



The Importance of Microorganisms in Depleting Striga Seed Banks to Enhance Sorghum Productivity: A Review

Mamo Bekele

¹Addis Ababa University College of Natural and Computational Science,
Department of Cellular, Microbial and Molecular Biology
Ethiopian Institute of Agricultural Research
E-mail:- mamob27@gmail.com

Abstract

The parasitic weed *Striga* is a major biological constraint to cereal production including sorghum in Sub-Saharan Africa causing yield losses worth US\$ 9 billion. It infests more than 50 million hectares of farmland with intensifying dissemination in Sub-Saharan Africa, which makes it one of the gravest threats to food security. Due to the life cycle of the weeds, control methods are too difficult and not feasible across the world. Knowing the biology of parasitic weeds, its systematic host infection and life cycle help to control and biological control is one of the most preferable new approach weapons for depletion of seed banks. Microorganisms such as bacterial and fungal species are more effective in controlling these biological constraints. They are used as suicidal germination, germination inhibitors and decaying seed banks, produce volatile organic compounds and challenge the viability of *Striga* seed banks. Indirect positive effects of those microbes are also when Plants are colonized by an astounding number of microorganisms that can have profound effects on seed germination, plant growth, development, nutrient acquisition and tolerance to (a) biotic stress factors. Hence, enriching the microbial habitat is very successful in their natural environment for the purpose of decaying parasitic seed banks.

Keywords: Biocontrol, Microorganism, Sorghum, Striga, Strigolactone,

1. Introduction

Weeds are one of the most biological constraints which cause yield losses and perturb food security and human welfares in the world. Among the weeds, *Striga* is a major constraint to cereal production; sorghum, finger millet, rice, teff, sugar canes, etc. in Sub-Saharan Africa causing yield losses worth US\$ 9 billion. It infests more than 50 million hectares of farmland with intensifying dissemination in Sub-Saharan Africa, which makes it one of the gravest threats to food security (Westwood et al., 2010). This parasitic weed completes its life cycle beneath the ground more than 80 percent and emerged above the ground only for stem formation and seed setting. During the life cycle below ground, it forms

haustorium, attaches and penetrates the host root cortex cells and sucking nutrients, minerals and water from it and cause final damage of host life (Ejeta, 2007).

Although much research has done to control *Striga* weeds, the life cycle and its host interaction cause difficult to control. The seeds stay more than 20 years in the soils without germination until it recognize signals to chemical stimulated by host plant (Parker and Riches, 1993). Limited studies indicate that microorganisms associated with weed seeds can contribute to seed bank depletion through attraction to

seeds by chemotaxis, rapid colonization of the spermosphere and production of enzymes and/or phytotoxins to kill seeds prior to germination (Compant et al., 2013).

To achieve success, more in-depth research on microbial factors affecting weed seed banks is required for effectively eliminating dormant, persistent seeds from soil. Therefore, the microorganism to be the more active participant in microbial-related seed-bank processes and the concept of useful (micro-) biological processes, including seed decay, germination stimulant by microbes (suicidal germination), germination inhibitors by microbes in future weed management strategies is promising (Abbasher and Sauerborn, 1995).

Understanding these phenomena will provide new weapons for the bio-control of weeds seed banks by improving the efficacy of bio-control agents. This review paper is focusing on the background history of the parasitic weeds in relation to host crop, the life

cycle of *Striga* weeds and mechanism of host infection, biological control and its mechanism as well.

2. The Parasitic Weed *Striga*

Striga is a hemiparasitic weed that parasitizes sorghum, millet, sugarcane, maize, rice and more of graminaceous species. They spend most of their life cycle underground and develop above ground for stem formation and flowering. It stands for the principal biological constraints of crop production than any other biological pests such as insects, birds, or plant diseases in sub Saharan Africa (Musyoki et al., 2015). It represents the largest challenges to food security affecting livelihoods of over 300 million peoples in 25 African countries and the problem is getting worse. Its rapid expansion and proliferation is due to disfavor climatic condition and soil fertility exhaustion (Ejeta, 2007).



Figure 1: Photo of *Striga hermonthica* taken from Western Hararghe, 2018 by the author)

Place of origin of the agriculturally important *Striga* species was described as Africa, particularly the Sudano-Ethiopia region, where also sorghum was hypothesized to be originated. There genus *Striga* contains 41 species which is found in African continent and some parts of Asia (Cochrane et al., 1997). However, three species (*S. hermonthica*, *S. asiatica* and *S. gesnerioides*) are economically important parasitic weeds and have significant impact on agricultures. *S. hermonthica* (Del.)Benth (fig. 1) is

extensive in the semi-arid zones of northern tropical Africa and it is as well found in the south-western part of the Arabian Peninsula(Mohamed et al., 2001) . In the eastern to southern part of Africa, Asia, Australia and the United States *S. asiatica*, on the other hand, has a wide distribution. The third species, *S. gesnerioides*, occurs in Africa, the Arabian Peninsula, the Indian subcontinent, and has been introduced to the United States (Musselman, 1980).

