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The Role of Soil Bacteria in the Control of Parasitic *Striga hermonthica* Weed

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Abstract

Striga hermonthica is a very devastative parasitic weed of *Sorghum bicolor* which is the fourth important crop in Ethiopia. It is hemi-parasite living with the host plant by attaching a small sucker root system to the host plant. Control of the weed is difficult due to the production of tiny dust-like seeds produced in large quantities (50,000 to 500,000 seeds per plant) that retains their germination capacity up to 20 years. So far, cultural and chemical methods as well as breeding for host resistance have been practiced to control striga weed. Recently different research works have been done on the role of soil microbes on *Striga* management. Different bacterial strains have been tested for their effect on *Striga* weed. The mechanism of *Striga* management by bacteria is depleting striga seed bank in the soil through stimulation of seed germination in the absence of the host crop (*Pseudomonas syringae, Klebsiella*) or decaying the seed (*Bacillus*) and by inhibition of germination attachment to the host. A combination of the bacterial strains *Azospirillum brasilense* and *Pseudomonas putida; A. brasilense* and *Azomonas spp; Azotobacter vienlandi* and *Bradyrhizobium japonicum; A. brasilense* and *Azomonas spp.* inhibited germination by 18 to 34% in comparison to the corresponding control.

Keywords: *Striga hermonthica*, sorghum, germination stimulant, inhibition,

1. Introduction

Striga hermonthica is a parasitic weed that is being a major challenge for cereal production including sorghum in Sub-Saharan Africa which makes it one of the severest fears to food security in the area. *Sorghum bicolor* is an important crop for millions of people in Sub-Saharan Africa which is mainly cultivated in drier areas, especially on shallow and heavy clay soils (Wortmann et al., 2009). It is the third major cereal crop in Ethiopia and is produced in many parts of the country, especially in drought prone areas (Demeke et al., 2013 and CSA, 2019). It is well-known for its adaptability and diversity and is produced over a wide range of agro-ecological zones. However, the production and productivity of sorghum is significantly affected due to several abiotic and biotic factors such as drought, *Striga* weed, diseases, insect pests, and birds.

Striga weed causes blotching, scorching, wilting, loss of vigor and finally death of the plant. It also affects a reduction in the ear size, plant height, stem diameter and weight of the whole plant. It also imparts severe damage on roots and causes stem lodging (Mahmoud et al., 2013). Hence, *Striga* infestation is number one constraint causing devastating loss in sorghum followed by low soil fertility.

So far, cultural and chemical methods as well as breeding for host resistance have been practiced to control *Striga* (Berhane, 2016). Different studies showed that different bacteria have the ability to suppress *Striga* seed germination by different mechanisms (Babalola et al., 2007), (Bouillant et al., 1997) and (Ahonsi et al., 2002). Bacteria can suppress *Striga* infestation by ethylene production in the absence of sorghum, and hence reduce the *Striga* seed bank. This is by synthesizing and releasing ethylene gas to the soil which is a *Striga* seed germination stimulant. *Pseudomonas syringae* pathovar glycinea was reported that it can synthesizes relatively large amounts of ethylene and it could stimulates *Striga* seed germination more than ethylene gas (Berner et al., 1999 and Babalola et al., 2007)

Some bacteria remain capable of promoting plant growth by different mechanisms and help the plant to overcome abiotic and biotic stress. Other bacterial species are capable of scavenging the root exudate released by the host that stimulates *Striga* seed germination and hence suppress it. Studies also showed that adding of bacteria *Pseudomonas* suspensions to the plant-root exudates of sorghum significantly reduced (100% germination) germination of *Striga* seeds under in vitro conditions (Hiba et al., 2013).

Therefore the objective of this article is to review the role of soil bacteria in *Striga hermonthica* weed management.

