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Potential of *Trichoderma harzianum* as a biocontrol agent against *Striga hermonthica* in sorghum

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A B S T R A C T

A series of laboratory and greenhouse experiments were conducted at the Environment, Natural Resources and Desertification Research Institute (ENDRI), National Centre for Research (NCR) and College of Agricultural Studies, Sudan University of Science and Technology (SUST), Sudan, to examine the efficacy of the fungus *Trichoderma harzianum*, culture age, inoculum type, application time, fungal extract, compost and bacterial strain on *Striga hermonthica* germination and sorghum infestation. The highest significant (P≤0.05) inhibition on *S. hermonthica* germination was obtained at 10 days by *T. harzianum* culture as compared to both controls. Application of all *T. harzianum* aqueous and ethyl acetate extracts concentrations significantly (P≤0.05) reduced *S. hermonthica* seed germination as compared to the corresponding control. *T. harzianum* inoculum extracted by ethyl acetate reduced germination by 97%. *T. harzianum* aqueous 100% induced germination during conditioning by 64 % in response to GR24 (0.1ppm). All types of *T. harzianum* inoculum (Autoclaved, culture and filtrate) significantly (P≤0.05) reduced germination, with application of *T. harzianum* culture filtrate gave the highest reduction on germination as compared to control and other inoculums. Application of the 3 inoculums at 2 hours reduced germination percentage more than at 4 hours. Filtrate and culture inoculums at 2 hours reduced germination by 79 and 68%, respectively. The combination of compost 100%+ *T. harzianum* + BMP+*Flavobacterium* reduced germination by 68%. The greenhouse results showed that the combination of compost plus BMP+ *Flavobacterium* gave lowest number of *S. hermonthica* emergence and the highest sorghum plant height. The combinations of compost with *T. harzianum* and with BMP+ *Flavobacterium* significantly reduced *S. hermonthica* dry weight, increased sorghum shoot and root dry weight insignificantly as compared to the control.

Introduction

Weeds are the most universal of all crop pest, proliferating each year on every farm in Africa (Obuo *et al.,* 1997). *Striga hermonthica*, *S. asiatica* (L.) Kuntze and *S. gennerioides* (Willd) Vatke are recognized as the largest biological constraint to food production in Africa. The genus *Striga* comprises about 30 obligate root parasitic plants, commonly known as witch weed (Babiker, 2007; Spalak *et al.,* 2013). Ejeta and Butler (1993) reported that sorghum production is constrained by many factors and one of the most serious threats is *Striga*. Several strategies have been developed for control of parasitic weeds which include improved cultural practices, breeding using wild and cultivated germplasms as sources of resistance, the use of chemical fertilizer(or) and phosphate - based seed priming (Jamil,2012). Chemical control is inappropriate and nondiscriminatory putting human and animal health at risk, as well as contaminating the environment (David, 2001). Therefore the use of integrated management of control methods including biological control can offer an alternative approach to control parasitic weeds.

Fungi have received great attention as biocontrol organism against pest (Benitez *et al.,* 2004). Regarding this, biological control using microorganisms (especially phytopathogenic fungi) showed high efficacy in controlling *S. hermonthica* under controlled and field condition (Zahran, 2008). The bio-agent *Trichoderma harzianum* is abundant in soil under all climates over different geographical regions. It was known as efficient decomposers of various substrates, having rapid growth rates and antimicrobial properties. Moreover, Celar *et al.,* (2005) stated that *Trichoderma* spp can be used as plant growth promoting fungi. They increase germination rate and percentage of emergence, plant height, leaf area and dry weight. It was estimated that 90% of fungi utilized in biocontrol were *Trichoderma* strains (Benítez *et al.,* 2004). *Trichoderma* can act indirectly, by modifying environmental conditions, promoting plant growth and induced plant defensive mechanisms and antibiosis, or directly, by mechanisms such as mycoparasitism, competition, enzyme activity (Vinale *et al.,* 2008).

