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Review Article

Biological Control Strategies of Purple Witchweed, *Striga hermonthica*: A Review

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ABSTRACT

The genus of *Striga* spp., particularly *Striga hermonthica*, is an obligate root-hemiparasitic weed. *Striga* affects 25 African countries annually and is considered a major biotic threat to food security. This obnoxious weed species has been managed using various control strategies. However, the strategies have not been highly effective due to the complexity of the *Striga* life cycle and special interactions with its host. Biological control, considered a safer and 'greener' alternative, has drawn attention due to numerous reports on the potential of biological agents, including insects and microorganisms, to control *Striga*. Although researchers agree on the importance of the biocontrol approach as one of the alternative eco-friendly methods to manage *Striga* spp., the decreasing effectiveness of some biocontrol agents when introduced into new environments, in addition to requirements before and during

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the application, restricts the application of biological control on a large scale until today. This review focuses on the current knowledge of control strategies to manage *Striga*, emphasizing the biological control method. The challenges that limit the application of biological control to manage *Striga* on a broader scale are also highlighted.

Keywords: African agriculture, bio-protection, crop, microorganisms, parasitic weed

INTRODUCTION

Parasitic plants are a type of plant that attacks another plant to get all or part of nutrients and water (Samejima & Sugimoto, 2018). Moreover, parasitism among plants is one of the relationships that usually occurs among a considerable number of terrestrial plants. For example, more than 4,500 flowering plant species have parasitic behavior on other plants with wide distribution in different habitats. Consequently, various criteria have been used to classify the parasitic plants, including the site of attachment with a host, photosynthetic ability, and degree of dependency on the host plant (Erdogan, 2021; Joel et al., 2013).

Parasitic plants are morphologically distinct and range in size from diminutive herbaceous plants, generally known as weeds, to large trees. Among the parasitic plant families, the Orobanchaceae family has received great attention as it includes members of parasitic weeds that can cause severe damage to economic and cash crops leading to a critical agriculture problem of global food security (Joel et al., 2013; Okazawa et al., 2021). Witchweed (*Striga* spp.) and broomrape (*Orobanche* and *Phelipanche* spp.) are obligate root parasitic weeds that belong to the Orobanchaceae family (Clarke et al., 2019). The *Striga* genus comprises more than 35 species, including the two most widespread and economically important species, *Striga hermonthica* (Del.) Benth and *Striga asiatica* (L.) Kuntze. Both species parasitize sorghum, pearl millet, maize, and rice (Mutuku et al., 2021).

Striga hermonthica is considered the most serious biotic threat to cereal agriculture, particularly in developing countries (De Groote et al., 2008). The species affected the lives of more than 100 million people in Africa and caused economic damage, equivalent to approximately 1 billion USD per year (Labrada, 2008; Teka, 2014; Waruru, 2013). Furthermore, grain yield losses can reach 100% in susceptible cultivars under a high infestation level and drought conditions (Haussmann et al., 2000).

Biological control of *Striga* weed is a promising field with notable successes, as there are many reports on the potential of using various microorganisms to reduce damage caused by *Striga*. However, special consideration must be put in place to avoid unintended effects on the host plant due to the intimate relationship between *Striga* and the host plant. Therefore, rigorous testing and validation are necessary to evaluate their efficacy and reliability for *Striga* control (Hasan et al., 2021; Neondo et al., 2017; Nzioki et al., 2016). Furthermore, a combination of compatible biocontrol agents with divergent modes of action is likely to yield better results than a single biocontrol agent (Neondo et al., 2017; Nzioki et al., 2016). In this review, the current state of knowledge on the biological control strategies to manage *Striga*, the mechanisms of control, and the obstacles that limit its application are described on a wider scale.

BIOLOGY AND LIFE CYCLE OF *STRIGA* SPP.