2. Sorghum and production constraints

Sorghum (*Sorghum bicolor*) is an important staple crop which is indigenous to Africa and grown in arid and moisture stressed areas (Plessis, 2008). It belongs to the grass family, *Graminae*, genus *Sorghum* and classified as *S. bicolor* (L.) Moench (Berenji et al., 2011). Sorghum is the fifth most important cereal globally and the dietary staple of around 500 million people. Sorghum is crucially important to food security in Africa as it is uniquely drought resistant among cereals and can withstand periods of high temperature. It is an important food crop in many parts of eastern and southern Africa as stated by Awika (2011).and Wortmann et al., (2009).

In Ethiopia it is the third most important cereal crop both in area coverage and production following teff and maize. It can grow in a wide range of agro-climatic conditions from a mean monthly rain fall of 228 ml to 43 ml and in a temperature ranges from 18 ^{0}C- 27^{0}C. Its altitude also ranges from 680-2100 masl (Wortmann et al., 2009). It is the single most important staple crop in drought prone areas (Demeke et al., 2013). Sorghum can be consumed in different types of non-fermented and fermented foods. Non-fermented food are whole grain either boiled or roasted, bread from Sorghum flour prepared from non-fermented dough, porridge, while the fermented foods include fermented bread, *enjera* and traditional beverages (Taylor, 2003).

Sorghum though very important crop in Africa especially for poor farmers, there are many production constraints. Among the constraints of production drought, low soil fertility, *Striga* infestation, storage pests, damage by birds, lack of improved varieties, lack of production inputs (fertilizers, insecticides, herbicides, fungicides, and improved seeds) and among these constraints *Striga* ranks first (Mrema et al., 2017).

3. *Striga hermonthica*

The word '*Striga*' is the Latin word which means 'witch'. Witch weed (*akenchira* in Amharic) is a common name for *Striga* because plants diseased by *Striga* display stunted growth and an overall drought-like phenotype long before *Striga* plants appear. The genus *Striga*, erected by the Italian botanist, Loureiro, in 1790, is characterized by opposite leaves, irregular flowers with a corolla divided in to a tube and spreading lobes, herbaceous habitat, and parasitism (Fig 1). The flowers are pink, red, white, purple or yellow, The seeds are tiny, some 0.3 mm long and 0.15 mm wide (Babiker, 2007).

Figure 1 *Striga* infested farm at western Harerggie

Approximately 30 *Striga* species have been described in the genus *Striga* and most parasitize grass species (Poaceae) except *Striga gesnerioides* (Willd.) which parasitize legumes (Spallek et al., 2013). A single *Striga* plant can release 50,000 up to 500,000 seeds and it can be stay dormant in the soil until the conditions are favorable for germination or the host plant release root exudate (Berner et al., 1995). *Striga* spp. are serious weeds of important food crops including Sorghum, maize, millet and rice, in sub-Saharan Africa, the Middle East and Asia. Their effects are severe, and complete loss of harvest is common in heavily infested areas. *Striga hermonthica* is one of the devastating parasitic weeds of this group and mainly attacks cereal crops (Sorghum, *Sorghum bicolor* (L. Moench), maize *Zea mays* L.), pearl millet (*Pennisetum glaucum* (L.) (Leeke), upland rice (*Oryza sativa* (L).) *S. hermonthica* plant beside its well-known devastating impacts on the most important food cereal crops in Africa and is deemed to be one of the main factors that threatens the food security in this continent (Faisal, 2011).

3.1. Status of *S. hermonthica* in Ethiopia

As different research reports showed Ethiopia is one of *Striga hermonthica's* habitations and it is assumed that the origin of *Striga* is around the border of Sudan and Ethiopia (Obilana, 1992) and (Faisal, 2011). It is a major biotic constraint in Sorghum growing parts of Ethiopia (Atsbha et al., 2016). Another research shows that genetic diversity was assessed in 12 *S. hermonthica* populations from different locations in Ethiopia. Of these, seven populations were parasitic on Sorghum, two each on tef and maize, and one on finger millet. Genetic differentiation between populations was relatively high, and all populations were significantly different from each other. FST values ranged from 0.032 to 0.293 and averaged 0.146 (Welsh et al., 2011). Under drought-prone agro-ecologies of Ethiopia according to farmer's perception next to moisture stress, *Striga hermonthica* is one of the major limiting factors of Sorghum production (Beyene et al., 2016).

