga* emergence and reduced *Striga* incidence on all cultivars. Sorghum inoculated with *A. brasilense* or *P. putida* alone and the combination between *A. amazonas* and *P. putida* sustained the least *Striga* infestation at peak emergence (7 WAS). Sorghum cv. Mugawim Buda-1 inoculated with the combination between *A. amazonas* and *P. putida* displayed significant increase in height plant growth promoter bacteria (PGPB) in comparison to the *Striga* infested un-inoculated control. Bacterial inoculation of resistant and/or tolerant sorghum cultivars further reduced *Striga* emergence and partially mitigated its effects on sorghum growth. Adoption of an integrated approach encompassing high yielding *Striga* resistant and/or tolerant crop cultivars and bacterial inoculation may provide a novel, cheap and easy to apply method for *Striga* control under substance low-input farming systems.

Key Word: Sorghum varieties; Bacteria strains; Suppression; PGPB; Biological control

INTRODUCTION

Striga hermonthica (Del.) Benth. is a scourge of cereal crops as losses ascribed to it vary from 0 to 100% (Kiriro, 1991). Root parasitic weeds generally damage their hosts plant even before they emerge above ground. Yield losses in West African cereals due to *Striga* species have been estimated to average 24%, but total loss can occur in some years in areas of heavy infestation (Sauerborn, 1991). Inoculation of soil with a soil borne pathogen, which attacks the parasite at the early developmental stages is advantageous as it may hinder the growth of the parasite and curtails its deleterious effects on hosts (Butler, 1995; Kroschel *et al*., 1996). A number of resistance mechanisms to *Striga* have been suggested (Hess *et al*., 1992; Babiker, 2007). These include low stimulant production, mechanical barriers to parasite ingress, chemical defense (antibiosis) in which the crop plants may produce chemical compounds that discourage subsequent development of *Striga* seedlings and hypersensitivity, where the host cells surrounding the endophytic part of the haustorium die and preclude further development of the parasite (Ejeta *et al*., 1993).

With regard to bio-control, fungi of the genus *Fusarium* are effective in controlling *S. hermonthica* (Del.) Benth. (Ciotola *et al*., 1995; Abbasher *et al.,* 1996). Work on bacteria as *Striga* suppressants was limited despite the recognized potential of such an approach and the anticipated ease of application in comparison to other biological agents (Berner *et al.,* 1995). Use of rhizobacteria for biological control of *Striga* is intriguing since they can easily be formulated as seed inoculants, thereby avoiding the need for application equipment, voluminous carriers and labour that would, otherwise be cost prohibitive. It was demonstrated that *A. brasilense* and *Striga* interacted during cereal root colonization as they compete for the host root surface Miche *et al*. (2000). Two strains of *A. brasilense* isolated from an African sorghum rhizosphere prevented germination of *Striga* seeds in presence of sorghum roots. *Azospirillum* cells suspended in a synthetic germination stimulant (GR24) did not inhibit *Striga* seeds germination, but did block

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radicle elongation. The radicles had an abnormal morphology and contained no vacuolated cells in the root elongation zone. However, lipophilic compounds extracted from the bacterium culture prevented germination of *Striga* seeds Miche *et al*. (2000). *Pseudomonads fluorescent,* because of nutritional versatility and fast growth rate, could rapidly become established in the rhizosphere, when routinely applied with cereal host seeds at planting (Kleopper *et al.*, 1980). Plant that are infected by *Striga* show lower level of indole-3-acetic acid (Press *et al*., 1999), whereas a number of microorganism increases root IAA content. The objectives of this study were to identify soil borne bacteria capable of suppressing, triggering suicidal germination and/or perturbing early developmental stages in *S. hermonthica* and develop an integrated *Striga* management strategy, which resides on biological control and tolerant or resistant sorghum cultivars.

MATERIALS AND METHODS

Two sets of green house experiments were conducted to study the effects of (i) bacterial isolates and strains on *Striga* incidence on sorghum cv. Abu Sabeen, (ii) bacterial isolates, strains and sorghum cultivars on *Striga* incidence.

Soil samples were collected from four locations in the Sudan (Shambat, Gadaref, Abuharaz & Wad Medani). The spread-plate method was used for isolation of 202 bacterial isolates as described by (Hassan *et al*., 2008). In addition, seven bacterial strains (*Azotobacter vienlandi, Pseudomonas putida*, *Azomonas* spp., *B. japonicum*, *Azospirillum brasilense, A. amazonas* & *Bacillus* spp.) were obtained from the Environment and Natural Resources Research Institute (ENRRI), the National Centre for Research and University of Khartoum, Khartoum, Sudan.