Striga spp. are annual root hemiparasitic plants that can produce an incredibly huge number of seeds per plant (up to 100,000 seeds plant-1) with high fecundity where it remains viable for more than 15 years, leading to a rapid increase in the seed bank (Samejima & Sugimoto, 2018; Teka, 2014). *Striga* spp. is characterized by a complex life cycle that initiates simultaneously with the life cycle of its host. The life cycle starts with germination, haustoria formation attachment, penetration, the establishment of vascular connections, the accretion of nutrients, flowering, and finally, the production of seeds (Cardoso et al., 2011; David et al., 2022). The distinct phases of the life cycles of both plants are harmonized through a signaling process before *Striga* sets new seeds (Figure 1). Before germination, *Striga* seeds must undergo a conditioning stage, which involves exposure to a sufficient temperature and high humidity conditions for two weeks to break seed dormancy and become responsive to germination stimulants (Cardoso et al., 2011). After the seeds germinate, germ tubes are produced and grown chemotropically toward the host root. Then radicals attach to the host root and form haustoria in response to the haustoria-inducing factor. An adhesive structure develops during the attachment phase to cement the parasite to the host surface. The haustorium then penetrates the root cortex of potential hosts and continues to connect with the xylem of the host plant. During the attachment phase, the parasite remains subterranean for several weeks and withdraws all the nutrients from the host plant before appearing above ground.

The Role of Strigolactones in the *Striga* Life Cycle

Soil deterioration correlates with *Striga* infestation via the increased production of secondary metabolites by the host plant in response to the poor soil condition that induces germination of the parasites (Jamil et al., 2014). The secondary metabolites, identified as strigolactones (SLs), which are abundantly present in mycotrophic plant roots, exudate in poor soil to help establish symbiotic interaction with mycorrhiza in the soil (Boari et al., 2016). SLs are also vital for the germination of *Striga* and other parasitic weeds. The first SLs to be characterized is strigol, isolated from cotton root, a trap host species (Aquino et al., 2021; Reigosa et al., 2006). Another established role for SLs is regulating root and shoot architecture based on phosphate availability. In a sufficient amount of phosphate, SLs inhibit lateral root formation, while in a

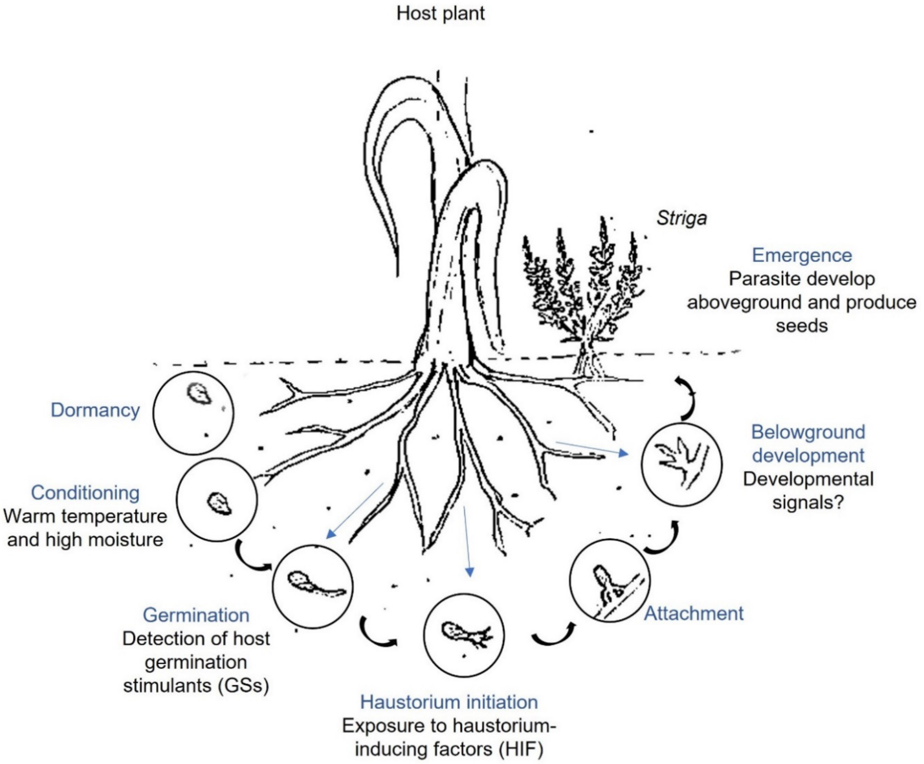

Figure 1. The life cycle of *Striga*

phosphate-limited environment, they can promote lateral root primordia formation (Xie et al., 2010). In addition to the effects on organ growth and development, SLs also affect plant metabolism through the biosynthesis of organic acids (Gamir et al., 2020). Previous research has confirmed that using nitrogen and phosphorus to improve soil fertility decreases SLs exudate and reduces *Striga* germination (Jamil et al., 2014; Mwangangi et al., 2021). Other than SLs, *Striga* seeds can also germinate in response to other compounds produced by plant roots, such as dihydrosorogoleone, kinetin, coumarin, jasmonate, ethylene, and fungal metabolites (Cardoso et al., 2011). However, the sensitivity of *Striga* seeds to these compounds is lower than their sensitivity to SLs. Furthermore, SLs can stimulate *Striga* seed germination even if secreted from the non-host roots, making SLs the most efficient compound for regulating *Striga* seed germination (Cardoso et al., 2011).