3.2. Effect of S. hermonthica in Sorghum production

S. hermonthica is an economically very important parasitic weed of sorghum. The infestation affect pre and post flowering stages of the crop growth phases; about 50% reduction in seedling vigor and 9% delayed days to 50% flowering for pre-flowering stress, while post flowering traits under *Striga* stress resulted in 37% reduction in panicle weight and 45% reduction in grain yield (Francis, 2006).

Growth reduction and the consequent loss of Sorghum yield as a result of infestation and parasitic activity of *Striga* was observed. It was thus concluded that *Striga* had a significant negative effect on growth of *Sorghum bicolor.* (Akomolafe, 2018).

3.3. The mechanism of attachment of *Striga* to sorghum root

The seeds of parasitic plants of the genera *Striga* and Orobanche will only germinate if there is an induction by a chemical signal exuded from the roots of their host. *Striga* have very small seeds that can survive for only a few days after germination before forming an association with a host. The limited carbohydrate reserves in *Striga* seeds restrict seedling root elongation before host attachment. Thus, arranging for germination to coincide with proximity of an appropriate host root is critical to *Striga* seedling survival. To ensure that germination occurs near host roots, *Striga* seeds germinate only in the presence of sustained (10–12 h) high concentrations of germination inducers exuded into the soil by host roots.

Germination inducers vary between different *Striga* hosts. To date, the only plant-produced *Striga* germination inducer that has been identified and characterized is Sorghum xenognosin (SXSg). SXSg is highly unstable in aqueous solution, a useful trait for a *Striga* germination inducer because it is unlikely to persist in the soil and falsely indicate the presence of a host. However, SXSg is so unstable that it initially seemed difficult to explain how SXSg persisted and traveled in the soil in quantities sufficient to affect nearby *Striga* seeds (Weir et al., 2010).

For *Striga* spp. several germination stimulants have been identified in the root exudates of host and non-host plants which are collectively described as the strigolactones (Matusova et al., 2005).

Phenols and quinones are common in the rhizosphere where they are known to function as signal molecules acting between plant roots and other organisms, including roots of other plants. The biological activity of these molecules is often associated with their redox state, and in some cases bioactivity is a function of the oxidoreduction cycle itself. Plants and other organisms have evolved detoxification systems that limit the cytotoxicity of radical molecules generated during redox cycling, and these mechanisms function in parasitic plants as well. However, parasitic plants have further evolved to use the redox-active molecules as signals to initiate haustorium development. In this way parasitic plants recruit biologically active and generally toxic molecules to signal the transition to a heterotrophic lifestyle (Bandaranayake et al., 2013).

Haustorium is a unique multicellular organ that formed upon detection of haustorium-inducing factors derived from the host plant. This multicellular organ penetrates the host root and connects to its vasculature which allows exchange of materials such as water, nutrients, proteins, nucleotides, pathogens, and retrotransposons between the host and the parasite (Yoshida et al., 2016).

Xylem connections between parasites and hosts (*Striga* and sorghum) involve very specific, clustered intrusions into the host's water conducting elements, mainly into the large vessel elements. One haustorial cell can penetrate a host vessel element with more than one intrusion. Then all intrusions become covered by an additional electron-opaque wall layer. During subsequent differentiation, dissolution of specific wall parts of the cell intrusions occurs so that open, cup- or trunk-like structures result. The vessel-like host contact can comprise up to five openings per a single intrusion. Correspondingly, the intrusions and the haustorial cells to which they belong lose their protoplasts and convert into elements which absorb water. Walls of the haustorial cells and both wall parts of their appendages come to be strongly lignified. Water and nutrient absorbing structures intered into the host vessel are called ‘oscula’ (Dörr, 1997). Then the new *striga* plant will grow attaching to the host root (Fig 2).