In all experiments, a soil mix made of river silt and sand (2:1 v/v) was sterilized in an oven at 160^{o}C for 4 h. The sterilized soil was used to fill plastic bags (19 cm diameter) with drainage holes at the bottom. *Striga* infestation was accomplished by mixing 10 mg of sterilized *Striga* seeds (*Ca* 1500 seeds) in the top 6 cm soil in each bag. Surface sterilized sorghum seeds (7/bag) were planted and immediately irrigated. Aliquots of the respective bacterial suspensions (15 mL each) were injected into the soil surface in each bag. Subsequent irrigations were made every 2 days. *Striga* infested and un-infested sorghum controls were included in each experiment for comparison. Emergent *Striga* plants (*Striga* incidence) were counted weekly starting three weeks after crop emergence. Sorghum and *Striga* height was measured at 15 weeks after sowing (WAS). In all experiments, treatments were arranged in factorial experiment in randomized complete block design with four replicates.

Effects of bacteria on *S. hermonthica* incidence on sorghum cv. Abu Sabeen. The experiment was carried out in the period 07 February to 21 June, 2006. A sterilized soil mix was prepared, infested with *Striga* and sown to sorghum cv. Abu Sabeen, as described above. Thirty six bacterial strains and isolates, selected on basis of their ability to suppress *Striga* seed germination under laboratory conditions (Hassan *et al*., 2008) were evaluated for ability to reduce parasitism on sorghum cultivar Abu Sabeen. Plants were thinned at 10 days after emergence to two plants/bag. *Striga* emergence, sorghum and *Striga* heights were measured as previously described.

Effects of bacteria and sorghum cultivar on *Striga* incidence. The experiment was conducted in the period 5 July to 1 October, 2007. Three bacterial strains *(P. putida, B. japonicum, A. brasilense)* an isolate (D46) and a combination between *P. putida and A. amazonas* were selected based on their ability to suppress S. *hermonthica* seed germination. The soil mix was prepared as described above. Three sorghum cultivars Abu Sabeen (*Striga* susceptible), Arfa Gadmac (*Striga* tolerant) and Mugawim Buda-1 (*Striga* resistant) were used. Sorghum thinning, *Striga* incidence, sorghum height and *Striga* heights were measured as shown above.

Statistical analysis. Data from the greenhouse experiments were transformed to log (x + 0.5) in which x is the number of *Striga* plants/bag and then subjected to analysis of variance (ANOVA). Means were tested for significance by LSD at 5%. The data were tabulated.

RESULTS

Effects of Bacterial Strains and Isolates on *S. hermonthica* Incidence on Sorghum cv. Abu Sabeen

Effects on *Striga.* *Striga* emergence was very low as only 5 *Striga* plants emerged on the untreated control (12 WAS) (Fig. 1). All bacterial strains and isolates, except isolates S9, G14 and *Bacillus* spp. (B3) reduced emergence of the parasite. Sorghum treated with isolates M20, S22, GSL, D8, S23 and *Bacillus* spp. (B2) displayed no *Striga* emergence.

Striga growth, as indicated by height, was differentially affected by the bacteria. Isolates S23, S22, G11, D20, D2, D50, D46, S25, D10, S10, D8, G18x, GSL, M2 and the bacterial strains *Bacillus* spp., *P. putida, Azotobacter* and the combination of *A. amazonas* and *P. putida* reduced *Striga* height (60 & 96%), significantly (Fig. 2). Isolate M34 and combination between *A. brasilense* and *P. putida*, on the other hand, increased *Striga* height.

Effects on Sorghum. The untreated *Striga* free plants were the tallest plants (average 154 cm). Un-checked *Striga* infestation reduced crop height by 64%. All bacterial strains and isolates increased sorghum height, significantly in comparison with the *Striga* infested control. The bacterial isolates M20, S25, S23, S19, S22 and bacteria strains *Bacillus* spp. and *P. putida* were the most effective. They increased sorghum height by 40 - 50% (Fig. 3).

Effects of Bacteria and Sorghum Cultivar on *Striga* Incidence

Effects on *Striga.* *Striga* infestation was influenced by the bacteria, the time the observation was made and by sorghum cultivar (Tables I-VI). At four WAS, *Striga* emergence was only observed on the un-inoculated sorghum cv. Abu

Table I. Effect of bacteria and sorghum cultivar on *Striga* incidence on sorghum (4WAS)

Treatment	*Striga* incidence (plants per bag)			
	Sorghum Cultivars			
	v1	v2	v3	Mean
B5S1	(0.70) 0	(0.70) 0	(0.70) 0	(0.70) 0
B4S1	(0.70) 0	(0.70) 0	(0.70) 0	(0.70) 0
B3S1	(0.70) 0	(0.70) 0	(0.70) 0	(0.70) 0
B2S1	(0.70) 0	(0.70) 0	(0.70) 0	(0.70) 0
B1S1	(0.70) 0	(0.70) 0	(0.70) 0	(0.70) 0
B0S1	(0.83) 0.3	(0.70) 0	(0.707) 0	(0.75) 0.1
mean	(0.73) 0.05	(0.71) 0	(0.71) 0	

