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Ethiopian Sorghum (*Sorghum bicolor* (L.) Moench) genotpyes: Striga (*Striga hermonthica* (Del.) Benth.) resistance

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Abstract: **Sorghum (*Sorghum bicolor* L.) is the most important cereal crop in semi-arid regions of the world, where it serves as the primary food source for the majority of the people. *Striga hermonthica,* a hemi-parasitic flowering weed, is the major biotic constraint for sorghum production in Sub-Saharan Africa. When a crop is highly infested with witch weeds, yield losses can reach 100% in countries such as Ethiopia and Sudan (*Striga spp*.). Overcoming striga-caused sorghum grain yield losses through resistance breeding has been impeded by a lack of appropriate screening techniques. Striga resistant cultivars provide the most feasible control strategy. Agar gel assay, low germination stimulant marker, and root system architecture were used in some study to screen or evaluate striga resistant sorghum germplasms.**

Keywords: **Resistance, Root system architecture, Striga, Strigolactone.**

ABBREVIATIONS

AATF	African Agricultural Technology Foundation
AGA	Agar Gel Assay
CSA	Central Statistical Agency
GAP	Good Agricultural Practices
FAO	Food and Agricultural Organization
IBC	Institute of Biodiversity Conservation
ISC	Integrated Striga Control
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IITA	International Institute of Tropical Agriculture
LGS1	Low Germination Stimulant 1
RSA	Root System Architecture
SSA	Sub-Saharan Africa

1. INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is the most important cereal crop in semi-arid regions of the world, where it serves as the primary food source for the majority of the population. It is generally, though not completely accepted, that it was domesticated in East Africa, possibly in the Nile or Ethiopia. The domestication of sorghum has its origins in Ethiopia and neighboring countries, commencing around 4000–3000 BC (Zidenga, 2004; Dillon *et al*., 2007). It belongs

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to the *Poaceae* family and has a genome of ($2n = 2x = 20$) compared to the model grass species, rice (394 Mb). The genome size of sorghum is approximately 740 Mb (Paterson, 1995). Its wide adaptation to harsh environments, tolerance to stress conditions, availability of diverse germplasm collections and its small genome size make sorghum an important botanical model crop for many tropical grasses with complex genomes and employing C4 photosynthesis (Menz *et al*., 2002).

Sorghum is grown all over the world, including the Americas and Asia, as well as its native Africa. It is a good choice for Africa since it is well-suited to low-input agriculture, particularly in locations where water is scarce. Sorghum is the continent's second most significant cereal after maize, accounting for 22% of total cereal area grown (FAO, 2015). Sorghum production area in Africa is around 23.14 million ha, with total output and average yield of 23.35 million metric tons and 1.01 ton/ha, respectively. Ethiopia is the fourth top sorghum producing country in the world following the United States of America, Nigeria and Mexico (FAOSTAT, 2017). In terms of geographical coverage and production, sorghum is the third most significant crop after tef and maize in Ethiopia. It is grown in almost every part of the country, with an estimated total land area of 1.6 million hectare. Sorghum accounts for 18.5 percent of total cereal production in the country, with a productivity of about 28 tons per hectare (CSA, 2018).

In Africa, the primary demand for sorghum and millets is for food, particularly in dry regions (FAO, 2015). The crop is used in a number of different ways, with the grain being used for human nutrition, homemade beverages, and feed. Sorghum juice can be converted to alcohol using normal fermentation technology that is currently available (Reddy et al., 2007). The sorghum crop ranks second (after maize) in grain-based ethanol production in the United States of America, and it contributes to weed biology as well as the improvement of a variety of other forage, turf, and biomass crops (Kresovich et al., 2005). The hemi-parasitic flowering weed *S. hermonthica* is the major biotic constraint on sorghum production in Sub-Saharan Africa. Striga infestation causes significant yield losses in African countries such as Ethiopia, Botswana, Burkina Faso, Eritrea, Kenya, Mali, Mozambique, Niger, Nigeria, Senegal, Sudan, and Tanzania (Gebisa Ejeta and Gressel, 2007). Integrated control packages based on resistant genotypes in combination with cultural and/or chemical control strategies appear to be the best option for striga management at the current (Tesfaye Tesso and Gebisa Ejeta, 2011). Resistance to these parasitic weeds, on the other hand, is a complex phenomenon that is also dependent on the interaction of the parasite, the host, and the environment. The striga life cycle consists of several phases, including seed germination stimulation, the initiation of an attachment organ (haustorium), penetration of the host root, linkage to the host xylem, and subsequent growth and development (Parker and Riches, 1993) (Fig.1).