CURRENT PRACTICES IN MANAGING *STRIGA* AND THEIR LIMITATIONS

The management strategies of *Striga* rely on achieving the following targets: (1) limiting seed dispersal out of the endemic area via agriculture tools, irrigation water, and pasture animals; (2) limiting new seed production by reducing the release of germination stimulants by the host, and (3) reducing seed bank accumulation in infested soil by stimulating the germination of *Striga* seed in the host's absence or blocking the germination of preconditioned seed (Jamil et al., 2021). Several control methods have been applied to attain at least one of the management targets, including chemical, cultural, and biological control, with varying degrees of success (Boari et al., 2016). However, many countries avoid the conventional (cultural) method, which involves hand pulling of emerging *Striga* stalk. It is ineffective since parasite damage already occurs at the subterranean phase (Figure 1). Likewise, crop rotation systems or using catch/trap crops and tolerant varieties are not considered efficient in eradicating this parasite, particularly if applied separately (Babiker, 2007; Hailu et al., 2018; Sibhatu et al., 2016).

Chemical control using herbicides, such as imazapyr and pyrithiobac, soil fumigation by methyl bromide, and ethylene as germination stimulants have been reported in numerous studies as effective methods to increase crop production and control *Striga* in the early season (Sibhatu et al., 2016). However, although the chemical approaches are widely adopted, their sustainability is compromised by the predicted emergence of herbicide-resistant weeds and unwanted off-target effects (Eizenberg et al., 2013). The latter can potentially disrupt biodiversity, reduce beneficial soil microbes, or compromise immunity against other pests and pathogens (Barzman et al., 2015; Druille et al., 2013). In addition, prolonged application of chemical herbicides was shown to have detrimental effects on humans by increasing the risk of cancer, congenital disabilities, and skin problems and by threatening the sustainability of natural resources (Bale et al., 2008; Kumar et al., 2021). Therefore, an eco-friendly approach to control *Striga* weed is critical and in high demand to avoid the negative impacts resulting from the accumulation of chemical residues and preserve environmental balance.

BIOLOGICAL CONTROL OF PARASITIC WEEDS

Biological agents to eliminate various noxious pests, including weeds, insects, and microbial pathogens, have been used for over a century. Regardless of the intentions, which may range from convenience to opportunism, the term 'biological control' has traditionally been used to describe actions to combat pests using other living agents (Cook & Baker, 1983; Stenberg et al., 2021). For example, the Weed Science Society of America (WSSA) defined the weed biological control method as 'the use of an agent, a complex of agents, or biological processes to bring about weed suppression' (Uludag et al., 2018). The ultimate advantage of biological control in terms of cost-effectiveness, safety, and benefits for the environment would be evident upon the establishment and reproduction of the released organisms (Teka, 2014).

Many reasons motivate the adoption of biological control in parasitic weeds. Among them are the restriction imposed on many common herbicides by the authorities, the evolution of herbicide-resistant parasitic weeds, increased understanding of weed control to target only unwanted species, conservation of environmentally sensitive or degradation-prone areas, contamination from chemical herbicides, and inclination to healthier and sustainable cropping systems (Myers & Cory, 2017; van Wilgen et al., 2013). Furthermore, the intimate relationship between the parasitic weed and its host hinders the application of chemical herbicides as they cannot all selectively distinguish between different species. On the other hand, the high specificity of some fungi, bacteria, and arthropods that feed exclusively on selected parasitic weeds leads to increased attention on exploiting these organisms as biocontrol agents, where other weed control options have failed (Teka, 2014; Uludag et al., 2018).

THE BIOLOGICAL APPROACHES FOR CONTROLLING *STRIGA*

Biological control of *Striga* is a system that relies on the interaction between three agents: the parasite (*Striga*), a living biocontrol agent targeting *Striga*, and a human stakeholder benefiting from the *Striga* control service provided by the biocontrol agent (Stenberg et al., 2021). In this case, the living biocontrol agents include bacteria, fungi, insects, and components extracted or synthesized from microorganisms *in situ*. According to the International Biocontrol Manufacturers Association (IBMA) (2018), bio-protection agents should originate from nature or be nature-identical when synthesized and have a low impact on human health and the environment.