Microorganisms can produce phytohormones, such as indole acetic acid (IAA) and cytokinins which have a positive effect on plant growth and parasitic weeds. Phytohormones generated by bacteria can be taken up by plants leading to an increase in hormone levels in these plants (Idris *et al.,* 2007). The bio-agents naturally present in soil are usually in low population thus increasing its population density through artificial inoculation is necessary to achieve successful control of target weed. Zhen *et al.,* (2014) reported that compost alone or in combination with bacteria fertilizer enhances soil enzyme activities, increase soil respiration rate and cultivable microorganisms whereas chemical fertilizers degrade the activities of soil enzymes.

The objective of this study was to investigate the effects of *Trichoderma harzianum* fungi, bacterial strains and compost on *Striga hermonthica* incidence on sorghum plants.

Materials and Methods

A series of laboratory and greenhouse experiments were conducted at the Environment, Natural Resources and Desertification Research Institute (ENDRI), National Centre for Research (NCR) and College of Agricultural Studies, Sudan University of Science and Technology (SUST), Sudan. Laboratory and greenhouse experiments were arranged in a Randomized Complete Design (RCD) and a Randomized

Complete Block Design (RCBD), respectively, with four replicates.

Laboratory experiments

S. hermonthica seeds conditioning and germination

S. hermonthica seeds were collected from sorghum field in Sinnar State, Sudan in 2015. The seeds were sterilized and conditioned as described by Ahmed *et al.,* (2013). The sterilized discs, placed in 9 cm petri dishes lined with filter paper (Whatman No.1), were moistened with 5ml of distilled water, nutrient broth medium inoculated or un-inoculated with respective microbial strains or compost (plant material). About 25-50 surface disinfected *S. hermonthica* seeds were sprinkled on each of the glass fiber discs in each Petri dish. The dishes were sealed with parafilm, placed in black polythene bags and incubated at 30°C in the dark for 10 days. For germination, each disc was treated with20µl of GR24 at 0.1or 0.01ppm, then the seeds were re-incubated in the dark at 30°Cand examined for germination 24h later using a stereomicroscope as described by Gafar *et al.,* (2015).

Microbial inoculum preparation

T. harzianum was obtained from Faculty of the Agriculture, Omdurman Islamic University. *T. harzianum* cultured on Potato Dextrose Agar medium (PDA), amended with 0.05g/l chloramphenicol and stored in the refrigerator at 4°C for further examination. The fungus was mass cultured aseptically in 90mm diameter Petri dishes containing 15ml of autoclaved PDA medium. The plates were incubated in the dark at 28°C for 7 days. On the seventh day, spore suspensions from the fungal inoculum was prepared by flooding the surface of the agar slant with 10ml sterile distilled water and the culture surface gently scraped to dislodge the spores. The spore suspension derived from one Petri plate, was transferred to 500ml flask containing 200ml sterile distilled water. Flask was shaken for 2 minutes to ensure that the spores were properly mixed. Three concentrations of the fungal strain (spore) were prepared (75, 50 and 25%). The fungal spore count for fungal strains was determined with a haemocytometer, so that the final counts were 0.58×10^7 spore/ml.

The combination of *Flavobacterium* and *Bacillus megatherium* var. *phosphaticum* (BMP) strains cultured in meat extract agar medium, was obtained from Biofertilizers and Biopesticide Department, ENDRI, NCR.

Effects of *T. harzianum* culture age on *S. hermonthica* germination

The *T. harzianum* was grown in 90mm Petri dishes containing PDA medium at 28°C for 7days. Autoclaved Erlenmeyer flasks (500ml) containing 250ml PD broth were inoculated with 8ml mycelium plugs of the fungus. The flasks were incubated under shaking at 28°C in a growth chamber for 10, 15, 20, 25 and 30 days. *S. hermonthica* seeds were treated with each *T. harzianum* culture, then the seeds were incubated for 10days in the dark at 30°C. GR24 (0.1ppm) was applied to each disc then re-incubated for 24h and examined for germination using a stereomicroscope. Distilled water and PD broth medium were used as control for comparison.

Effects of *T. harzianum* culture, culture filtrate, sterilized culture and application time on *S. hermonthica* germination

Three *T. harzianum* inoculum types (culture, filtrate culture and sterilized culture) were used in this experiment. Inoculums were prepared by adding 8ml mycelium plugs of the fungus to 3 sterilized Erlenmeyer flasks

(500ml) containing 250ml PD broth, then incubated under shaking at 28°C for 10days. After incubation time, the filtered inoculum was prepared through a sterile glass funnel (pore 100µM), while the sterilized inoculum was made by autoclaving the culture at 121^{o}C and 15ib/inch^{2} for 30min.