LSD bacteria n.s
LSD cultivar n.s
n.s. =non-significant
( ) indicates square root transformed data (√x+0.5 x: variable)
v1 = Abu Sabeen, v2 = Arfa gadmac, v3= Mugawim Buda-1 S1: *Striga* infestation
B1: *P. putida*, B2: *A. brasilense*, B3: D46 isolate, B4: *P.putida +A. amazonas,* B5*: B. japonicum* B0: control

Table II. Effect of bacterial strains, isolates and cultivar on *Striga* incidence on sorghum (5WAS)

	Striga incidence (plants per bag)			
	Sorghum cultivars			
Treatment	v1	V2	v3	Mean
B5S1	(2.24) 8	(1.12) 1	(0.70) 0	(1.35) 3
B4S1	(1.79) 5	(0.96) 0.5	(0.70) 0	(1.15) 2
B3S1	(2.15) 6	(1.92) 4	(0.92) 1	(1.67) 3
B2S1	(2.67) 9	(0.70) 0	(0.70) 0	(1.36) 3
B1S1	(1.51) 4	(0.70) 0	(0.70) 0	(0.97) 1
B0S1	(2.78) 9	(1.19) 1	(0.92) 1	(1.63) 4
mean	(2.19) 7	(1.10) 1	(0.77) 0.17	
LSD interaction	(±1.435)			
LSD bacteria	(±0.828)			
LSD cultivar	(±0.585)			

( ) indicates square root transformed data (√x+0.5 x: variable)
v1 = Abu Sabeen, v2 = Arfa gadmac, v3= Mugawim Buda-1 S1: *Striga* infestation
B1: *P. putida*, B2: *A. brasilense*, B3: D46 isolate, B4: *P.putida +A. amazonas,* B5*: B. japonicum* B0: control

Table III. Effect of bacterial strains, isolates and cultivar on *Striga* incidence on sorghum (6WAS)

	Striga incidence (plants per bag)			
	Sorghum Cultivars			
Treatment	v1	v2	v3	Mean
B5S1	(5.2) 29	(1.93) 4	(1.06) 1	(2.73) 11
B4S1	(3.52) 16	(1.35) 2	(1.19) 1	(2.02) 6
B3S1	(3.79) 17	(3.29) 12	(1.06) 1	(2.71) 10
B2S1	(4.20) 19	(2.39) 8	(0.92) 1	(2.50) 9
B1S1	(2.20) 8	(1.40) 2	(1.41) 2	(1.67) 4
B0S1	(3.94) 19	(1.50) 3	(0.99) 1	(2.14) 7
Mean	(3.81) 18	(1.98) 5	(1.11) 1	
LSD interaction	(±1.934)			
LSD bacteria	(±1.117)			
LSD cultivar	(±0.789)			

( ) indicates square root transformed data (√x+0.5 x: variable)
v1 = Abu Sabeen, v2 = Arfa gadmac, v3= Mugawim Buda-1
B1: *P. putida*, B2: *A. brasilense*, B3: D46 isolate, B4: *P.putida +A. amazonas,* B5*: B. japonicum* B0: control S1: *Striga* infestation

Sabeen (Table I). At five WAS, *Striga* un-inoculated Abu Sabeen, sustained the highest infestation (9 *Striga* plants/bag) (Table II). Arfa gadmac and Mugawim Buda-1, on the other hand, sustained less *Striga* emergence. Sorghum inoculated with bacteria, irrespective of cultivar, sustained less *Striga* emergence than the respective un-inoculated controls. Sorghum, irrespective of cultivar, inoculated with *P. putida* and its combination with *A. amazonas* sustained the least infestation. Interaction of sorghum Abu Sabeen with *P. putida* alone and in combination with *A. amazonas* reduced *Striga* emergence by 56 and 44%, respectively. *Striga* emergence on Arfa gadmac and Mugawim Buda-1 was negligible.