3. Striga Life Cycle and Mechanism of Host Infection

The presence of parasitic host and their secondary metabolites have great role in their interaction and regulation for the lifecycle of the parasitic weeds *Striga*. These secondary metabolites are involved in signaling for example in the induction of parasite germination and the formation of the haustorium, and in plant defense against the parasite (e.g. phytoalexins) (Bouwmeester et al., 2003). Cotton can also serve as false trap crop to produce germination stimulant strigol from its root exudates and used to suicidal germination of parasitic *Striga* seed (Sato et al., 2005).

Despite non host crop produce germination stimulant, the strigolactones are known to be the most effective

stimulant, eliciting germination at nanomolar or even picomolar concentrations in seeds of many *Striga* species (Bouwmeester et al., 2003). These strigolactones are also used for germination stimulants of *Orobanchaceae*, *Phelipanche* spp., and *Alectra* species. This chemical produced mainly to induce colonization by symbiotic arbuscular mycorrhizal fungi in the rhizosphere. However, different plant species and different cultivars of the same species determine amounts and composition of strigolactones production (Xie et al., 2013). A crystal structure of a highly sensitive strigolactone receptor from *Striga* revealed a larger binding pocket than that of the *Arabidopsis* receptor, which could explain the increased range of strigolactone sensitivity. Thus, the sensitivity of *Striga* to strigolactones from host plants is driven by receptor sensitivity.

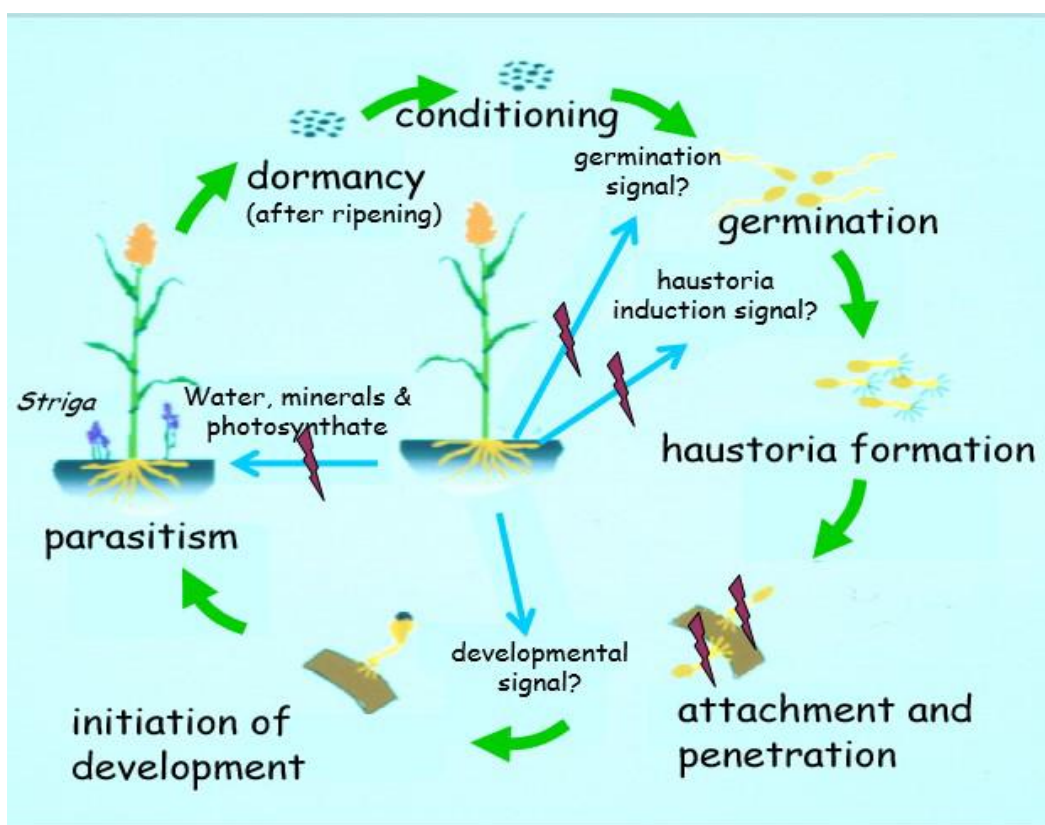


Fig. 2: Illustrated *Striga* life cycle (Ejeta et al., 1993)

Subsequent to germination, the parasites attach to a host through a specialized organ known as the haustorium and regulate the development of this organ through the recognition of chemical factors from host plants (Berner, 2007). The haustorium factor, 2,6-

dimethoxy-p-benzoquinone (DMBQ), is a product of lignin oxidation and decarboxylation of phenolic acids found in plant cell walls described as one of the best exogenous haustorial inducing factors obtained from sorghum root extracts.