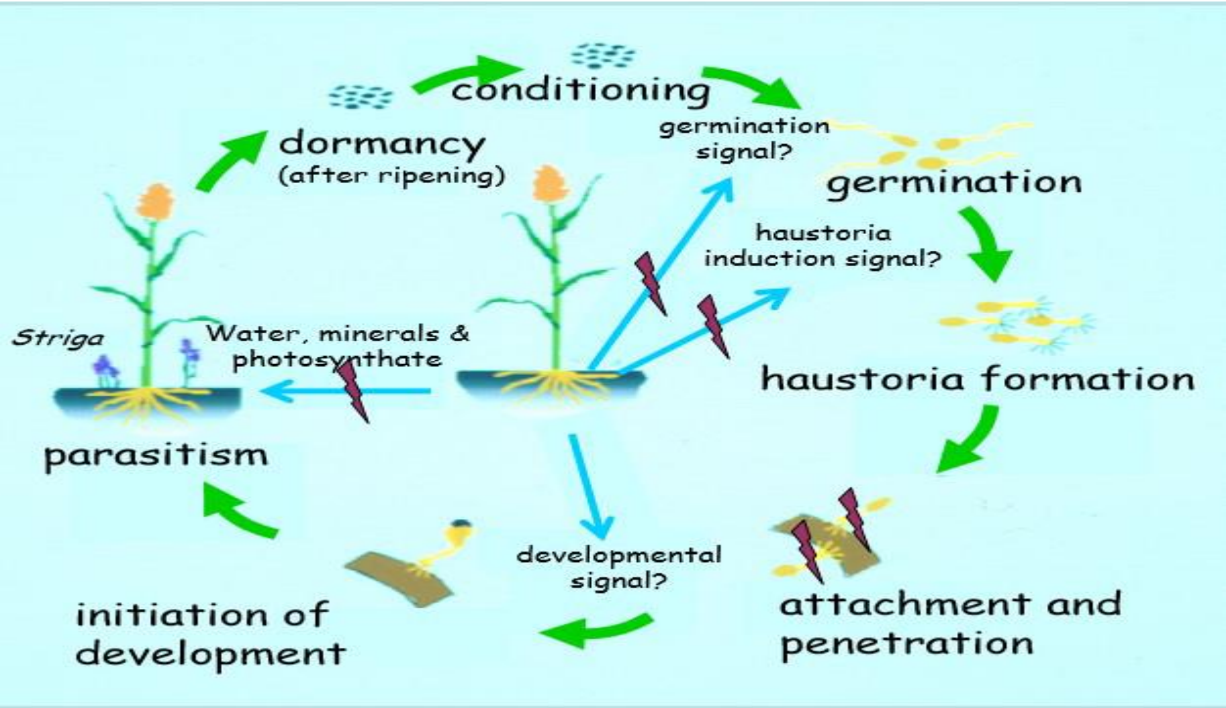

Figure: 1. Striga life cycle (Source: Gebisa Ejeta *et al*., 1993).

To allow germination, striga seed dormancy must be overcome under warm and moist conditions (a process known in the lab as "pre-conditioning"), followed by exposure to certain exogenous signaling chemicals released by their host's roots (Bouwmeester et al., 2003). Different germination stimulants may be produced and released by the roots of striga hosts and some non-hosts (Sato et al., 2003). However, strigolactones are recognized to be the most effective stimulant, inducing germination in seeds of several striga species at nanomolar or even picomolar concentrations (Bouwmeester et al., 2003). Following germination, the striga radicle extends (possibly chemotropically) towards the host root, where it stops growing upon recognition of a second host-derived signal and forms a haustorium, the multicellular attachment and penetration organ. The initiation of the haustorium represents the transition from an autotrophic to a parasitic style of life (Babiker, 2007). Striga resistance is broadly categorized as pre- and post-attachment resistance (Yoder and Scholes, 2010). Pre-attachment resistance refers to the disruption of one or more of the events that occur between striga germination and haustorium attachment.

Low germination stimulation is the most generally characterized kind of pre-attachment resistance (lgs). Interruption of sorghum root penetration and/or striga developmental phases is a form of post-attachment resistance. The development of mechanical barriers, hypersensitive response, antibiosis, and blockage and sealing up of the host vasculature can all result in the interruption of striga penetration of the host root (Mohammed et al., 2003). Low germination stimulation (lgs) is the well-documented of these pre- and post-attachment resistance mechanisms (Hess et al., 1992). The presence of strigolactones in the root exudates of its hosts stimulates striga germination. The LGS1 locus contains one gene associated with striga pre-attachment resistance. LGS1 is a gene that encodes a sulfotransferase enzyme (Daniel Gobena, et al., 2017). Functional loss of this gene causes in a change of the dominant strigolactone (SL) in root exudates from 5-deoxystrigol, a highly active striga germination stimulant, to orobanchol, a SL with opposite stereochemistry (Xie et al., 2013).