At six WAS, *Striga* emergence showed differential response to crop cultivar and to the bacterial inoculation. Emergence of the parasite increased substantially on Abu Sabeen and was high on the un-inoculated treatment (19 *Striga* plants/bag) (Table III). On un-inoculated Arfa gadmac and Mugawim Buda-1, *Striga* emergence was negligible. *P. Putida* and its combination with *A. amazonas* reduced *Striga* infestation on Abu Sabeen albeit not significantly. *B. japonicum*, on the other hand, resulted in a significant increase in *Striga* emergence. *B. japonicum*, *P.*

Table IV. Effect of bacterial strains, isolates and cultivar on *Striga* incidence on sorghum (7WAS)

Treatment	*Striga* incidence (plants per bag)			
	Sorghum Cultivars			
	v1	v2	v3	Mean
B5S1	(6.48) 44	(2.95) 9	(1.96) 4	(3.80) 19
B4S1	(4.07) 19	(2.17) 5	(1.51) 3	(2.59) 9
B3S1	(5.02) 29	(3.28) 11	(2.50) 7	(3.60) 15
B2S1	(5.44) 33	(3.47) 13	(2.40) 8	(3.77) 18
B1S1	(3.6) 17	(1.98) 4	(2.6) 9	(2.78) 10
B0S1	(4.48) 23	(2.00) 4	(1.98) 5	(2.82) 10
mean	(4.86) 27	(2.64) 8	(2.17) 6	
LSD interaction	(±2.140)			
LSD bacteria	(±1.236)			
LSD cultivar	(±0.874)			

( ) indicates square root transformed data (√x+0.5 x: variable)
v1 = Abu Sabeen, v2 = Arfa gadmac, v3= Mugawim Buda-1 S1: *Striga* infestation
B1: *P. putida*, B2: *A. brasilense*, B3: D46 isolate, B4: *P.putida +A. amazonas,* B5*: B. japonicum* B0: control

Table V. Effect of bacterial strains, isolates and cultivar on *Striga* incidence on sorghum (8WAS)

	Striga incidence (plants per bag)			
	Sorghum Cultivars			
Treatment	v1	v2	v3	Mean
B5S1	(5.34) 34	(3.34) 11	(2.52) 7	(3.74) 17
B4S1	(2.63) 8	(2.00) 4	(2.09) 5	(2.2) 6
B3S1	(4.07) 18	(2.85) 9	(3.12) 10	(3.35) 12
B2S1	(3.43) 20	(3.89) 18	(3.47) 13	(3.59) 17
B1S1	(3.61) 18	(2.91) 10	(2.83) 10	(3.12) 12
B0S1	(3.40) 14	(2.34) 6	(2.31) 6	(2.68) 9
mean	(3.75) 18	(2.89) 9	(2.72) 8	
LSD interaction	(±2.416)			
LSD bacteria	(±1.395)			
LSD cultivar	(±0.98)			

( ) indicates square root transformed data (√x+0.5 x: variable)
v1=Abu Sabeen, v2=Arfa gadmac, v3=Mugawim Buda-1 S1: *Striga* infestation
B1: *P. putida*, B2: *A. brasilense*, B3: D46 isolate, B4: *P.putida +A. amazonas,* B5*: B. japonicum* B0: control

Fig. 1 Effects of bacterial strains and isolates on *Striga* incidence on sorghum (cv. Abu Sabeen), at 12 WAS (Vertical bar indicates LSD)

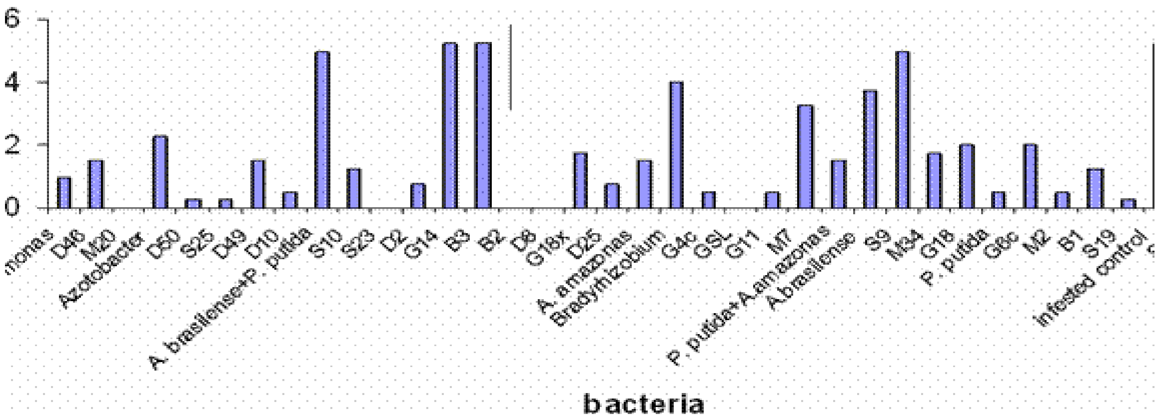


Fig. 2. Effects of bacterial strains and isolates on *Striga* height at 15 WAS, (Vertical bar indicates LSD)