The level of host recognition in *Striga* is mediated through their enzymatic digestion of the host root surface. Degradation of surface components liberates quinonoid compounds, such as 2,6-DMBQ, which in turn trigger haustorial development. Some chemicals released by plant roots for defense against other competing plants, parasites or pathogens have also been found to trigger parasite seed germination. Examples of these chemicals are sorgoleone and hydroquinone sorghum xenognosins (SXSg). The chemicals are distinct from strigolactones but can trigger *Striga* germination (Keyes, et al 2001).

After attachment the haustorium invades epidermal cells, penetrates into the root cortex and proceeds to form a xylem-to-xylem connection with the host and then starts to acquire nutrients and water. The penetration of haustorium cells into host tissue is carried out mechanically by pressure on the host endodermal cells and by hydrolytic enzymes. Subsequently adventitious roots are often produced, shoot development follows and *Striga* eventually emerges above ground and matures within a few weeks and sets seeds (Musselman, 1980).

4. Impacts of *Striga* on Sorghum Production

Prolific seed production and prolonged viability of the seeds result in a rapid buildup of huge seed banks in fields, eventually abandoned, because the field becomes unsuitable for sorghum production (Ejeta, 2007). Although this parasite has green leaves, they exhibit only low rates of photosynthesis and therefore they need to deprive most of organic matter from their hosts. Moreover these parasitic plants exhibit high rates of transpiration and consequently they obtain a large amount of water and minerals from their hosts (Musselman, 1980). These facts result in the parasites causing yield losses from a few percent to complete crop failure depending on crop species, crop variety and severity of infection (Gebisa, 2007).

When nitrate is assimilated by host, there is rapid transfer of nitrogen to parasite and parasite have approximately equal amount of nitrate and amino acid mostly glutamine and asparagines, infection alter free amino acid profiles (Pageau et al., 2003). Frost, et al., (1997) reported that infected sorghum plant by *Striga* have less shoot and root biomass, smaller leaf area, lower stomata conductance and steady state photosynthesis with having twice ABA concentration than uninfected sorghum crops. Additionally, affected

sorghum and maize crops grain yield significantly reduced due to the decrement of photosynthetic rates in field evaluation. *Striga* infested plant fails to flower and water use efficiency and reduced to 72% when compared to the control treatment (Gebremedhin et al., 2000).

5. Mechanisms of *Striga* Weed Control

In developing countries, weeds continue to be one of the most important contributing factors to yield loss in agricultural production. Significant weed seed bank increments through prolific seed production, competition for water and nutrients, cost associated with seed cleaning are the main *Striga* weed to contribute for crop yield losses. However, there are fundamental weed management methods include cultural, mechanical chemical and biological methods, but there appears to be a continued reliance on herbicides as the main weed control methods.

5.1 Biological Control of *Striga*

Most of the damage to the host is done before the parasitic weed emerges above the soil. Therefore, control methods should focus on reducing soil seed bank and interfere with the parasite's early developmental stages. Because of the close interconnection between the parasitic weed and its host, herbicidal control is difficult since herbicides cannot selectively distinguish between the species. The high specificity of many organisms (fungi, bacteria, arthropods), feeding exclusively on selected hosts, only in parasitic weeds, can be considered an advantage because these organisms may work as bio-control agents where other weed control options have failed. So far, several fungal genera (Ciotola et al., 1995; Abbasher et al., 1998) and bacteria (Berner et al., 1999; Ahonsi et al., 2002) pathogenic to *S. hermonthica* were identified from *Striga* infested areas across the world.

Complete suppression of weed is unfeasible by using any mechanism and biological weed control strategy relatively reduces the establishment of weed population to below the economic threshold (Teka, 2014). However, due to diversity and numerous metabolic pathways, microbes form a remarkable resource for the biological management of crops weeds. Some plant pathogenic microbes have ability to mitigate plant defense responses by disrupting the plants ability to perceive or react to the pathogen (Jones and Dangl, 2006). Such microbes have

potential of being used as biological control agents against parasitic weeds if the target host is only the weed plant.