Although not all striga-resistant sorghum lines had low striga germination stimulant activity, striga resistance was found in all low-stimulant sorghums that were field-tested (Gebisa Ejeta, 2007). Low striga germination stimulant activity has been an important resistance trait in sorghum improvement, but not so much in maize, millet, or rice, which are striga's other crop hosts (Perez-Vich et al., 2013). According to genetic studies, inheritance of low striga germination stimulant activity in sorghum is through a mutant allele (lgs) expressed in homozygous recessive individuals. It's relatively simple to track striga germination stimulation by sorghum. Introducing genotypes with lower striga germination stimulation has the benefit of minimizing striga infection and seed bank building (Haussmann et al., 2004). In 1991, ICRISAT provided accessions SRN39 and IS9830 as varieties exhibiting field resistance due to low germination stimulant production (Bantilan et al., 2004). Indeed, in the past decade or so, several sorghum varieties with striga resistance based on *LGS1* have been introduced, such as SRN39 and IS9830 in Sudan, and Abshir, Gobiye and Birhan in Ethiopia (Tefera Hailu et al., 2012). The most important component of pre-attachment resistance is germination, and as stated below, low germination has been successfully introduced into sorghum varieties to obtain striga resistance (Gebisa Ejeta, 2007). However, establishing a uniform level of infestation at an optimum intensity level for consistent and reproducible results is difficult. Several striga resistance mechanisms have been reported (Doggett, 1988). One of the best-studied processes is the host plant roots' abnormally low production of root exudate chemicals that promote striga seed development (Vasudeva, 1987). Sorghum varieties that show this characteristic are resistant because striga seeds do not germinate unless they are exposed to a particular stimulant from the host root (Vasudeva, 1987).

Striga is a mandatory parasite that only survives a few days after germination unless it successfully parasitizes a host root (Worsham and Egley, 1990). As a result, the agar gel assay is useful technique for assessing striga pre-attachment resistance in order to more effectively screen for the host plant's potential to boost striga germination. Since plants are unarguable important to humans and indeed, to most life on earth by providing foods, fuel shelter etc., their growth and survival depends on the environment. The spatial organization of primary roots and root-and stem-derived branches (lateral roots, adventitious roots) that play a critical role in plant adaptation to adverse soil conditions by improving plant growth and productivity is defined as root-system architecture (RSA) (Smith and Smet, 2012). Several studies have found that the RSA of various cereal crops is affected by the genotype of the crop, the environment in which it grows, and genotype by environment (GXE) interactions. It has been proposed, for example, that cereal crops with the deepest main root length, few lateral roots, and long lateral roots have a greater chance of surviving drought (Lynch, 2013).

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Plants interact with every other organism in the soil, including parasitic plants, within the environment. When mature, striga can produce up to 500,000 seeds (Dixon and Parker, 1984). For parasitism to occur, these seeds must interact with a host root. However, not all of the seeds in the soil are equally effective in developing successful interactions. Those seeds which are most effective on sorghum are located in the upper 5 to 30 cm of the soil profile (Robinson and Kust, 1962; Babiker et al., 1987), whereas corn parasitism occurs mainly in the top 10-cm of the soil profile (Bebawi et al., 1984). As a result, genotypes with different root system architectures may have varying levels of resistance or susceptibility to striga. Because most parasite seeds are found in the top soil, it is hypothesized that the sorghum genotype with the deepest main root, few lateral roots, and, if present, long lateral roots will be resistant to *Striga hermonthica* (Robinson and Kust, 1962).

2. LITERATURE REVIEW

2.1. Sorghum Origin and Domestication

Sorghum originated in Africa (Ethiopia, Sudan, and East Africa), where it is observed in the greatest diversity of wild and cultivated species (Acquah, 2007). The presence of both wild and cultivated sorghums in Ethiopia indicates that Ethiopia is the primary center of origin and diversity for this crop (Firew Mekibeb, 2006). There is also indication that cultivated sorghum was domesticated around 5000-7000 years ago via selections from a wild progenitor, subspecies verticilliflorum (Purseglove, 1972). Improved sorghum types, wild types, and intermediate types have resulted from a balance of farmer selection for cultivated traits and natural selection for wild ones (Doggett, 1970). A large number of sorghum varieties have been developed as a result of the process of disruptive selection, which happens when selection for more than one level with a certain character occurs within a population. These results from a balance of farmer selection for cultivated traits and natural selection for wild characteristics, generating improved sorghum types, wild types and intermediate types (Olembo *et al*., 2010). There is further evidence that sorghum was domesticated between 5,000 and 7,000 years ago in Ethiopia and parts of the Congo, with secondary centers of origin in India, Sudan, and Nigeria (Acquah, 2007). Ethiopia is often recognized as the center of sorghum domestication due to the country's greatest genetic diversity in both cultivated and wild varieties (Masresha Fetene et al., 2011).