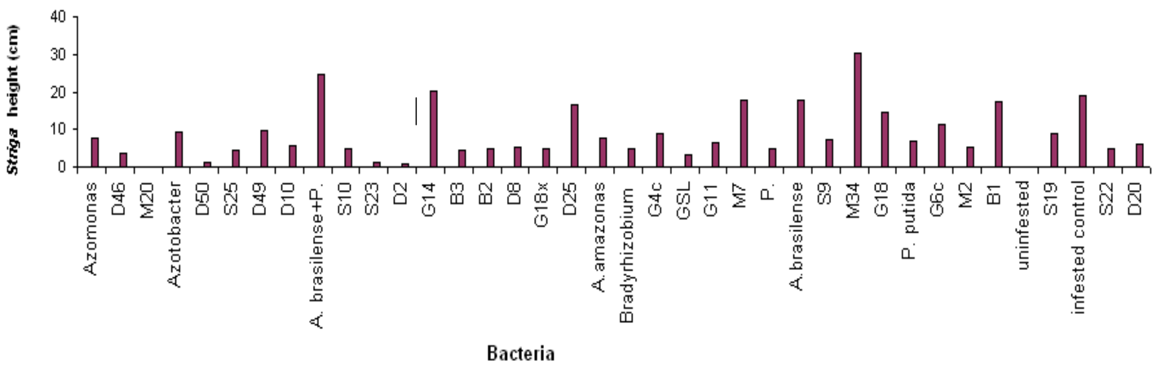
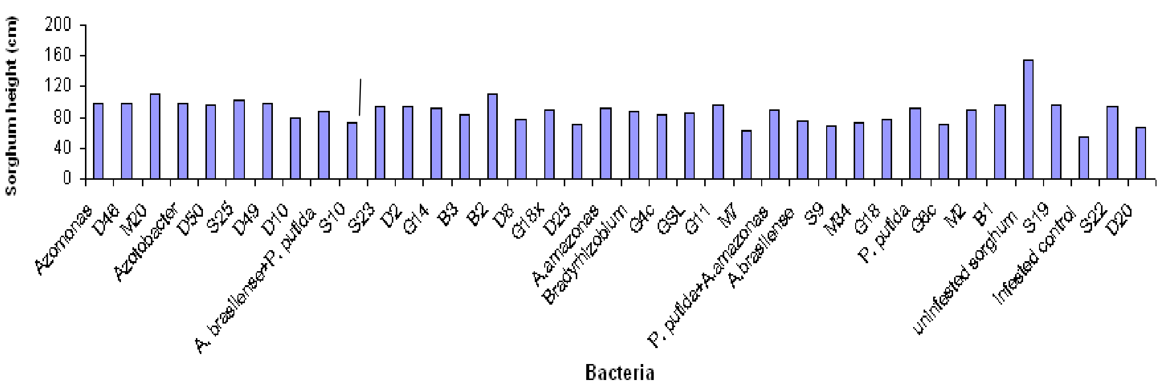


Fig. 3. Effects of bacterial strains and isolates on sorghum at 15 WAS, (Vertical bar indicates LSD)



putida and its combination with *A. amazonas* had no effect on *Striga* emergence on Arfa gadmac, while *A. brasilense* and isolate D46 resulted in a significant increase. *Striga* emergence was significantly low (1-2 plants/bag) on Mugawim Buda-1, irrespective of bacterial inoculation (Table III).

At seven WAS, *Striga* emergence increased on all cultivars, with Abu Sabeen sustaining the highest emergence. Emergence of the parasite displayed differential response to bacterial inoculation. In general, it followed the same trends as at six WAS (Table IV).

At eight WAS, the un-inoculated sorghum cultivars Abu Sabeen, Arfa gadmac and Mugawim Buda-1 showed 14, 6 and 6 *Striga* plants/bag, respectively (Table V). *P. putida* and *A. brasilense* had no effect on *Striga* emergence on Abu Sabeen and the combination between *P. putida* and

Fig. 4. Effects of bacteria and sorghum cultivars on *Striga* height, at 7 WAS

Key: v1: Abu Sabeen, v2: Arfa gadmac, v3: Mugawim Buda-1. B1: *P. putida*, B2: *A. brasilense*, B3: D46 isolate, B4: *P. putida* plus *A. amazonas,* B5:*B. japonicum,* B0: control, S1: *Striga*, S 0: without *Striga*. Vertical bar indicates LSD