Microbes used as bio-control in two approaches; classical approach which is characterized by the importation, introduction and release of natural enemy from the same geographical origin of the weed into an area. In this approach, the natural enemy bacteria or fungi pathogen is allowed to self-perpetuate, survive and establish, thus providing long-term weed control over several years. The second approach is inundative through repeated application of inoculums. The pathogens are often indigenous, artificially mass-produced and applied during the growing season. Weed control is short term when compared to classical biological approach and the microbes are not expected to persist in the environment (Charudattan and Dinooor, 2000).

5.1.1 Bacteria as Biological Control of *Striga*

Bacteria are one of the most famous biological control of *Striga* and increase the yield and yield components of cereal crops. They inhibit the *Striga* seed germination and hamper its development stages at any level. There are different bacterial species used as bio-control of *Striga* weeds. The genus *Azospirillum* inhibits *Striga* seed germination and good at PGPR which affect sorghum vulgare growth (Bouillant et al., 1997).

Pseudomonas putida and *Bacillus* species also reduce *Striga* germination and minimize its incidence at 90-100 percent at peak emergence of *Striga*. They are known as germination inhibitors. *Pseudomonas syringae* is high efficacy in stimulating germination of seeds of *Striga* than volatile compounds, root exudates and synthetic stimulant GR-24. This shows that bacteria are higher ethylene gas producer, stimulate *Striga* seed germination in the absence of host plant and used as suicidal germination (Berner et al., 1999).

The increment of maize shoot biomass and decrement of *Striga* parasitism in maize production due to *Fluorescent pseudomonas* rhizobacterium suppress germination of *Striga hermonthica* was reported by (Ahonsi et al., 2004). *Klebsiella oxytoca* and *enterobacter sakazakii* have similar function in *Striga* infested on farm land of cereal crop.

Moreover, most of microorganisms which cause *Striga hermonthica* seed decay are bacteria isolates which had close genetic relationship with member of the genus *Basillus*. Moreover, *Bacillus subtilis* and *Bacillus amyloliquefaciens* are found to be excellent colonization capacity and remarkable versatility in protecting crops from phytopathogenic fungi and environmentally safe biological agents (Zhao et al., 2013)

Two strains of *Azospirillum brasilense* L2 and L4 isolated from the rhizosphere of sorghum were able to prevent germination of *S. hermonthica* seeds when stimulated to grow in the presence of *Sorghum vulgare* roots (Bouillant et al., 1997). Under this study L4 has a plant growth promoting effect therefore was beneficial for sorghum growth. When suspended in a synthetic germination stimulant, *Azospirillum* cells blocked radicle elongation forming germ tubes that were shorter and thicker. The radicles manifested an abnormal morphology and had no vacuolated cells in the root elongation zone which could cause the lack of germ tube growth. These bacterial cells were not detected at the surface or inside the *Striga* radicles (Miché et al., 2000).

Bacillus spp. also produces phytohormones, indole acetic acid (IAA) and cytokinins which have a positive effect on plant growth (Idris et al., 2007). Phytohormones generated by bacteria can be taken up by plants leading to an increase in hormone levels in these plants (Patten and Glick, 1996). In addition, a number of *Bacillus* strains fix nitrogen; solubilize phosphate and control plant diseases (Kloepper et al., 2004). Their heat-resistant spores make it easier for the bacteria to be formulated into stable biofertilizer or biocontrol products (Deng et al., 2011).

5.1.2 Fungi as Biological Control of *Striga*

Fungi are more successful in decaying of parasitic seed bank and enhance sorghum productivity as indicated by many researchers. Though there are diverse fungal genera in soil, *Fusarium* species and Arbuscula mycorrhae are the most *Striga* seed bank depleting microorganisms. *Fusarium nygamai* and *Fusarium semitectum* reduce *Striga* emergence and germination in the soil up to 97 and 87 percent respectively and improved sorghum performance in Sudan while 100 and 93 percent inhibit *Striga* emergence when sorghum seed inoculated with 10ml

of inoculums 8×10^6 spores per ml. This inhibition is due to fungi spore attack *Striga* germ tubes (Abbasher and Sauerborn, 1995).

In Ghana two *Fusarium oxysporum* isolates reduce *Striga* emergence 88 and 98 percent and *Fusarium semitectum* 76 percent, while increase 26 percent of sorghum yield (Abbasher and Sauerborn, 1995). Fungal mycelium of *Fusarium nygamai* penetrated the *Striga* seeds in soils and parasitize inside of it, host specific reduce *Striga* biomass 10-50 percent and increase maize vigor and yield. Arbuscular mycorrhizae fungi increase sorghum biomass when sorghum seed treated and sorghum biomass reduced when untreated. Root colonization by Arbuscular mycorrhizae reduce stimulation of *Striga* seed germination, it lowers parasite incidence (Lendzemo and Kuyper, 2001).