2.2. Taxonomy, Ecology and Botanical Description of Sorghum

Sorghum was first described by Linnaeus in 1753 under the name of *Holcus*. Moench later separated the genus sorghum from the *Holcus* and gave it the binomial of *Sorghum bicolor*. The present formal taxonomic idea of the sorghum genus and species is consistent with Moench's. All of the different names given by different taxonomists are thus considered synonyms of [*Sorghum bicolor* (L.) Moench]. Sorghum is a Poaceae family herbaceous annual grass of tropical origin that is sown from seed and stores a significant amount of sugar while requiring little water. Sorghum can grow in a variety of soil types, from heavy clay to light sand, with pH levels ranging from 5.0 to 8.5. Sorghum grows well in arid and saline settings and matures in 90 to 180 days. It is regarded as a crop of universal value since it can be grown in tropical, subtropical, temperate, and semi-arid climates worldwide. It is adaptable to existing cropping systems, can be utilized as a secondary crop, and is used as a fodder and silage source for livestock production systems (Smith and Frederickson, 2000). Sorghum is an annual and primarily self-pollinated cereal, with spontaneous crosspollination reaching up to 30% in some circumstances depending on panicle type (Poehlman and Sleper, 1995; Dje et al., 2004). Sorghum plants have a deep root system that can reach 1.5 to 2.5 meters into the soil and extend one meter from the stem. The enormous amount of root material helps to the build-up of soil organic carbon when the aerial portions of the plant are removed, and can alleviate problems about soil organic matter loss caused by the removal of Stover (Wilhelm et al., 2004).

Sorghum culms can grow to be 0.6-4.5 m tall, depending on the variety and type. It has the potential to produce two or more tillers. The stalk is strong. To taste, the middle of the stem can be dry or juicy, insipid or sweet. The leaves of a dry stalked variety have a white or yellow midrib, but the leaves of a juicy stalked variety have a dull green midrib due to the presence of juice rather than air spaces in the pithy tissues. Depending on the cultivar, the number of leaves on the plant ranges from 7 to 24. The inflorescence of sorghum is a panicle that can be free or dense. It is normally straight, although it can curve to form a "gooseneck." The panicle has a central rachis and short or long primary, secondary, and mature tertiary branches that bear spikelet groups. The shape of the panicle is determined by the length and closeness of the panicle branches, which range from densely packed conical or oval to spreading and slack. A fully grown panicle can have up to 2,000 grains, each of which is normally partially covered by glumes (Acquah, 2007).

2.3 Diversity of sorghum

Sorghum is grown in Ethiopia under a wide range of environmental conditions, which has resulted in a wealth of genetic variability in terms of grain color, quality, plant height, pest and disease resistance, and tolerance to a wide range of temperature and moisture regimes. Such highly diverse genetic resources are extremely beneficial to the sorghum improvement program (Ayana Adugna and Endashew Bekele 1998; Ayana Adugna et al., 2000; Adugna Abdi et al., 2002; Firew Mekbib, 2008). It is the best crop grown in eight major agro ecologies and twenty sub agro ecologies, which account for around 66 percent of the country's total land mass (Geremew Gebeyehu et al., 2004). The sorghum growing environment is highly diversified in terms of both biotic (weeds like striga, diseases, insect pests, and birds) and abiotic (drought, soil fertility, and frost) stresses that drastically reduce sorghum productivity and production. Germplasm evaluation based on needs and requirements helps in the better exploitation of existing resources.

Ethiopia has provided a good base for sorghum improvement programmes worldwide. Haile Mengesha *et al.,* (1989) noted that 1446 and 3018 sorghum germplasm was collected by Rockefeller foundation and ICRISAT, respectively from Ethiopia until June 1986. Aberra Deressa *et al.,* (1995) reported that over 10,000 indigenous sorghum germplasm accessions were collected from different sorghum producing regions of the country and evaluated for some agronomic and taxonomic characteristics by the Ethiopian sorghum improvement program now called Institute of Biodiversity Conservation (IBC). This shows that the traditional sorghum growing ecologies are diverse and evaluating the diverse germplasm can help to identify valuable landraces which can be incorporated in to a crop improvement program. Selected accessions have been found very useful and used in various breeding for striga resistance, drought tolerance, disease and insect pest resistance, etc. to transfer some of the desirable traits.