The 3 inoculums were added to *S. hermonthica* seeds and incubated for 0, 3, 6 and 9 days. GR24 (0.1ppm) was applied to *S. hermonthica* seeds and re-incubated for 24h and examined for germination by using a stereomicroscope (as described by Gafar *et al.,* 2015). Distilled water and PD broth medium were used as control for comparison.

Effects of *T. harzianum* ethyl acetate extract and application time on *S. hermonthica* germination (during conditioning)

T. harzianum growth in PD broth was extracted using ethyl acetate solvent. Then the extraction was diluted to four concentrations (25, 50, 75 and 100%). *Striga* seeds conditioned in ethyl acetate extracts were incubated for 3, 6 and 9 days. Distilled water and ethyl acetate were used as control. Germination bioassays were performed as described previously (Gafar *et al.,* 2015).

Effects of *T. harzianum* inoculums persistent on *S. hermonthica* germination

This experiment was conducted to study the effect of *T. harzianum* inoculums (culture, sterilized culture and filtrate) and incubation period (2 and 4 hours) on *Striga* germination. The inoculums were prepared as described previously. *S. hermonthica* seeds were treated with GR24 at 0.1ppm and incubated for 2 and 4 hours. Then *T. harzianum* inoculums were applied to *S. Hermonthica* seeds, re-incubated 24h and examined for germination. Distilled water and PD broth medium were used as control.

Effects of *T. harzianum*, bacterial strains and compost on *S. hermonthica* germination

This experiment was conducted to investigate the effects of *T. harzianum* fungi, bacterial strains and compost on *S. hermonthica* germination. The fungal culture was prepared as described above. Bacterial strains (BMP+*Flavobacterium*) were grown in 90mm Petri dishes containing meat extract medium incubated at 30°C for 2days. Two concentrations of the compost aqueous extract, 50 and 100%, were prepared. *S. hermonthica* `seeds were treated with the fungi, bacterial strains or compost extracts either alone or in combinations. The treatments were incubated for 10 days. GR24 (0.1ppm) applied to *S. hermonthica* seeds and re-incubated 24h and examined for germination as described above. Distilled water, PD and meat extract broth media were used as control for comparison.

Greenhouse experiment

This experiment was conducted to study the effects of *T. harzianum*, bacterial combination (BMP+*Flavobacterium*) and compost on *S. hermonthica* incidence and sorghum performance. Plastic pots (19cm diameter), with drainage holes at the bottom, were filled with soil mixture (7Kg/pot) of river silt and sand (1:1v/v). Artificial infestation of soil was accomplished by mixing *S. hermonthica* seeds (1g) with 1kg soil, *S. hermonthica* infested and uninfested controls were included for comparison. *Sorghum bicolor* seeds (5/pot) were sown at 2cm soil depth. The pots were subsequently irrigated every 2 days. *S. bicolor* seedlings were thinned to 2 plants per pot after 2 weeks of sowing. Five grams of *T. harzianum* inoculum carried on rice were added in each pot at sowing where applicable. Five milliliters per plant of bacterial combination (BMP+*Flavobacterium*) broth was inoculated to seedlings after thinning where applicable. Fifteen grams per pot of compost were added to the pots before sowing where applicable.

Data collected for *S. hermothica* emergence were measured at 2, 4, 6 and 8 weeks after sowing (WAS) and dry weight. Data collected for sorghum growth were plant height (at 2, 4, 6 and 8 WAS), shoot and root dry weight.

Statistical analysis

Prior to analysis data on percentage (germination) were arcsine transformed, data on *S. hermonthica* emergence and dry weight were square root transformed to fulfill ANOVA requirements. The analysis were performed across experiments using Microsoft Excel. Means separations were made by the LSD at 5%.

Results and Discussion

Effects of *T. harzianum* culture age on *S. hermonthica* germination

Results presented in table 1 elucidate that the germination of *S. hermonthica* seeds increased by increasing *T. harzianum* culture age. The highest significant (P≤0.05) inhibition on germination obtained by 10 days culture as compared to both controls.