Field operation of strains of *F. oxysporum*, naturally pathogenic to *S. hermonthica* and then selected for their secretion of certain amino acids, could extensively increase maize yield of smallholder farmers under actual production environment in Kenya (Nzioki et al., 2016). *Fusarium oxysporum* f. sp. *Strigae* (Foxy2) are best fungal bio-control option and has been revealed to decrease emergence of *S. hermonthica* and *S. asiatica* plants through destruction of appressorium, hyaline tissue, xylem vessels or cortical parenchyma (Gonzalez et al., 2015).

Trichoderma species are also other fungal pathogen which affects *Striga hermonthica* seeds. The main mechanisms involved in the bio-control action of *Trichoderma spp.* are competition for space and nutrients, production of diffusible and volatile antibiotics and hydrolytic enzymes like chitinase and -1,3-glucanase. These hydrolytic enzymes partially degrade the pathogen cell wall and lead to its parasitization (Sato et al., 2005).

6. Mechanism of Microbes Action on Striga control

There are different mechanisms by which biological agents exhibit biological control action: direct antibiosis, competitive exclusion, interference with pathogen signaling and induction of plant resistant mechanism. The majority of microbes used in biological control of crop pests, weeds and diseases emit myriad metabolites that perform on the pathogen by either depriving the pathogens of nutrients and space, lysing cell and blocking specific functions

linked to pathogen growth or inducing host plant resistance (Zhao et al., 2013).

Considering the mechanisms through which the bio-control of plant weeds, pests, and diseases occur is serious to the ultimate improvement and wider use of biocontrol technique. The majority of bio-control agents are specific in action; they do not pollute the environment through residues and are more proper and inexpensive than inorganic fertilizer and genetically engineered crops as well (Heydari and Pessarakli, 2010).

Sicua et al., (2015) reported that bacteria isolates; *Bacillus* species and fungal isolates *Aspergillus* species are microbes which have high extracellular enzymes produces which inhibit *Striga* seed decay. Other microbes such as *B. amyloliquefaciens* produce plant growth hormones Indole Acetic Acid through colonizing plant roots (Borriss et al., 2011). In addition, they also produce antimicrobial and bioactive metabolites such as surfactin, iturin and fengycin (Xie et al., 2013). *Bacillus atrophaeus* strain on the other hand has capacity to adapt and use several external nutrients as energy sources and this cause *Striga hermonthica* seed decay (Sella et al., 2008).

Cereal crops growing in phosphorous and nitrogen deficient soils also produce strigolactones. These compounds are essential recognition signals that aid germination of root parasitic weeds such as *S. hermonthica* (Xie et al., 2013). Therefore, any biological strategy aimed at increasing rhizosphere phosphorous content ultimately ameliorates *S. hermonthica* suppression. This probably rationalizes the classification of soils with isolates *Bacillus* species and *Rhizobium species* as *S. hermonthica* suppressive soil. This is because these two isolates probably enhance phosphorous mobilization in the soil thereby scaling down the production of *Striga* seed germination.

Streptomyces also used to control *Striga* by proction of catabolic enzymes that degrade biopolymers, quantitatively and qualitatively important in the plant rhizosphere where they influence plant growth and protect plant roots against invasion by root pathogens (Tarkka et al., 2008).

In addition, *Trichoderma* is believed to influence plant development in several mechanisms and these include, production of phytohormones, the solubilization of sparingly soluble minerals, induction

of systemic resistance in the host plant, reduction in pollutant toxicity (organic or heavy metal), and the regulation of rhizospheric microflora (Li et al., 2015).

The *Aspergillus* spp. is a fascinating group of fungi exhibiting immense ecological and metabolic diversity. Several members of *Aspergillus* spp. have been found to be involved in phosphorous solubilization and bioremediation processes in the rhizosphere (Singh et al., 2011). The close genetic affiliation to genus *Aspergillus* by most of the screened fungal isolates cultured from *S. hermonthica* suppressive soils underlines their role in *S. hermonthica* suppression (Nzioki et al., 2016).

Plant growth-promoting rhizobacteria (PGPR) colonize roots of monocots and dicots, and enhance plant growth by direct and indirect mechanisms. These systems enhance sorghum growth and inhibit the *Striga* attachment to the host plant. Modification of root system architecture implicates the production of phytohormones and other signals that enhance lateral root branching and development of root hairs. PGPR also modify root functioning, improve plant nutrition and influence the physiology of the whole plant (Vacheron et al., 2013). Mineral nutrients up taking and gaining, preventing pathogenic organisms by synthesizing antibiotics and directly stimulating plant growth by either providing plant hormones such as auxin or cytokinin, or lowering plant ethylene levels through the action of the enzyme 1-aminocyclopropane-1-carboxylate (ACC) deaminase.