Many studies demonstrate that Ethiopia possesses a potential source of striga resistant sorghum accessions; nonetheless, most efforts in breeding resistant varieties in Ethiopia have been confined to alien germplasm (Wondemu Bayu et al., 2001). Despite the fact that Ethiopia is the center of crop diversity and farmers' knowledge of striga resistance/tolerance sorghum landraces, no or little effort has been made to exploit the local genetic pool. Traditional landraces and wild relatives evolve resistance to specific pests, diseases, and environmental stresses over centuries of introgression and natural and human selection, and can be used as sources of resistance. The germplasm was evaluated for striga resistance, biotic stress (drought and temperature stress), and the ability to emerge at higher soil temperatures. Some germplasm accessions were found to be striga resistant and were used in breeding programs (Rao et al., 2004). According to Gebisa Ejeta et al. (2007), selected African sorghum landraces gathered from African countries including Ethiopia were utilized to generate crosses and testing in large plot trials, with data collected accordingly. According to field evaluation data, some of the populations collected were striga resistant. As a result, plant genetic resources are a valuable resource for maintaining and enhancing agricultural productivity. Due to concerns about genetic resource depletion, the collection and conservation of genetic diversity of important food crops such as sorghum has attracted a lot of attention. Despite this, only a small portion of the entire accessible collection has been completely utilized by breeders, who have focused their efforts on introducing exotic material.

2.4. Economic Importance of Sorghum

Sorghum is the world's fifth most significant cereal crop, following wheat, maize, rice, and barley (FAOSTAT 2013). It is grown on a wide range of continents, including the Americas, Africa, Asia, and the Pacific. Despite the fact that sorghum has become an important crop in developed countries, it remains primarily a developing-country crop, with Africa and Asia accounting for 90 percent of global acreage. Sorghum is critical to African food security since it is the only cereal that is drought-resistant and can tolerate periods of high temperatures (Taylor, 2002). Sorghum grain output in Africa has increased from time to time, with much of the increase owing to increased production area. This suggests that most Sub-Saharan African countries continue to rely on sorghum as their primary source of food, and that sorghum is replacing less drought-resistant crops as environments become too difficult to grow drought-resistant crops (http://www.asareca.org).

Sorghum is also a major staple cereal crop in Eritrea, Ethiopia, Tanzania, Kenya, Uganda, and other countries in the region. Aside from human consumption, it is also used to make alcoholic drinks and as a major feed crop for chickens and other livestock (http://www.asareca.org). In Ethiopia's dry land areas, it ranks third in total production, after teff and maize, and second to teff in injera (pancake-like bread) making quality (Berhane Sibhatu, 1982). Grain sorghum is gluten-free and can be used in place of cereal grains such as wheat, barley, and rye by people who have celiac disease (Delserone, 2008). Sorghum is a promising biofuel crop for marginal lands. It has a diverse range of adaptations, including drought resistance and salinity tolerance (Reddy et al., 2007; Shoemaker and Bransby, 2010).

2.5. Sorghum Production Constraints

A combination of abiotic and biotic stressors decreases sorghum's potential productivity. Low soil fertility (nutrient inadequacy) and drought are examples of abiotic causes. The parasitic weed striga (mostly *S. hermonthica* and *S. asiatica*), foliar and panicle diseases, stem borers, and shoot flies are all major biotic constraints (Wortmann et al., 2006). Among the major sorghum diseases, anthracnose, smuts, and rusts cause significant yield losses in Ethiopia. Within Ethiopia, sorghum production constraints vary across the region. Drought and Striga weed have been identified as the most important constraints in Ethiopia's northern and north-eastern regions (Rebka Gebretsadik et al., 2014). *Striga spp*. (witch weeds, also families of the Orobanchaceae) are hemi-parasites, but because they have chlorophyll and basal photosynthetic activity, they also act as hollo-parasites (Parker and Patrick, 1993).

In Ethiopia, approximately 30% of low altitude (1500 m.a.sl) areas where sorghum is the primary staple crop are infested with striga, resulting in yield losses ranging from 50% to 100% (Watson et al., 2007). (Temam Husseni, 2006; Tesfaye Tesso et al., 2007). A few striga-resistant sorghum varieties have recently been introduced and released in the country (Asfaw Adugna, 2007; Gebisa Ejeta, 2007).When used in association with moisture conservation measures and soil amendment inputs, these types can substantially reduce striga infestation while increasing sorghum yield by up to 40%.

2.6. Sorghum-Striga Interaction

The complicated parasite-host interaction, which is still poorly understood, is one of the barriers to efficient striga management (Gebisa Ejeta and Butler, 1993; Runo et al., 2012). In some host-parasite systems, the amount of resistance of host genotypes or the virulence of parasite genotypes may be the most important determinant of species interactions (Grech et al., 2006). Sorghum and Striga hermonthica have a long history of co-evolution (Welsh and Mohamed, 2011). To combat the severity of the parasitic weed, it is critical to understand how sorghum and striga interact. The parasite's life cycle is highly synchronized with that of the host, from germination through maturity (Park and Patrick, 1993). As a consequence, the chemical cross talk that regulates striga germination and the formation of physical interaction with the host is well characterized (Palmer et al., 2004). The array of signal exchanges between striga and its hosts that leads to successful parasitism is a fascinating biological phenomenon in this situation. Specific chemical signals provided by host plants are required to trigger parasite seed germination and attachment organ formation (Patrick and Gebisa Ejeta, 2008).