Mechanisms of Action of Biological Control Against *Striga*

The biocontrol mechanisms of the living agents used for controlling *Striga* occur through direct or indirect antagonisms (Figure 2). The former involves natural enemies such as pathogens and insect predators that attack and consume *Striga* organs or produce secondary metabolites, which cause diseases that inhibit *Striga* seeds germination or interfere with host-*Striga* signaling (Ndambi et al., 2011). The latter occurs via disruption of the *Striga* life cycle or reduction of *Striga* attachment in the host root by enhancing nutrient acquisition, which consequently halts strigolactones biosynthesis in the host plant. Alternatively, indirect antagonism may occur via induced systemic resistance (ISR) in the host plants against *Striga* via changes in plant defense pathways, particularly salicylic acid, and jasmonic acid. It is worth mentioning that the precise knowledge of the control mechanism is behind the expansion of the term biocontrol to bio-protection to include the indirect effects of the living organisms on *Striga* (Masteling et al., 2019).

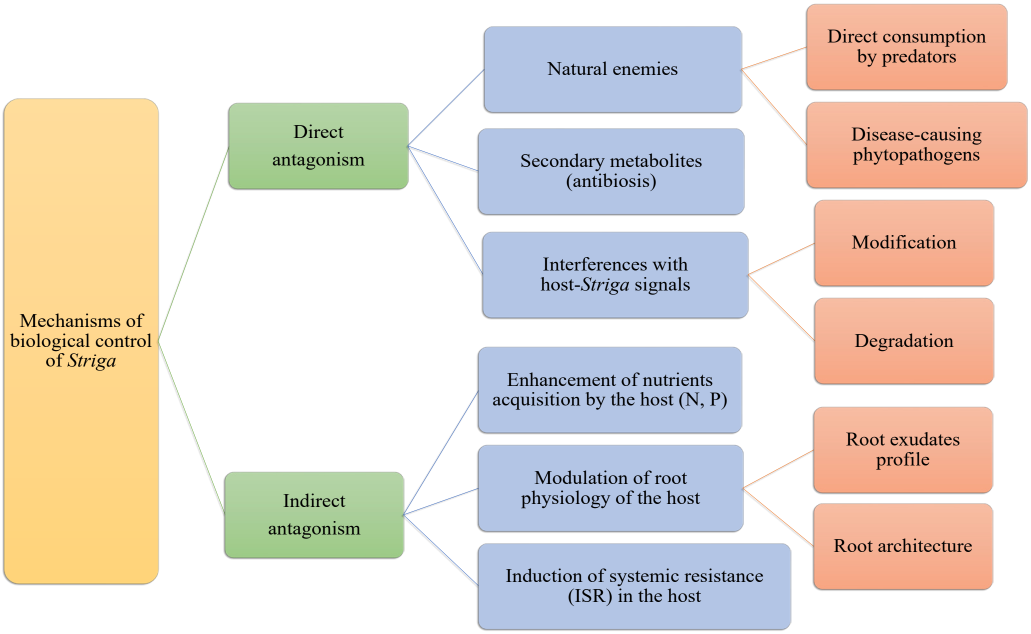

Figure 2. Mechanisms of biological control against *Striga*

Biocontrol of *Striga* Using Insects

Damaging *Striga* directly through natural enemies, such as herbivorous insects, is one of the most applied biocontrol techniques. Furthermore, many insects indigenous to India and Africa have been reported to attack *Striga* spp. The genus of greatest interest concerning biological control is *Smicronyx*, of which several species are highly specific to *Striga* (Parker & Riches, 1993). According to their effect on *Striga*, the insects are classified as defoliators, gall-formers, shoot borers, miners, inflorescence feeders, and fruit feeders (Bashir, 1987; Kroschel et al., 1999) (Table 1). For example, the release of *Smicronyx albovariegatus* and *Eulocastra argentisspara* in Ethiopia in 1974 signified the first attempt to adopt the classical biological control for *Striga*. The event was followed by a second release of *S. albovariegatus* four years later (Kroschel et al., 1999; Parker & Riches, 1993).