Vast majority of host plants of *Striga* are colonized by PGPR, attachment of a parasitic plant to a host plant could lead to a tripartite system within which nutrients, water and carbohydrates flow from one associate to another. The flow of substances within such a system could be more complex if the root parasites are themselves colonized or parasitized by the PGPR, a phenomenon commonly referred to as hyperparasitism. Defense mechanisms employed by plants against *Striga* weeds have been reported (Yoder and Scholes, 2010).

7. Conclusion

Sorghum bicolor is a key staple crop for millions of people in sub-Saharan Africa and used for different purpose. *Striga hermonthica* is a root parasitic weed of sorghum and its infestation can cause yield loss annually. Though various control methods, to date, none of control measures has proved to be effective.

Furthermore, several of control measures are not accessible or too expensive for resource-poor famers in Africa. Hence, there is a strong need for novel, effective, affordable, integrated and durable control strategies. So, exploring and identifying the potential microbes in rhizospheres that adversely affect and decay i) *Striga* seed germination ii) haustorium formation, iii) attachment which consistently suppresses *Striga* infections as an effective, generic and environmentally-sound approach to improve crop productivity is essential. Because, the life cycle of *Striga* and host infection mechanism enforce to use bio-control by microbes for seed bank depletion. Therefore, microbes' isolation and understanding of interactions between seeds and microorganisms followed by isolation and evaluation of tripartite relationships (*Striga*, sorghums and microbes) will have important implications for future weed management systems targeting seed banks depletion and enhance sorghum productivity for smallholder farmers.

8. References

- Abbasher, A. A., Hess, D. E., and Sauerborn, J. 1998. Fungal pathogens for biological control of *Striga hermonthica* on sorghum and pearl millet in West Africa. *Afr. Crop Sci.* 6(2): 179-188.
- Abbasher, A. A., and Sauerborn, J. 1995. Pathogens attacking *Striga hermonthica* and their potential as biological control agents. In *Proceedings of the Eight International Symposium on Biological Control of Weeds*. Lincoln University, Melbourne, Australia (pp. 527-533).
- Ahonsi, M. O., D. K. Berner, A. M. Emechebe, and S. T. Lagoke. 2002. Selection of rhizobacterial strains for suppression of germination of *Striga hermonthica* (Del.) Benth. seeds. *Biol. Control.* 24 (2):143–152.
- Ahonsi, M. O., Berner, D. K., Emechebe, A. M., and Lagoke, S. T. 2004. Effects of ALS-inhibitor herbicides, crop sequence, and fertilization on natural soil suppressiveness to *Striga hermonthica*. *Agr. Ecosyst. Environ.* 104(3): 453-463.
- Berner, A. 2007. *Striga*: The spreading scourge in Africa. *Plant Growth Regul.* 42(1): 74-87.
- Berner, D. K., Schaad, N. W., and Völksch, B. 1999. Use of ethylene-producing bacteria for stimulation of *Striga* spp. seed germination. *Biological Control*, 15(3): 274-282.