Effects of *T. harzianum* aqueous extract on *S. hermonthica* germination

The results in table 2 show that application of all *T. harzianum* aqueous extract concentrations significantly (P≤0.05) reduced *S. hermonthica* seed germination during and after conditioning in response to GR24 (0.1 and 0.01ppm) as compared to the corresponding control.

There were no significant differences in germination between different concentrations. *T. harzianum* aqueous extract 100% induced germination during and after conditioning by 64 – 33% respectively, in response to GR24 (0.1ppm).

Effects of *T. harzianum* inoculum types and application time on *S. hermonthica* germination

All types of inoculums significantly (P≤0.05) reduced germination when applied at 6 and 9days (Table 3). Generally, application of *T. harzianum* culture filtrate gave the highest reduction on germination as compared to control and other types of inoculum, it significantly (P≤0.05) inhibited germination by 68, 54 and 46% when applied at 3, 6 and 9days as compared to medium control.

Effects of *T. harzianum* inoculum extracted by ethyl acetate and application time on *S. hermonthica* germination

All concentrations of *T. harzianum* inoculum extracted by ethyl acetateat all application times significantly (P≤0.05) reduced *S. hermonthica* germination as compared to the controls (Table 4). The increasing of application time reduced *S. hermonthica* germination. Application of *T. harzianum* extract concentrations (100, 50 and 75%) at 9days gave the highest inhibition on *S. hermonthica* germination by 97, 95 and 94%, respectively.

Effects of *T. harzianum* inoculums persistent on *S. hermonthica* germination

All inoculum types applied at 2 and 4 hours after incubation significantly (P≤0.05) reduced *S. hermonthica* germination as compared to the medium control (Table 5). Application of the 3 types of inoculums at 2 hours reduced germination more than at 4 hours. Filtrate and culture inoculum at 2 hours reduced germination by 79 and 68%, respectively.

Effects of *T. harzianum*, bacterial strains and compost on *S. hermonthica* germination

The results in table 6, show that all treatments significantly (P≤0.05) reduce *S. hermonthica*

germination as compared to the corresponding control, except compost extract 50% concentration. The combination of compost 100%+ *T. harzianum* + BMP+*Flavobacterium* gave the highest germination reduction by 68%, followed by compost 100%+BMP+*Flavobacterium* which reduced germination by 60%.

Greenhouse experiment

Effects of compost, *T. harzianum* and bacteria on *S. hermonthica* emergence

Results showed that at 2 weeks after sowing application of BMP+ *Flavobacterium* alone or in combination with compost and *T. harzianum* alone significantly (P≤0.05) reduced *S. hermonthica* emergence as compared to the control (Table 7). At 4, 6 and 8 WAS the combination of compost with *T. harzianum* and with BMP+ *Flavobacterium* gave an insignificant reduction on*S. hermonthica* count. The overall mean showed that the lowest number of *S. hermonthica* emergence was obtained by the combination of compost plus BMP+ *Flavobacterium*.

Effects of compost, *T. harzianum* and bacteria on sorghum plant height

Application of all treatments gave an insignificant effect on sorghum plant height (Table 8). The overall mean showed that the highest sorghum height was obtained by the combination of compost plus BMP+ *Flavobacterium*.

Effects of compost, *T. harzianum* and bacteria on sorghum and *S. hermonthica* dry weight

The combination of compost with *T. harzianum* and with BMP+ *Flavobacterium* increased sorghum shoot dry weight insignificantly as compared to the infested control (Table 9). *T. harzianum* alone or in combination with compost increased sorghum root dry weight insignificantly as compared to the control. Application of the combination of compost with *T. harzianum* and with BMP+ *Flavobacterium* significantly (P≤0.05) reduced *S. hermonthica* dry weight as compared to the control.

Parasitic weeds can be controlled either by preventing seed germination or enhancing germination in the absence of host plants, a phenomenon commonly referred to as inefficient germination (Rubiales and Fernández-Aparicio, 2012).