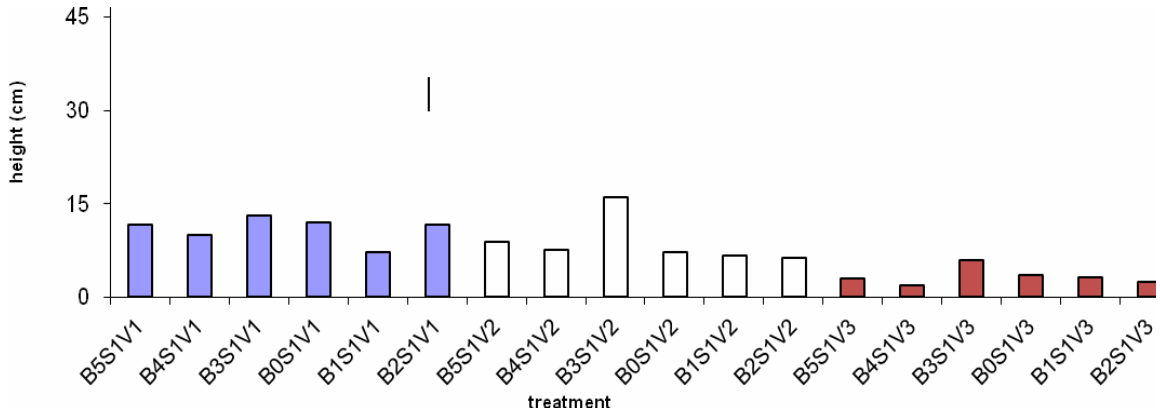


Fig. 5. Effects of bacteria on sorghum height in presence and absence of *Striga*, at 7 WAS

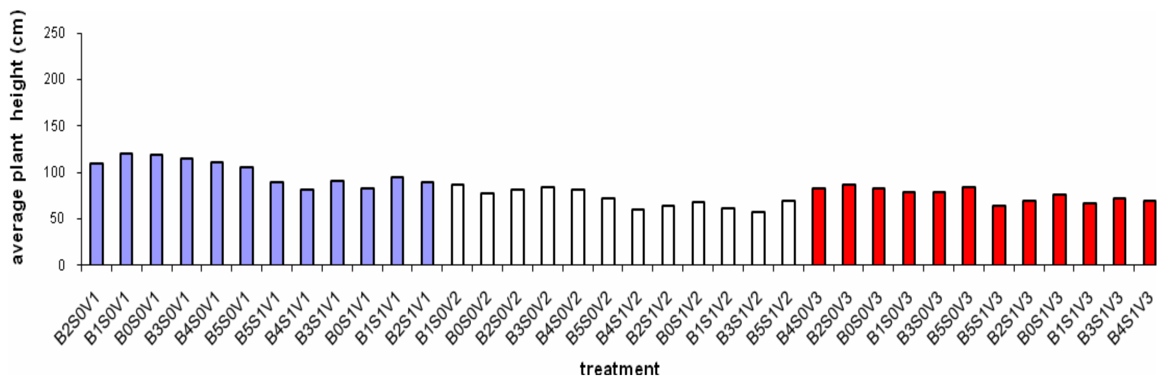
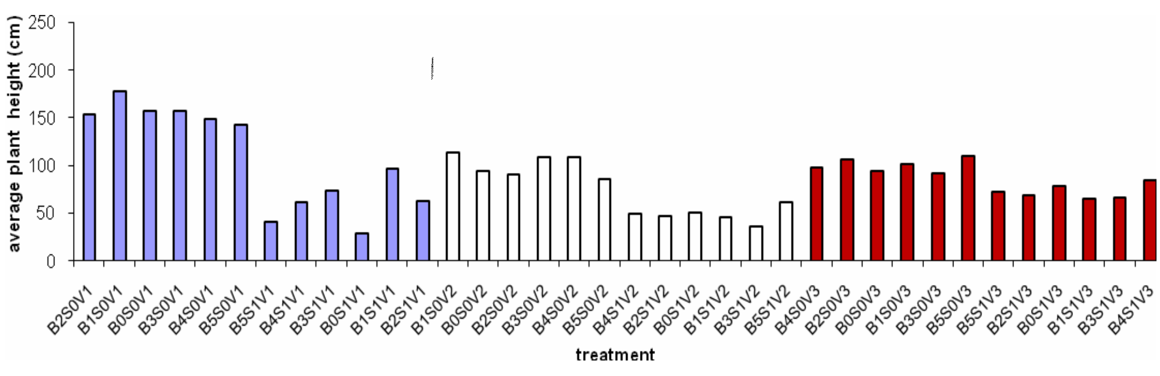


Fig. 6. Effects of bacteria on sorghum height in presence and absence of *Striga*, at 11 WAS

Key: v1: Abu Sabeen, v2: Arfa gadmac, v3: Mugawim Buda-1. B1: *P. putida*, B2: *A. brasilense*, B3: D46 isolate, B4: *P. putida* plus *A. amazonas,* B5*: B. japonicum,* B0: control, S1: *Striga*, S 0: without *Striga*. Vertical bar indicates LSD.



A. amazonas reduced *Striga* emergence albiet not significantly. Isolate D46 and *B. japonicum*, on the other hand, effected a significant increase in *Striga* incidence and emergence of the parasite was highest (34 plants/bag) on sorghum inoculated with *B. japonicum*. On Arfa gadmac *Striga* emergence was only reduced on inoculation with *P. putida* and *A. amazonas* combination. The other inoculants a significant increase in emergence of the parasite. On Mugawim Buda-1 *P. putida*, *A. brasilense* and isolate D46, on the other hand, caused a significant increase in *Striga* emergence (Table V).