- Borriss, R., Chen, X. H., Rueckert, C., Blom, J., Becker, A., Baumgarth, B., and Junge, H. 2011. Relationship of *Bacillus amyloliquefaciens* clades associated with strains DSM 7T and FZB42T: a proposal for *Bacillus amyloliquefaciens* subsp. *amyloliquefaciens* subsp. nov. and *Bacillus amyloliquefaciens* subsp. *plantarum* subsp. nov. based on complete genome sequence comparisons. *Int. J. Syst. Evol. Microbiol.* 61(8): 1786-1801.
- Bouillant, M. L., Miché, L., Ouedraogo, O., Alexandre, G., Jacoud, C., Sallé, G., and Bally, R. 1997. Inhibition of *Striga* seed germination associated with sorghum growth promotion by soil bacteria. *Comptes Rendus de l'Académie des Sciences-Series III-Sciences de la Vie*, 320(2): 159-162.
- Bouwmeester, H. J., Matusova, R., Zhongkui, S., and Beale, M. H. 2003. Secondary metabolite signalling in host-parasitic plant interactions. *Current opinion in Plant Bio.* 6(4): 358-364.
- Charudattan, R., and Dinoor, A. 2000. Biological control of weeds using plant pathogens: accomplishments and limitations. *Crop Prot.* 19(8-10), 691-695.
- Ciotola, M., Watson, A. K., and Hallett, S. G. 1995. Discovery of an isolate of *Fusarium oxysporum* with potential to control *Striga hermonthica* in Africa. *Weed Res.* 35(4): 303-309.
- Cochrane, V., and Press, M. C. 1997. Geographical distribution and aspects of the ecology of the hemiparasitic angiosperm *Striga asiatica* (L.) Kuntze: a herbarium study. *J. Trop. Ecol.* 13(3):371-380.
- Compant, S., Brader, G., Muzammil, S., Sessitsch, A., Lebrihi, A., and Mathieu, F. 2013. Use of beneficial bacteria and their secondary metabolites to control grapevine pathogen diseases. *BioControl*, 58(4): 435-455.
- Deng, Y., Zhu, Y., Wang, P., Zhu, L., Zheng, J., Li, R., and Sun, M. 2011. Complete genome sequence of *Bacillus subtilis* BSn5, an endophytic bacterium of *Amorphophallus konjac* with antimicrobial activity for the plant pathogen *Erwinia carotovora* subsp. *carotovora*. *J. Bact.* 193(8): 2070-2071.
- Ejeta, G. 2007. Breeding for *Striga* resistance in sorghum: exploitation of an intricate host-parasite biology. *Crop Sci.* 47(3): S-216.
- Ejeta, G., and Butler, L. G. 1993. Host-parasite interactions throughout the *Striga* life cycle, and their contributions to *Striga* resistance. *Afr. Crop Sci.* 1(2).
- Frost, D. L., Gurney, A. L., Press, M. C., and Scholes, J. D. 1997. *Striga hermonthica* reduces photosynthesis in sorghum: the importance of stomatal limitations and a potential role for ABA?. *Plant Cell and Environ.* 20(4): 483-492.
- Gebremedhin, W., Goudriaan, J., and Naber, H. 2000. Morphological, phenological and water-use dynamics of sorghum varieties (*Sorghum bicolor*) under *Striga hermonthica* infestation. *Crop Prot.* 19(1): 61-68.
- Gonzalez-Munoz, E., Avendano-Vazquez, A.O., Montes, R. A., De Folter, S., Andres-Hernandez, L., Abreu-Goodger, C., and Sawers, R. J., 2015. The maize (*Zea mays* ssp. *mays* var. B73) genome encodes 33 members of the purple acid phosphatase family. *Frontiers in Plant Sci.* 6:341.
- Heydari, A., and Pessarakli, M. 2010. A review on biological control of fungal plant pathogens using microbial antagonists. *J. Biol. Sci.* 10(4): 273-290.
- Idris, E. E., Iglesias, D. J., Talon, M., and Borriss, R. 2007. Tryptophan-dependent production of indole-3-acetic acid (IAA) affects level of plant growth promotion by *Bacillus amyloliquefaciens* FZB42. *Mol Plant Microbe In.* 20(6): 619-626.
- Jones, J. D., and Dangl, J. L. (2006). The plant immune system. *Nature*, 444(7117): 323.
- Keyes, W. J., Taylor, J. V., Apkarian, R. P., and Lynn, D. G. 2001. Dancing together. Social controls in parasitic plant development. *Plant Physiol.* 127(4):1508-1512.
- Kloepper, J. W., Ryu, C. M., and Zhang, S. 2004. Induced systemic resistance and promotion of plant growth by *Bacillus* spp. *Phytopathol.* 94(11): 1259-1266.
- Lendzemo, V. W., and Kuyper, T. W. 2001. Effects of arbuscular mycorrhizal fungi on damage by *Striga hermonthica* on two contrasting cultivars of sorghum, *Sorghum bicolor*. *Agr Ecosyst Environ.* 87(1): 29-35.
- Li, R. X., Cai, F., Pang, G., Shen, Q. R., Li, R., and Chen, W. 2015. Solubilisation of phosphate and micronutrients by *Trichoderma harzianum* and its relationship with the promotion of tomato plant growth. *PLoS One*, 10(6): e0130081.
- Miché, L., Bouillant, M. L., Rohr, R., Sallé, G., and Bally, R. 2000. Physiological and cytological studies on the inhibition of *Striga* seed germination by the plant growth-promoting bacterium *Azospirillum brasilense*. *Eur. J. Plant Pathol.* 106(4): 347-351.
- Mohamed, K. I., Musselman, L. J., and Riches, C. R. 2001. The genus *Striga* (scrophulariaceae) in