Table 1

Insects with the potential to control Striga *spp.*

Pathogen / Agent scientific name	Classification	Action / Response and mechanism	Reference(s)	Target of *Striga* spp.
Smicronyx albovariegatus	Insect	Induce gall formation on *Striga*	Kroschel et al. (1999)	*Striga hermonthica*

Table 1 *(Continue)*

Pathogen / Agent scientific name	Classification	Action /Response and mechanism	Reference(s)	Target of *Striga* spp.
Smicronyx umbrinus	Insect	Destroy seeds in the range of 80-95%	Smith and Webb (1996); Smith et al. (1993)	*Striga hermonthica*
Junonia spp.	Insect	Defoliator	Bashir (1987); Kroschel et al. (1999)	*Striga hermonthica*
Apanteles sp.	Insect	Shoot borer	Bashir (1987); Kroschel et al. (1999)	*Striga hermonthica*
Ophiomyia strigalis	Insect	Miner	Bashir (1987); Kroschel et al. (1999)	*Striga hermonthica*
Stenoptilodes thtaprobanes	Insect	Inflorescence feeder	Bashir (1987); Kroschel et al. (1999)	*Striga hermonthica*
Eulocastra spp.	Insect	Fruit feeder	Bashir (1987); Kroschel et al. (1999)	*Striga hermonthica*

Biocontrol of *Striga* Using Microorganisms

Apart from using insects, researchers interested in biological control to combat *Striga* have focused on exploiting microorganisms (Table 2) by directly applying or extracting and manipulating their biological compounds (Stenberg et al., 2021). Pathogenic fungi account for nearly 50% of the living organism candidates for biological control of *Striga*. Most candidates were reported to target *S. hermonthica*, except for *Fusarium oxysporum* f. sp. *strigae* (*Fos*), *Curvularia geniculate*, *Rhizoctonia solani*, and *Sclerotium rolfsii* that also target species other than *S. hermonthica*. For example, a direct application of *Fos* successfully blocked the xylem vessels of mature (emerged) plants by its hyphae or caused complete tissue digestion of younger plantlets belowground, leading to wilting and death on *Striga* (Ndambi et al., 2011). Alternatively, the application of amino acids L-leucine and L-tyrosine extracted from *Fusarium oxysporum* was found to be toxic to *Striga* and were able to inhibit its germination. However, at the same time, it is innocuous to the host.

Myriad signaling molecules, such as sterols, isothiocyanates, and organic acids, can induce germination and haustorium formation of parasitic root weed (RPW), including *Striga*, which are secreted by microbes in the plant rhizosphere. Arbuscular mycorrhiza fungi (AMF) enhance the growth performance of cereals to withstand

Striga damage by facilitating the uptake of water, phosphorus, and micronutrients from the soil through the wide net of extraradical fungal hyphae (Bonfante & Genre, 2010). Consequently, increased phosphorus uptake through symbiotic interaction by AMF could ultimately reduce SLs exudation by the host in the soil, thereby lowering *Striga* infection (Lendzemo et al., 2007; Lo´pez-Ra´ez et al., 2011).

In addition to fungi, bacteria also contribute to a large proportion of microbes in the plant rhizosphere. The root-associated bacteria mainly belong to the plant growth-promoting rhizobacteria (PGPR). They include various bacterial genera, such as *Bacillus* sp., *Azospirillum* sp., *Gluconacetobacter* sp., *Pseudomonas* sp., and *Rhizobium*. Augmentation of the rhizosphere microbiome by adding a new member might interfere with the signaling, thus suppressing seed germination, and disrupting the development of radical and/or haustoria (Masteling et al., 2019). Moreover, *Striga* seed germination and the number of attachments to the host root were reduced notably after treating sorghum root exudates with epiphytic bacteria from sorghum seeds. These occur following a change in the phenolic compound profile in the root exudates (Ali et al., 2013). These bacteria play an important role in plant growth by regulating the secretion of auxins, gibberellins, indole-3-acetic acid, and cytokinin, in addition to increasing soil mineral bioavailability by diazotrophic nitrogen fixation. Therefore, these bacteria contribute indirectly to managing *Striga* by strengthening the immune system in the host plant (Danhorn & Fuqua, 2007; Mounde et al., 2020; Taylor et al., 1996).