2.7. Origin, Occurrence and Distribution of Striga

As it is demonstrated in Hayelom Berhe (2014), plants belonging to the genus Striga comprise obligate root parasites of cereal crops that hinder normal host growth. Striga is primarily found in semiarid, tropical areas of Africa, but has been recorded in more than 40 countries. *Striga hermonthica* and *Striga asiatica* are thought to have originated in Sudan's Nubian Hills and Ethiopia's Semien Mountains. These areas are also known to be the source of sorghum and pearl millet, both of which are vulnerable to witch weed infection. *Striga gesnerioides* is thought to have evolved in West Africa. Through human activity, striga has spread to different parts of Sub-Saharan Africa over the years (Atera et al, 2013). Striga prefers infertile soils in semi-arid tropical open grasslands and savannah. Their seeds are highly adapted to hot, dry conditions, and they remain dormant until rain falls (Zerihun Sarmiso, 2015).

Striga hermonthica is especially damaging to sorghum, maize, and millet, but it is also becoming more common in sugarcane and rice areas. According to Mesfin Abate (2016), Striga hermonthica is the only species that causes economic losses in sorghum. According to Hayelom Berhe (2014), upland rice is becoming increasingly important in African agriculture, not least because it can maintain more people per crop area than maize or sorghum. Crops that were previously unharmed by striga are now severely infested. Striga is thus rapidly becoming a pandemic of alarming proportions in Africa due to its vast geographic spread and economic impact on millions. The parasite's enzyme systems thrive in conditions of low soil fertility and moisture stress, as most soils have been depleted of fertility due to the removal of organic matter and the limited application of manure.

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2.7.1. General characteristics of *Striga hermonthica*

Striga hermonthica is a flowering root parasitic plant with a hemi-parasitic lifestyle. It is thought to be one of the most common parasitic weeds of food crops (Koua, 2011). It is believed to have co-evolved with wild relatives of sorghum during domestication in Africa's Sudano-Ethiopian area (Mohamed et al., 1998). By parasitizing the roots of the host crop, *S. hermonthica* severely restricts cereal crop productivity in the SSA. It has a diverse host range that includes various food and fodder crops; nevertheless, the majority of the damage caused by this parasite is on staple crops of the rural poor on the African savanna, with sorghum [*Sorghum bicolor* (L.) Moench] being one of the best hosts (Gebisa Ejeta, 2007a). The striga life cycle is intimately tied to those of its hosts. Conditioning or preconditioning under appropriate temperature and moisture conditions causes them to emerge from dormancy (Gebisa Ejeta, 2007b). *Striga hermonthica* is an herbaceous plant (Koua, 2011) with a hairy, stiff, quadrangle-shaped stem (Csurhes et al., 2013) and narrow leaflets (Kagot, 2013). Its height is no more than one meter. It bears purple flowers that are occasionally white. The seeds normally form in little capsules that burst open when they reach maturity, releasing the seeds for dispersal. Between 250 and 500 minute seeds can be found in one seed capsule. As a result, a single *S. hermonthica* plant can generate over 500,000 seeds. If the germination conditions are not favorable, the seeds can survive in the soil for up to 20 years (Kagot, 2013). In striga, the root system is vestigial (Fig. 2), with the germinated seed radical producing haustorium instead of the typical angiosperm root in order to communicate with the host (Koua, 2011).

Figure 2: Pictures of *S. hermonthica*, Photo: Marco Schmidt 2009

2.7.2 Geographical distribution of *Striga hermonthica*

The geographical distribution and infestation level of striga are expanding, especially in SSA. There are several factors that contribute to the spread and infestation of striga. The factors include the trading and transport of contaminated seeds, livestock movement between fields, striga seed dispersal by wind and surface water flows, and a lack of awareness and control methods for striga. Future climate change may have an even greater impact on striga's geographic spread and invasive potential, as habitats appropriate for striga growth may expand and/or move to new places (Cotter, 2012). According to Koua (2011), striga is primarily found in tropical arid and semi-arid zones with annual rainfall of 400-1000 mm. *Striga hermonthica* is likely to have originated in the Nuba Mountains of Sudan and, to a lesser extent, Ethiopia. Mali, Upper Volta, Niger, Nigeria, Cameroon, Chad, Sudan, Ethiopia, and India have been hit the most. Crop yields may be reduced by 60-70 percent on a regular basis in some areas of these countries where striga is prevalent. Crop losses are also widespread in regions of the Gambia, Senegal, Mauritania, Togo, Ghana, Kenya, Tanzania, Uganda, Botswana, Swaziland, and Mozambique, as well as elsewhere in Africa, Asia, Australia, and the United States (Ayensu et al., 1984).