At nine WAS or more *Striga* emergence displayed a sharp decline and differences between treatments were not significant (Table VI).

At seven WAS, *Striga* growth, irrespective of treatment, was less vigorous on Mugawim Buda-1 than on Abu Sabeen and Arfa gadamac*.* *Striga* plants on un-inoculated sorghum Abu Sabeen, Arfa gadmac and

Table VI. Effect of bacterial strains, isolates and cultivar on *Striga* incidence on sorghum (9WAS)

Striga incidence (plants per bag)				
	Sorghum Cultivars			
Treatment	v1	v2	v3	Mean
B5S1	(5.03) 30	(3.98) 16	(2.96) 10	(3.99) 18
B4S1	(2.59) 8	(2.48) 7	(2.67) 8	(2.58) 8
B3S1	(3.74) 15	(2.77) 9	(3.57) 13	(3.36) 12
B2S1	(3.64) 16	(3.39) 13	(3.73) 14	(3.59) 14
B1S1	(3.11) 13	(3.28) 12	(3.23) 13	(3.21) 12
B0S1	(3.3) 12	(2.85) 8	(3.54) 13	(3.24) 11
mean	(3.57) 16	(3.13) 11	(3.28) 11	

LSD bacteria n.s; LSD cultivar n.s; n.s. =non-significant
( ) indicates square root transformed data (√x+0.5 x: variable)
v1 = Abu Sabeen, v2 = Arfa gadmac, v3= Mugawim Buda-1 S1: *Striga* infestation
B1: *P. putida*, B2: *A. brasilense*, B3: D46 isolate, B4: *P.putida +A. amazonas,* B5*: B. japonicum* B0: control

Table VII. Effect of bacterial strains, isolates and cultivar on *Striga* incidence on sorghum (10WAS)

Striga incidence (plants per bag)				
	Sorghum Cultivars			
Treatment	v1	v2	v3	Mean
B5S1	(1.57) 2	(3.30)11	(2.25) 5	(2.37) 7
B4S1	(1.76) 3	(1.51)2	(2.91) 8	(2.06) 6
B3S1	(2.17) 5	(1.4)2	(2.61) 7	(2.07) 5
B2S1	(1.87) 3	(1.99)4	(4.10) 21	(2.65) 10
B1S1	(2.27) 5	(1.73)3	(2.48) 6	(2.16) 6
B0S1	(1.05) 1	(2.1) 4	(3.35) 11	(2.19) 6
Mean	(1.78) 4	(2.02)5	(2.95) 11	
LSD interaction	(±1.902)			
LSD bacteria	(±1.098)			
LSD cultivar	(±0.776)			

( ) indicates square root transformed data (√x+0.5 x: variable)
v1 = Abu Sabeen, v2 = Arfa gadmac, v3= Mugawim Buda-1 S1: *Striga* infestation
B1: *P. putida*, B2: *A. brasilense*, B3: D46 isolate, B4: *P.putida +A. amazonas,* B5*: B. japonicum* B0: control

Table VIII. Effect of bacterial strains, isolates and cultivar on *Striga* incidence on sorghum (11WAS)

Striga incidence (plants per bag)				
	Sorghum Cultivars			
Treatment	v1	v2	v3	Mean
B5S1	(1.19) 1	(2.13) 5	(2.01) 4	(1.78) 3
B4S1	(1.38) 2	(1.48) 2	(2.30) 5	(1.72) 3
B3S1	(1.45) 2	(1.12) 1	(1.93) 4	(1.50) 3
B2S1	(0.92) 1	(1.30) 2	(2.56) 7	(1.59) 3
B1S1	(1.40) 2	(1.28) 2	(2.13) 4	(1.61) 3
B0S1	(0.83) 1	(0.83) 1	(2.02) 6	(1.23) 2
Mean	(1.201) 1	(1.36) 2	(2.16) 5	
LSD interaction	(±1.406)			
LSD bacteria	(±0.812)			
LSD cultivar	(±0.574)			

( ) indicates square root transformed data (√x+0.5 x: variable)
v1 = Abu Sabeen, v2 = Arfa gadmac, v3= Mugawim Buda-1 S1: *Striga* infestation; B1: *P. putida*, B2: *A. brasilense*, B3: D46 isolate, B4: *P.putida +A. amazonas,* B5*: B. japonicum* B0: control

Mugawim Buda-1 showed an average height of 12, 7 and 4 cm, respectively. Inoculation of sorghum cv. Abu Sabeen, with *P. putida* reduced *Striga* height by 42%. Inoculation of sorghum cv. Mugawim Buda-1 with a combination of *P. putida* and *A. amazonas* reduced *Striga* height by 50%. Inoculation of sorghum cv. Arfa gadmac with isolate D46, on the other hand, increased *Striga* height by 56% (Fig. 4).