Though not pathogenic, other bacterial genera, such as *Bacillus*, can cause *Striga* seed decay by extracellular xylanases, pectinases, and amylases (Masteling et al., 2019). In another report, *Pseudomonas fluorescens* and *Pseudomonas putida* significantly inhibited *S. hermonthica* seed germination under screen house experiments (Babalola et al., 2007). In addition, Gafar et al. (2015) reported inhibition effects on *Striga* seed germination and haustorium initiation during conditioning with endophytic bacteria isolated from sugarcane suspected to belong to *Gluconacetobacter* spp. Conversely, ethylene from some *Pseudomonas* spp. and *Bradyrhizobium japonicum* can induce the germination of *Striga* seed in the absence of the host (suicidal germination), leading to a reduction of *Striga* seed bank (Table 2) (Ahonsi et al., 2003; Okazawa et al., 2021).

CHALLENGES AND LIMITATIONS IN THE BIOLOGICAL CONTROL OF PARASITIC WEED

In contrast to common weeds, controlling RPW, including *Striga*, is faced with several difficulties, as reviewed by Nzioki et al. (2016). Among them is the unique biology of parasitic weeds, which limits the number of metabolic pathways that current commercial herbicides can target. However, it can generate opportunities for discovering parasitic weed-specific herbicide targets (Fernández-Aparicio et al., 2017, 2020). In addition, the tiny size of RPW seeds,

Table 2
Microorganisms with the potential to control Striga *spp.*

Pathogen / Agent scientific name	Classification	Action / Response and mechanism	Reference (s)	Target of *Striga* spp.
Fusarium oxysporum	Phytopathogenic fungi	Disrupt amino acid homeostasis (Antibiosis)	Nzioki et al. (2016)	*Striga hermonthica*
Fusarium oxysporum f. sp. *strigae* (*Fos*)	Phytopathogenic fungi	Inhibit *Striga* emergence	Nzioki et al. (2016); Rebeka et al. (2013)	*Striga asiatica* and *Striga hermonthica*
Fusarium semitectum var. *majus*	Phytopathogenic fungi	Attack on *Striga* germ tube by the fungal spores and reduce *Striga* emergence by up to 82%	Abbasher et al. (1995)	*Striga hermonthica*
Fusarium solani	Phytopathogenic fungi	Culture filtrates inhibit *Striga* seed germination (mycotoxin)	Ahmed et al. (2001)	*Striga hermonthica*
Fusarium nygamai	Phytopathogenic fungi	Attack on *Striga* germ tube by the fungal spores and reduce *Striga* emergence by up to 97%	Abbasher et al. (1995)	*Striga hermonthica*
Curvularia geniculate	Phytopathogenic fungi	Cause disease in *Striga*	Meister and Eplee (1971)	*Striga* spp.
Sclerotium rolfsii	Phytopathogenic fungi	Cause disease in *Striga*	Meister and Eplee (1971)	*Striga* spp.
Cercospora	Phytopathogenic fungi	Cause disease in *Striga*	Zummo (1977)	*Striga hermonthica*
Fusarium equiseti	Phytopathogenic fungi	Cause disease in *Striga*	Zummo (1977)	*Striga hermonthica*

Table 2 *(Continue)*

Pathogen / Agent scientific name	Classification	Action / Response and mechanism	Reference (s)	Target of *Striga* spp.
Alternaria, *Aspergillus*, and *Verticillium*	Phytopathogenic fungi	Reduce *Striga* emergence and biomass	Joel et al. (2013)	*Striga hermonthica*
Glomus mosseae	Fungi	Increase total dry matter and yield of the host plant, reduce *Striga* emergence by up to 62%	Gworgwor and Weber (2003)	*Striga hermonthica*
Glomus clarum *Gigaspora margarita*	Fungi	Reduce *Striga* shoot number, increase the yield of the host plant, and reduce *Striga* germination by up to 97%	Lendzemo et al. (2007)	*Striga hermonthica*
Glomus and *Paraglomus* spp. alone or in combination with *Flavobacterium*, *Azotobacter*, or *Bacillus* sp.	Fungi and Bacteria	Reduce seed germination, interfere with seedling attachment and delay *Striga* emergence	Hassan, Abdelhalim, et al. (2011)	*Striga hermonthica*
Azospirillum brasilense	Bacteria	Inhibit seed germination and radicle elongation (antibiosis)	Miché et al. (2000)	*Striga hermonthica*
Azospirillum brasilense, *Pseudomonas putida*, and other isolates	Bacteria	Inhibit germination by 40–85%, haustorium initiation by 52–85%, and attachment by 78–81%	Hassan, Gani, et al. (2011)	*Striga hermonthica*
Pseudomonas	Bacteria	Reduce *Striga* seed germination via degradation of SLs (interference with host-*Striga* signals)	Ali et al. (2013)	*Striga hermonthica*
Pseudomonas syringae pathovar glycinea (*Psg*)	Bacteria	Promote seed germination (suicidal germination)	Berner et al. (1999)	*Striga hermonthica, Striga aspera*, *Striga gesnerioides*