2.8. Striga species

Witch weeds (*Striga spp*.) are root-parasitic plants in the Orobanchaceae family that are recognized as the most severe biotic factor. It is a parasitic weed that infests cereals and invades farmlands. It causes crop plants to be stunted, discolored, and twisted by attaching itself to their roots and sucking on their nutrition. It has overrun an estimated 22 to 40 million hectares of African cropland, inflicting annual damage of more than US $3 billion. Striga is a substantial contributor to food insecurity and rural stagnation in Africa (AATF, 2006). According to Hayelom Berhe (2014), striga species (witch weed) are root parasitic flowering plants that are abundant in Sub-Saharan Africa (SSA), causing serious crop production constraints. It thrives by diverting essential nutrients that cereal crops like sorghum and maize can use. Striga is the Latin word for "witch"; striga is also known as "witch weed" because striga-infected plants have stunted development and a drought-like phenotype. It has given different local names, some of these are; in Kenya, farmers refer to it as Kyongo (Luo), Oluyongo (Loyal), Imato (Teso).

In Ethiopia, it is known as Akenchira (Amharic), Metselem (Tigrigna), (Hayelom Berhe, 2014), and Atikur (Personal communication). Striga species are annual (IITA, 1997) obligatory hemiparasite plants that adhere to their host's root to deliver water, nutrients, and carbohydrates (Hayelom Berhe, 2014). Crop yield loss caused by striga invasions varies according to striga seed density, soil fertility, rainfall distribution, cereal host species, and variety (Hayelom Berhe, 2014). They are chlorophyllous, but they must be supported by a host to complete their life cycle (IITA, 1997). As indicated in Larsson (2012), globally there are 30 to 35 different species of the genus *Striga* and of these about 23 species can be found in SSA. Striga species are among the most troublesome and harmful weeds on the planet. Those that can infest agricultural crops, in particular, are of enormous economic importance, with the most important striga species being purple witch weed (*Striga hermonthica*) and asiatica witch weed (*Striga asiatica* (L.) Kuntze). Striga hermonthica is the most devastating parasitic weed of these two striga species (Atsbha Gebrelsaie et al., 2016), and it is an obligate chlorophyll-bearing root parasite, which indicates that the weed is dependent on its plant host during its entire life cycle, germination flowering reproduction (Larsson, 2012). *Striga hermonthica* (Del.) Benth and Striga asiatica (L.) Kuntze infect cereals (maize, sorghum, millet, and upland rice), and Striga gesnerioides (Willd.) Vatke legumes and tobacco. *Striga forbesii* (Benth.) and *Striga aspera* (Willd.) Benth.) have also been reported to have unpredictable effects on cereal crops (Atera et al., 2013). Grassland has the highest diversity of striga species. *Striga hermonthica*, on the other hand, is mostly found in farmland, infecting grasses. The parasite's destructive effect occurs prior to its emergence from the soil, and it can cause yield losses in cereals ranging from 15% to 100% under favorable conditions (Atera et al., 2013).

2.9. Economic importance of striga weeds

Food security in SSA is worsening significantly, owing to striga infestations in places considered to be the continent's "food baskets." In SSA, the agricultural production sector is the primary source of food, foreign exchange, and, most significantly, family income through direct and indirect employment (AATF, 2006). However, striga poses a danger to the same source of income (AATF, 2006). Striga infestation has led to Africa's low food output (FAO, 2006). Striga is regarded as the most significant biological constraint to crop production in SSA, as well as the most damaging or severing pest experienced by farmers farming sorghum, millet, and maize in the region (Rasha et al., 2009). The economic cost of striga is tremendous (Runo et al., 2012). Striga infests two-thirds of Africa's arable land and is the single most important biological cause of crop destruction in the continent (Gebisa Ejeta, 2007b). The payoff for managing striga is progress in food security, economic development, and the well-being of millions of Africans (Atera et al., 2013).

It is vital to note that striga weed is widespread, so time is of the essence in controlling it. It is predicted that striga seeds have invaded around 100 million hectares of land in Africa (Scholes and Press, 2008), causing a 30% to 50% loss of Africa's agricultural economy in 40% of its arable area (Amudavi et al., 2007; Hearne, 2009). In African countries, the weed is responsible for approximately 26% of sorghum and millet losses (Gressel et al., 2004). According to FAO (2006), cereal yields in SSA increased by 29 percent between 1961 and 2005, despite a 216 percent increase in population. According to Gebisa Ejeta (2007a), the striga problem is widespread in several African countries and appears to be worsening. This means that much effort should be placed into cereal production in SSA in order to feed the world's rapidly rising population. The impacts of striga infestation are significant, leaving small-scale farmers in SSA vulnerable and often puzzled.