Figure 2 *Striga* attachment to sorghum root (a photo taken during sample collection)

4. *Striga* control methods

Different researches were conducted on the control mechanisms of *Striga* weed for the last 60 years. There are three principles *Striga* weed management. These are reducing number of *Striga* seeds in soil, preventing production of new seeds and preventing spread from infested to non-infested soils (Obilana et al., 1992 and Runo et al., 2018). Host –plant resistance, host seed treatment, transplanting, and biological control reduce the amount of *Striga* seeds in the soil, stop *Striga* reproduction and reduce crop loss (Berner et al., 1995. These control methods can be generalized as cultural, chemical, and biological.

4.1. Cultural control

Cultural *Striga* management includes hand weeding, crop-rotation, inter-cropping, trap and catch croping and improving soil fertility. As many scholars agreed hand weeding is not effective management of *Striga* weed (Babiker, 2007). Still these practices are not adopted by farmers. Because they are perceived by poor farmers as unaffordable or uneconomical, labor intensive, impractical, or not congruent with their other farm practices (Berhane, 2016).

4.2. Chemical

Various chemicals including herbicides, fumigants (e.g, methyl bromide) and germination stimulants (e.g., ethylene) have been reported as means of control of *Striga* Herbicides like Imazapyr and pyrithiobac applied as seed dressing to maize were reported to give efficient control of the parasite. The excellent control capacity of the herbicides is most likely due to their relatively long persistence in the rhizosphere. Furthermore, multi-location testing showed that this herbicide provided excellent early season control of both *S. asiatica* and *S. hermonthica* and could increase yield 3 to 4-fold in heavy infested fields (Kanampiu et al., 2003)

4.3. Biological

The biological control of *Striga* weed includes herbivorous insects, microorganisms and smothering plants (Berhane, 2016). Insects can attack *Striga* in different sites and can be classified according to their site of damage. They are defoliators such as *Junonia* spp., gall forming such as *Smicronyx* spp., shoot borers as *Apanteles* spp., miners as *Ophiomyia Strigalis*, inflorescence feeders as *Stenoptilodestaprobanes* and fruit feeders as *Eulocastra* spp. (Kroschel, 1999). Twenty eight fungi and two bacteria were found to be associated with *Striga*hermonthica in Sudan. Among the fungi, only Fusarium nygamai and Fusarium semitectum var. majus showed potential to be used as bio-agents for the control of *Striga* (Zahran, 2008)

But in general, it was reviewed that no single management option has been found effective across locations and time. Hence, an integrated *Striga* management approach, currently, offers the best possibility for reducing impact at the farm level (Berhane, 2016). It was also reported that 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 (Hassan et al., 2009).Especially in Africa the control methods should be simple, easy to apply, inexpensive and sustainable by considering the capacity of poor farmers (Babiker, 2007).

4.4. The role of microorganisms in *Striga* management

Currently the use of microorganisms for control of *Striga* is getting an attention. As different research reports shows different fungi and bacterial isolates have very important roles in *Striga* weed management in different mechanism. According to *Striga hermonthica* seed mortality under field conditions with non-sterile soil was 86% greater than sterile soil and due to this it was suggested that microbial activity is the major cause of seed mortality during the rainy season (Van Mourik et al., 2003). There are soil microbes with potential of being used as bio control agents produce several extra-cellular lytic enzymes and antibiotic compounds (Neondo et al., 2017). Subbapurmath also reported that some soils have microorganisms which naturally suppress the *Striga* germination and it is possible to isolate, test and use these microorganisms in managing *Striga* menace.