Table 2 *(Continue)*

Pathogen / Agent scientific name	Classification	Action / Response and mechanism	Reference (s)	Target of *Striga* spp.
Pseudomonas syringae pv. *glycinea* with *Bradyrhizobium japonicum*	Bacteria	Promote seed death (suicidal germination) during non-host rotation	Ahonsi et al. (2003)	*Striga hermonthica*
Pseudomonas fluorescens *Pseudomonas putida*	Bacteria	Inhibit seed germination	Ahonsi et al. (2002); Babalola et al. (2007)	*Striga hermonthica*
Streptomyces and *Rhizobium* sp.	Bacteria	Produce compounds with antibiotic activity and extracellular enzymes, causing *Striga* seed decay	Neondo et al. (2017)	*Striga hermonthica*
Bacillus subtilis GBO3	Bacteria	Prevent *Striga* germination and promote the growth of the host plant	Mounde et al. (2015)	*Striga hermonthica*

*Recorded as the causal agent for diseases in *Striga* (natural control) sometimes called dust seeds, can be easily spread over a wide range (Teka, 2014; Westwood et al., 2013). Moreover, intimate contact of the parasite with the host plant roots that lasts most of its life cycle makes controlling it more difficult because the control method must not harm the host plant. Further complicating the matter is the complex life cycle of *Striga* (Figure 1). Each phase requires a comprehensive study before any biological control agent can be applied in the field to adjust the optimum time of application.

Although biological control of weed can be effective, it is sometimes uneconomical because it requires in-depth studies on its efficacy, toxicological effects, and environmental effects before any biocontrol agent can be registered. Furthermore, even if the biocontrol agent is isolated locally, some still produce inconsistent results when applied at different locations due to a lack of adaptability to a new environment (Pereg & Mcmillan, 2015; Teka, 2014). For example, the inconsistency of *Fos* isolates to control genetically diverse *S. hermonthica* populations effectively lowers its reliability as an efficient mycoherbicide against *S. hermonthica* in various agroecological zones. Consequently, it hinders the widespread acceptability of *Fos* as a biocontrol agent against *S. hermonthica* (Velivelli et al., 2014; Massart et al., 2015). Furthermore, the viability of microbes may decrease during the traditional delivery system of packaged microbes for long-term storage to be distributed on a farm later because the microbes are still dormant when applied to the soil. Hence, a new and improved delivery technique is required to ensure maximum viability (Mohammadi, 2019; Nzioki et al., 2016).

While microbes effectively modify or degrade the host signals (Figure 2) and/or induce defense responses in the host plant *in vitro*, the in-planta efficacy and the impact on the mutualistic interactions between the host and the symbionts, such as AMF, are still under-explored. Hence, the underlying signal-transduction pathways and their conclusive role in *Striga* suppression are yet to be resolved. Furthermore, the knowledge gap is considered a challenge because the local environment interferes with the efficiency of microbes (Masteling et al., 2019). Finally, the usage of insects as classical biological control is costly and may be affected by political unrest in the African region. In addition, the inundative release of insects is not practical in third-world countries, mainly due to the infeasibility of mass rearing (Kroschel et al., 1999).

CONCLUSION

Various control methods have been applied to manage *Striga,* including chemical, cultural, and biological, with varying degrees of success. The limitations of the chemical and cultural methods and the list of benefits offered by the biological control method motivate the research on the latter and push its adoption. Insects and microorganisms are the two biocontrol agents used to control *Striga*, and they operate via both direct and indirect mechanisms. However, controlling parasitic weeds such as *Striga* poses more challenges than common weeds. Among them is the unique and complex biology of the parasitic weed, the tiny size of the seeds, and the intimate contact of the parasite with the host plant roots that lasts most of its life cycle. Therefore, more research is needed, especially on the field adaptability of the biocontrol agents, delivery techniques, and *planta* efficacy.

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