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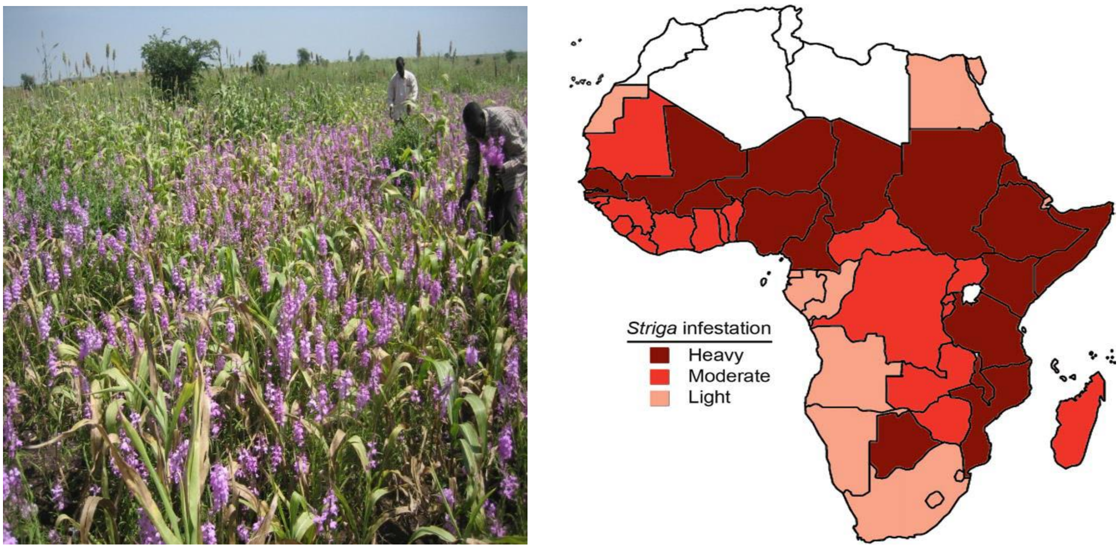

A **B**

Figure: 3 A) Striga infestation in sorghum fields, B) Striga infestation in SSA is most severe in the most food insecure areas. Adapted from a report by Gressel *et al*., (2004)

2.10. Striga Control and Management

Appropriate agricultural technologies for weed management have been suggested, including restoring soil fertility, using certified seeds, implementing Good Agricultural Practices (GAPs), minimizing weed soil seed banks, and lowering disease and pest load on crops (Bruce, 2010). Several private and public institutions have been involved in or have sponsored striga research. These institutes have recommended control techniques for African farmers in order to reduce infestations and damage (AATF, 2011). Among these options are intercropping cereals and legumes, crop rotation, the use of trap crops that induce suicidal germinations, the application of manure and nitrogen fertilizers, and the use of resistant crop varieties (AATF, 2011).

Trap cropping can also be utilized as a means of control. This entails planting a species in an affected field that inhibits striga seed germination but does not allow the parasite to attach. This strategy has been used to plant Celosia argentea in sorghum fields and Desmodium uncinatum in maize fields (Radford, 2003). Suicidal germination can be employed as a control measure in fields that have not yet been planted with crops. This approach includes pumping ethylene gas into the soil to cause seeds to germinate. The natural physiological reaction associated with host recognition is mimicked by ethylene gas. Because there will be no host roots exposed, the seedlings will fail to adhere and die. However, this technology is relatively pricey and out of reach for developing-country subsistence farmers (Olupot et al., 2003).

The use of such resistant cultivars is regarded as an efficient and cost-effective component of an integrated striga control strategy (Yoder and Scholes, 2010). Resistant cultivars have the ability to resist or limit striga attachment and growth, boosting and producing in striga-infested environments. Integrated Striga Control (ISC) is a control option in which a number of technologies are incorporated into a program for striga control as opposed to the use of a single approach in the control. For efficient striga control, ISC is recommended. According to Franke et al. (2006), the ISC approach reduced the soil striga seed bank by 46% while increasing crop productivity by 80%. The primary goal of ISC is to diminish striga densities in the soil in order to prevent new plants from growing in coming seasons.

3. CONCLUSION

Sorghum is the most important crop for food security in Ethiopia's harsh conditions, where other food crops are difficult to grow. Farmers reported striga infestation, drought, declining soil fertility, a lack of availability of improved varieties and other agricultural inputs, and bird damage as the most significant constraints limiting sorghum production. Sorghum yield losses caused by S. hermonthica can be substantial for Ethiopian subsistence farmers who cannot afford or have limited access to inputs that can mitigate the problem. Currently, resource-constrained farmers in Ethiopia and across Africa require striga management options such as environmentally friendly and cost-effective resistant genotypes.

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