Results of laboratory experiments in this study revealed that application of all *T. harzianum* aqueous (types) and ethyl acetate extracts concentrations significantly (P≤0.05) reduced *S. hermonthica* seed germination during and after conditioning in response to GR24 (0.1 and 0.01ppm) as compared to the corresponding control. The increasing of application time reduced *S. hermonthica* germination. The highest significant (P≤0.05) inhibition on germination was obtained by 10 days old culture as compared to both controls. This can be attributed to the toxic secondary metabolites which are commonly implicated in the biocontrol activity of soil borne microorganisms (Kumar *et al.,* 2014).

Application of *T. harzianum* culture filtrate gave the highest reduction on germination as compared to control and other inoculums. All inoculum types (filtrate, culture and sterilized) applied at 2 and 4 hours significantly (P≤0.05) reduced *S. hermonthica* germination as compared to the medium control. Filtrate and culture inoculum at 2 hours reduced germination by 79 and 68%, respectively. This may be possibly be due to production of a range of toxic secondary metabolites, including gliovirin, gliotoxin, viridian, and viridiol, of which viridiol is strongly

phytotoxic by *Trichoderma* spp. (Jones and Hancock, 1987). Some *Trichoderma* spp. also possesses a high level of rhizosphere competence (Harman, 2000). Mabrouk *et al.*, (2014) reported that living and heat-kill cells of the *Rhizobium leguminosarum* strain P.SOM induce in pea roots systemic resistance to infection by *Orobanche crenata*.

In addition the combination of compost extracted at 100%concentration + *T. harzianum* + BMP+*Flavobacterium* gave the highest Striga seeds germination reduction (68%), followed by compost 100%+BMP+*Flavobacterium* (60%). Lowest number of *S. hermonthica* emergence was obtained by the combination of compost plus BMP+ *Flavobacterium*. Application of the combination of compost with *T. harzianum* and with BMP+ *Flavobacterium* significantly ($P \leq 0.05$) reduced *S. hermonthica* dry weight as compared to the control. Hassan *et al.*, (2009) reported that some bacterial isolates and strains have both detrimental and positive effects on *Striga* control and sorghum growth.

Table.1 Effects of *T. harzianum* culture age on *S. hermonthica* germination

***T. harzianum* culture age**	**Germination (%)**
Water (control)	70.72* (88.64)**
Medium (control)	62.81 (79.03)
10days	33.98 (31.30)
15 days	34.33 (31.94)
20 days	38.97 (39.60)
25 days	45.92 (51.59)
30 days	45.27 (50.47)
LSD	**6.73**

*Data out of brackets are arcsine transformed for analysis.
**Data between brackets are original data

Table.2 Effects of *T. harzianum* aqueous extract on *S. hermonthica* germination

***T. harzianum* aqueous extract conc.**	**GR24**	**Germination %**	
		After conditioning	**During conditioning**
0% (water)	**0.1**	75.20* (93.43)**	90.00 (100.00)
	0.01	58.51 (72.48)	69.51 (85.97)
25%	**0.1**	49.48 (56.98)	81.30 (91.86)
	0.01	44.41 (48.98)	55.16 (67.23)
50%	**0.1**	41.25 (43.49)	56.94 (69.72)
	0.01	42.43 (45.59)	57.96 (71.13)
100%	**0.1**	35.32 (33.76)	55.58 (67.34)
	0.01	35.07 (33.32)	55.97 (68.45)
LSD *T. harzianum* aqueous conc.		**5.66**	**6.78**
LSD GR24		**4.38**	**5.25**
LSD Interaction		**9.80**	**11.74**

*Data out of brackets are arcsine transformed for analysis.
**Data between brackets are original data.

Table.3 Effects of *T. harzianum* inoculum types and application time on *S. hermonthica* germination

Time (days)	Germination (%)				
	Water	Medium	*T. harzianum* inoculum type		
			Sterilized culture	Culture	Culture filtrate
0	67.35* (85.14)**	59.14 (71.88)	43.06 (46.70)	50.81 (60.03)	47.74 (52.62)
3	68.06 (85.83)	65.23 (82.07)	49.43 (57.60)	47.81 (54.85)	30.50 (26.26)
6	64.27 (81.11)	56.84 (69.80)	35.08 (33.05)	41.28 (43.68)	33.74 (32.07)
9	67.77 (85.59)	57.23 (70.29)	56.04 (68.59)	46.42 (52.47)	37.57 (37.76)
LSD Inoculum type			**6.10**		
LSD Time			**5.46**		
LSD Interaction			**12.20**		