- Africa. *Annals of the Missouri Botanical Garden*, 60-103.
- Musselman, L. J. 1980. The biology of *Striga*, *Orobanch*, and other root-parasitic weeds. *Annual review of phytopathology*, 18(1): 463-489.
- Musyoki, M. K., Cadisch, G., Enowashu, E., Zimmermann, J., Muema, E., Beed, F., and Rasche, F. 2015:. Promoting effect of *Fusarium oxysporum* [f.sp.] on abundance of nitrifying prokaryotes in a maize rhizosphere across soil types. *Biol. Control*. 83(11):37-45.
- Nzioki, H. S., Oyosi, F., Morris, C. E., Kaya, E., Pilgeram, A. L., Baker, C. S., and Sands, D. C. 2016. *Striga* biocontrol on a toothpick: a readily deployable and inexpensive method for smallholder farmers. *Front. Plant Sci*. 7: 1121.
- Pageau, K., Simier, P., Le Bizec, B., Robins, R. J., and Fer, A. 2003. Characterization of nitrogen relationships between *Sorghum bicolor* and the root-hemiparasitic angiosperm *Striga hermonthica* (Del.) Benth. using K¹⁵NO₃ as isotopic tracer. *J.Exp. Bot*. 54(383), 789-799.
- Parker, C., and Riches, C. R. (1993). *Parasitic weeds of the world: biology and control*. CAB International Press, Wallingford, Oxon, Ox 108 DE, UK,332p
- Patten, C. L., and Glick, B. R. 1996. Bacterial biosynthesis of indole-3-acetic acid. *Can. J. Microbiol*. 42(3): 207-220.
- Sato, D., Awad, A. A., Takeuchi, Y., and Yoneyama, K. 2005. Confirmation and quantification of strigolactones, germination stimulants for root parasitic plants *Striga* and *Orobanch*, produced by cotton. *Biosci Biotech Bioch*. 69(1): 98-102.
- Sella, S. R. B., Dlugokenski, R. E. F., Guizelini, B. P., Vandenberghe, L. P., Medeiros, A. B., Pandey, A., and Soccol, C. R. 2008. Selection and optimization of *Bacillus atrophaeus* inoculum medium and its effect on spore yield and thermal resistance. *Appl. Biochem. Biotech*. 151(2-3): 380-392.
- Sicuaia, O. A., Grosu, I., Constantinescu, F., Voaides, C., and Cornea, C. P. 2015. Enzymatic and genetic variability in *Bacillus* spp. strains with plant beneficial qualities. *AgroLife Sci.. J*. 4: 124-131.
- Singh, A., Parmar, N., Kuhad, R. C., and Ward, O. P. (2011). Bioaugmentation, biostimulation, and biocontrol in soil biology. In *Bioaugmentation, Biostimulation and Biocontrol* (pp. 1-23). Springer, Berlin, Heidelberg.
- Tarkka, M. T., Lehr, N. A., Hampp, R., and Schrey, S. D. 2008. Plant behavior upon contact with *Streptomyces*. *Plant signaling and behavior*, 3(11): 917-919.
- Teka, H. B. 2014. Advance research on *Striga* control: A review. *Afr. J. Plant Sci*. 8(11): 492-506.
- Vacheron, J., Desbrosses, G., Bouffaud, M. L., Touraine, B., Moënné-Loccoz, Y., Muller, D., and Prigent-Combaret, C. 2013. Plant growth-promoting rhizobacteria and root system functioning. *Frontiers in Plant Sci*. 4:356.
- Westwood, J. H., Yoder, J. I., Timko, M. P., and dePamphilis, C. W. 2010. The evolution of parasitism in plants. *Trends Plant Sci*. 15(4):227-235.
- Xie, X., Yoneyama, K., Kisugi, T., Uchida, K., Ito, S., Akiyama, K., and Yoneyama, K. 2013. Confirming stereochemical structures of strigolactones produced by rice and tobacco. *Mol. Plant*. 6(1): 153-163.
- Yoder, J. I., and Scholes, J. D. 2010. Host plant resistance to parasitic weeds; recent progress and bottle necks. *Current opinion in Plant Biol*. 13(4): 478-484.
- Zhao, Q., Ran, W., Wang, H., Li, X., Shen, Q., Shen, S., and Xu, Y. 2013. Biocontrol of *Fusarium* wilts disease in muskmelon with *Bacillus subtilis* Y-IVI. *BioControl*, 58(2): 283-292.

How to cite this article:

Mamo Bekele. (2020). The Importance of Microorganisms in Depleting *Striga* Seed Banks to Enhance *Sorghum* Productivity: A Review. *Int. J. Adv. Res. Biol. Sci*. 7(4): 107-115.

DOI: <http://dx.doi.org/10.22192/ijarbs.2020.07.04.011>

Access this Article in Online



Website:
www.ijarbs.com

Subject:
Agricultural
Sciences

Quick Response Code

DOI: [10.22192/ijarbs.2020.07.04.011](http://dx.doi.org/10.22192/ijarbs.2020.07.04.011)