Effects on sorghum height. At 7 WAS*,* the bacterial strains and isolates had no adverse effects on *Striga* free sorghum growth as indicated by height. *Striga*, irrespective of crop cultivar, bacterial strain and isolate, reduced sorghum height, significantly (Fig. 5).

At 11 WAS, *Striga*, irrespective of the bacterium used, reduced sorghum growth, significantly in comparison to the respective *Striga* free control. Un-restricted *Striga* growth reduced height of Abu Sabeen, Arfa gadamac and Mugawim Buda-1 by 82, 46 and 16%, respectively (Fig. 6). In Abu Sabeen, all bacterial strains and isolates increased sorghum height by 29-70% in comparison to the respective *Striga* infested un-inoculated control. Arfa gadmac inoculated with isolate D46 displayed significant decrease in height in comparison to the control. Inoculation with *B. japonicum* increased height, albeit not significantly. In Mugawim Buda-1, all bacterial strains and isolates, except the combination between *P. putida* and *A. amazonas,* had no effect on sorghum height in comparison to the *Striga* infested un-inoculated control.

DISCUSSION

The present study was undertaken to evaluate the potentials of native soil borne bacteria to perturb early stages of *Striga* growth. The study focused on inhibition and/or perturbation of early growth stages of the parasite in an endeavour to develop an integrated control strategy that takes into account the low purchasing power of subsistence farmers, predominance of illiteracy and lack of access to information and inadequate extension service. The strategy should be simple and easy to implement. Referring to the available published literature, this study provides the first detailed investigation on the possible use of soil borne bacteria for the control of *Striga hermonthica* through inhibition and/or perturbation of the early developmental events in the parasite life cycle.

The results revealed that some of the bacterial strains and isolates reduced and delayed *Striga* emergence on sorghum, others reduced *Striga* infestation and growth, while some had enhancing effects. Some bacterial strains and isolates increased sorghum growth in comparison to the *Striga* infested un-treated control and bacteria strains and isolates were more suppressive to *Striga* emergence on resistant and tolerant sorghum cultivars than on the susceptible. Sorghum inoculated with isolate M20, S22, S23, B2, D8 and GSL sustained no *Striga* emergence (Fig. 1). *P. putida,* D20, S19, M2, S25 and D50 showed significant reduction of *S. hermonthica* emergence at 12 WAS. The observed reduction and delay in *Striga* emergence caused by bacterial strains and isolates may be attributed to reduced germination, reduced haustorium initiation and attachment (Hassan *et al*., 2008). Auxin and auxin-like compounds have been reported to inhibit *Striga* (Keyes *et al.*, 2000). *Azotobacter* spp., *P. putida*, *A. brasilense* and *Klebsiella* spp. are known to produce auxin and auxin-like compounds in plants rhizosphere (Frankenberger & Arshad, 1995). However, the decline in the suppressive effects of the strains and isolates with time may be due to competition with soil microflora, disintegration of inoculated bacteria and/or to utilization of precursors of compounds initially present at low concentrations in soil. The differential responses of sorghum varieties to *Striga* infestation confirm previous findings (Babiker, 1997). Abu Sabeen, *Striga* susceptible, sustained the highest *Striga* infestation, followed by Arfa gadmac, *Striga* tolerant, which supported moderate infestation, while Mugawim Buda-1, *Striga* resistant, supported the least infestation. Inoculation of these cultivars with bacteria delayed and reduced infestation (Tables I-VI). The reduced infestation suggests that an integrated *Striga* management comprising tolerant and/or resistant crop cultivars together with bacterial inoculation may provide adequate control of the parasite. At least a considerable delay in *Striga* infestation could be displayed on inoculation of sorghum with bacteria. Delayed infestation by the parasite was reported to cause less damage than early infestations (Delft & Van, 1997). Some soils are suppressive to the parasite and their suppressiveness was attributed to microbial population (Ciotola *et al*., 1995). Of the 757 soil inhabiting bacteria screened for ability to produce ethylene, 229 isolates were reported to be capable of producing the phytohormones (Nagahama *et al*., 1992). Resistance varieties are considered the cheapest methods and most easy to apply (Parker & Riches, 1993). However, their number is limited; they are often low yielder with inferior grain qualities. Furthermore, resistance often varies with locality. Currently, there is no universally accepted and adopted control method for *Striga*. The present study indicated the possibility that good control of the parasite may be achieved by manipulation of the host-rhizosphere microorganisms in combination with *Striga* tolerant sorghum cultivars.

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