*Data out of brackets are arcsine transformed for analysis.
**Data between brackets are original data

Table.4 Effects of *T. harzianum* inoculum extracted by ethyl acetate and application time *on S. hermonthica* germination

Time (days)	Germination (%)					
	Water	Ethyl acetate	*T. harzianum* extract conc.			
			25%	50%	75%	100%
3	73.00* (91.21)**	70.60 (88.56)	36.09 (34.72)	26.28 (20.06)	22.89 (15.31)	23.84 (17.13)
6	70.87 (88.66)	66.11 (83.39)	33.16 (30.19)	18.57 (10.73)	16.88 (8.55)	23.31 (16.36)
9	70.60 (88.79)	65.19 (80.45)	26.04 (19.63)	11.58 (4.09)	12.51 (4.81)	8.98 (2.44)
LSD Extract			**19.66**			
LSD Time			**13.90**			
LSD Interaction			**34.06**			

*Data out of brackets are arcsine transformed for analysis.
**Data between brackets are original data.

Table.5 Effects of *T. harzianum* inoculums persistent on *S. hermonthica* germination

Time (h)	Germination (%)				
	Water	Medium	*T. harzianum* inoculum type		
			Sterilized culture	Culture	Culture filtrate
2	68.94*(85.46)**	57.91 (69.14)	48.03 (55.24)	28.02 (22.42)	21.99 (14.44)
4	75.58 (93.49)	75.22 (91.37)	60.44 (75.17)	56.48 (69.30)	50.09 (58.73)
LSD Inoculum type			**3.64**		
LSD Time			**2.82**		
LSD Interaction			**8.92**		

*Data out of brackets are arcsine transformed for analysis.
**Data between brackets are original data.

Table.6 Effects of *T. harzianum*, bacterial strains and compost on *S. hermonthica* germination

Treatment	Germination (%)
Water	68.05* (84.87)**
Medium (PD broth)	65.01 (81.96)
Medium (Meat extract broth)	62.77 (78.82)
Compost 50%	67.99 (85.81)
Compost 100%	53.39 (64.40)
Compost 50%+ *T. harzianum*	51.06 (60.40)
Compost 100%+ *T. harzianum*	38.11 (38.14)
Compost 50%+ Bacteria#	42.77 (46.21)
Compost 100%+ Bacteria	35.06 (33.16)
Compost50%+*T. harzianum* + Bacteria	47.57 (54.47)
Compost 100%+ *T. harzianum* + Bacteria	30.61 (26.24)
LSD	**7.65**

*Data out of brackets are arcsine transformed for analysis.
**Data between brackets are original data. #Bacteria = BMP+*Flavobacterium*

Table.7 Effects of compost, *T. harzianum* and bacteria on *S. hermonthica* emergence

Treatments		*Striga* count				Mean
		Time after sowing (weeks)				
Compost	Microbe	2	4	6	8	
0g/pot	Without	1.98*(4.50)**	3.32 (11.25)	5.13 (28.25)	4.77 (26.25)	**17.56**
	T. harzianum	1.00 (0.75)	3.18 (10.75)	5.33 (28.25)	4.95 (24.25)	**16.00**
	BMP+*Flavobacterium*	0.97 (0.50)	3.27 (10.75)	5.12 (26.25)	4.60 (21.25)	**14.69**
15g/pot	Without	1.70 (2.50)	3.25 (10.50)	4.94 (24.50)	4.52 (20.75)	**14.56**
	T. harzianum	1.13 (1.00)	2.60 (6.75)	4.49 (20.75)	4.37 (21.00)	**12.38**
	BMP+*Flavobacterium*	0.93 (0.50)	2.65 (7.25)	4.52 (20.50)	3.66 (13.25)	**10.38**
LSD Compost		**0.56**	**0.81**	**0.96**	**1.17**	
LSD Microbe		**0.68**	**1.00**	**1.17**	**1.44**	
LSD Interaction		**0.96**	**1.41**	**1.66**	**2.03**	

* Indicates square root transformed data (√x+0.5 x: variable)
**Data between brackets are original data.