Some microbial isolates are not only controlling *Striga* attachment, but also found to have a significant role in improving plant growth. Total nitrogen, P concentration, chlorophyll content, plant height and plant biomass were significantly increased by the inoculation of *Striga* suppressive bacteria, fungi and actinomycete isolates (Subbapurmath, 2012). Babiker also suggested that the microorganisms involved in soil suppressiveness need to be identified and crop management practices which enhance their proliferation and effectiveness need to be ascertained (Babiker, 2007). It was also reported that good control of parasitic *Striga* could be achieved by manipulating host-rhizosphere microorganisms in combination with *Striga* tolerant Sorghum cultivars (Hassan et al., 2009).

4.5. Bacteria effect on *Striga* control

It was reported 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 (Hassan et al., 2009). Bacterial isolates are found to deplete *Striga* seed bank by different mechanisms. These mechanisms are by stimulation of germination for suicidal germination, decaying *Striga* seed or inhibiting seed germination (Babalola et al., 2007, Bouillant et al., 1997 and Ahonsi et al., 2002). Therefore bacteria can be considered as an important biological control of *Striga hermonthica*.

4.6. *Striga* seed germination stimulant bacteria

Different bacterial isolates were reported to germinate *Striga* seeds in the absence of the host crop. *Pseudomonas* sp. was reported to germinate *Striga* seeds significantly (Babalola et al., 2007). *Klebsiella*, which is known to be an ethylene producer, elicited considerable germination of the parasite. Microbes – derived ethylene could be used to induce suicidal germination of the parasite and thus deplete the seed reserves in the soil (Hassan et al., 2010). It was also reported that ethylene-producing bacteria are highly effective in promoting seed germination in *Striga* spp. and also suggested as a practical means of biological control of *Striga* spp. (Berner et al., 1999).

4.7. *Striga* seed decaying bacteria

Neondo et al. reported that antibiosis and enzymatic properties of potential bio-control isolates of some *Bacillus* spp. correlated positively and recorded high antibiosis, enzymatic and seed decay values (Neondo et al., 2017). Some saprophytic bacteria also have an important role in decaying of *Striga* seed because of their nutritional versatility, fast growth rate, and high specificity of their inhibitory activity (Elliot and Lynch, 1984; Kennedy et al., 1991) cited in (Subbapurmath, 2012). Therefore soil bacteria can deplete *Striga* seed bank by killing *Striga* seeds.

4.8. Bacterial Inhibition of *Striga* seed germination

It was reported that out of four strains of *Azospirillum brasilense*, isolated from soil where sorghum is grown, have been tested for their effect on germination of *Striga* hermonthica seeds assayed two of them significantly inhibited germination of the parasite (Bouillant et al., 1997). On the other hand 15 *Pseudomonas fluorescens/P. putida* isolates were tested and all of them significantly inhibited germination of *S. hermonthica* seeds (Ahonsi et al., 2002). Hiba and his colleagues were also reported that a bacterial isolate that belongs to the genus *Pseudomonas* was found to inhibit *Striga* germination up to 100%. This is because of growth of the bacteria with production of the active enzyme could result in germination stimulant being destroyed as fast as it is produced or it computes for strigol (Hiba et al., 2013).

The use of more than one bacterial strain for *Striga* management was also reported as the best way of *Striga* inhibition. Combinations of bacterial strains were often more suppressive to haustorium initiation than individual isolates and strains. A combination of the bacterial strains *Azospirillum brasilense* and *Pseudomonas putida; A. brasilense* and *Azomonas spp; Azotobacter vienlandi* and *Bradyrhizobium japonicum; A. brasilense* and *Azomonas spp.* inhibited germination by 18 to 34% in comparison to the corresponding control (Hassan et al., 2010).

5. Conclusion

According to this review bacteria have different mechanism to control *Striga* weed. These mechanisms are by stimulation of germination for suicidal germination, decaying *Striga* seed or inhibiting seed germination. Some of the bacterial strains (*Pseudomonas fluorescens, Azospirillum brasilense,)* and isolates reduced and delayed *Striga* emergence on sorghum, others reduced *Striga* infestation and growth, whereas 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. Therefore bacteria can be considered as an important biological control agent of *Striga hermonthica* weed and further research should be done on this area.

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