Table.8 Effects of compost, *T. harzianum* and bacteria on sorghum plant height (cm)

Treatments		Plant height (cm)				Mean
		Time after sowing (weeks)				
Compost	Microbe	2	4	6	8	
Control (without *Striga*)		23.95	36.00	44.25	44.88	**36.68**
0g/pot	Without	21.58	29.40	30.75	35.10	**29.80**
	T. harzianum	15.60	29.45	28.05	29.30	**25.60**
	BMP+*Flavobacterium*	17.23	29.55	28.90	32.68	**27.09**
15g/pot	Without	20.98	26.95	27.63	34.63	**27.54**
	T. harzianum	22.23	32.65	31.30	31.78	**29.49**
	BMP+*Flavobacterium*	18.73	33.55	33.47	34.90	**30.16**
LSD Compost		**4.98**	**5.24**	**6.95**	**6.87**	
LSD Microbe		**6.09**	**6.42**	**8.51**	**8.42**	
LSD Interaction		**8.62**	**9.08**	**12.04**	**11.90**	

Table.9 Effects of compost, *T. harzianum* and bacteria on sorghum and *S. hermonthica* dry weight

Treatments		Dry weight (g)		
Compost	**Microbe**	**Sorghum shoot**	**Sorghum root**	***Striga***
Control (without *Striga*)		82.50	111.75	//
0g/pot	**Without**	34.25	63.50	3.30* (10.50)**
	T. harzianum	49.00	100.25	3.23 (10.50)
	BMP+*Flavobacterium*	43.50	68.50	3.03 (8.75)
15g/pot	**Without**	34.50	92.25	3.95 (15.25)
	T. harzianum	51.75	123.25	2.93 (8.50)
	BMP+*Flavobacterium*	51.00	64.75	2.54 (6.50)
LSD Compost		**25.90**	**57.68**	**0.55**
LSD Microbe		**31.73**	**70.64**	**0.68**
LSD Interaction		**44.87**	**99.91**	**0.96**

* Indicates square root transformed data (√x+0.5 x: variable)
**Data between brackets are original data.

Auxins are also associated with strong inhibition to *Striga* attachment and haustorium development because of their antagonistic nature with cytokinins and benzoquinone, both of which favor attachment and haustorium development (Keyes *et al.,* 2000).

The highest sorghum height was obtained by the combination of compost plus BMP+*Flavobacterium*. Hameeda *et al.,* (2006) reported that Plant Growth Promoting Rhizobacteria (PGPR) stimulated germination and promoted plant growth and their application with composts synergistically enhanced plant growth. Such PGPB can be applied as additional inoculants along with composts and make a synergistic treatment for improving plant growth. Since *Striga* infection lowers IAA levels in hosts (Press *et al.,* 1999) and auxins such as Indole Acetic Acid (IAA) are thought to inhibit *Striga* germination (Miché *et al.,* 2000), *Bacillus* strains could offer growth benefits to sorghum and suppressive effect on *Striga* due to their IAA producing ability. For instance, Hussain and Hasnain (2011) reported an increase in wheat (*Triticum aestivum*) growth following improvement of the plant's IAA and cytokinins pool by PGPR. Additionally, application of exogenous cytokinins have been found to increase plant height, nitrogen, phosphorus and potassium uptake and total biomass in rice (Zahir *et al.,* 2001). Cytokinins are known to boost chlorophyll production which is an indication of sorghum plants' improved capacity to fix carbon hence the increase in biomass observed in *Striga*-free sorghum plants.

The combination of compost with *T. harzianum* and BMP+ *Flavobacterium* increased sorghum shoot dry insignificantly as compared to the infested control. *T. harzianum* alone or in combination with compost increased sorghum root dry weight insignificantly as compared to the control. Application of composts with bacterial strains improved plant growth up to 88%. These results confirm the synergistic effect of bacteria and fungi applied with compost on growth of pearl millet reported by (Hameeda *et al.,* 2006). In this context Zafar-ul-Hye *et al.,* (2015) recorded that *Pseudomonas*

bacterial strains improved maize root and shoot length and dry weight.

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