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Impact of Witch Weeds (*striga hermonthica*) on Sorghum Production and Its Managements in Ethiopia

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Abstract: *Striga hermonthica* (Del.) Benth is a major constraint to sorghum productivity. Striga can cause a small percentage loss in yield and, in some situations, complete crop collapse. Striga resistant sorghums can be a valuable component if resistance is built into well-adapted and productive cultivars. Sorghum's potential output has been diminished due to a variety of abiotic and biotic stresses. Abiotic stressors like as drought and low soil fertility (nutrient deficit) are two of the most common. Parasitic animals are expected to cost the world £1.5 trillion every year. Heterotrophic flowering plants that may cling to their host crop are known as parasitic weeds. Haustorium acts as a physiological link between the parasite and the plant it parasitizes. Striga is a genus of Orobanchaceae hemiroot parasites that includes roughly thirty species. Striga is a photosynthesizing obligate hemi-parasite. Striga can be found in Africa, the Middle East, Asia, and Australia in tropical and semi-arid climates. Striga are root-parasitic, annual, chlorophyll-bearing plants that require a host plant to complete their life cycle. Striga seeds can produce 100,000 to 200,000 seeds per plant, but they must be pretreated and stored in a moist, warm environment (300C in germination). Over the course of its 20-year existence, Striga has the ability to produce thousands of seeds. If a chemical cue is released by the host plant's roots, they germinate. Therefore the purpose of this review paper is to assess influence of witch weeds (*striga hermonthica*) on sorghum production and its management's methods.

Keywords: Sorghum, Striga, Yield, Weed, Host

1. Introduction

The parasitic weed *Striga hermonthica* (Del.) Benth. is a major constraint to sorghum (*Sorghum bicolor L.* Moench) productivity in semi-arid Sub-Saharan Africa. When striga infects sorghum crops, it causes severe damage, especially when moisture and nutrients are scarce. Grain yield declines as a result have a negative impact on resource-poor subsistence farmers [53]. It is one of the biotic factors reducing sorghum (Sorghum bicolor) productivity in several tropical and subtropical parts of Sub-Saharan Africa, particularly Ethiopia [1].

Striga infestation can cause a minor percentage decrease in output and, in severe cases, catastrophic crop failure [62]. Sorghum production losses of 65 percent to 100 percent have been observed in Ethiopia and Sudan [22]. The utilization of high-yielding Striga-resistant or Striga tolerant genotypes is recognized as the most cost-effective and efficient control technique in the fight against Striga [21]. Striga resistant sorghums can be a key component of integrated Striga control efforts if resistance is included into well-adapted and productive cultivars [48]. Infested soils can benefit from resistant cultivars that lower both fresh Striga seed output and the Striga seed bank. When cultivated under Striga infection, the genotypes support much fewer striga plants and produce significantly more than a susceptible cultivar [17, 18].

Several instances of striga resistance mechanisms have surfaced. Low germination stimulant production, mechanical barriers, and root exudate inhibition of germ tube exoenzymes, phytoalexine synthesis, incompatibility, antibiosis, Striga toxin sensitivity, and root growth habit avoidance are among them. Striga resistance mechanisms have been proposed in a variety of ways [19]. Low stimulant production, mechanical parasite barriers, chemical defense (antibiosis), in which crop plants produce chemical compounds that inhibit the growth of Striga seedlings, and

iv) hypersensitivity, in which the host cells surrounding the endophytic part of the haustorium die, preventing the parasite from developing further. Sorghum has achieved the most improvement in resistance breeding among all crops. The goal of this review was to determine the impact of striga on sorghum production and management.

2. Literature Review

2.1. Sorghum Production and Importance

Sorghum (Sorghum bicolor (L.) Moench) is a C4 plant that has a better photosynthetic efficiency and is more resistant to abiotic stress. Sorghum originated and was first domesticated roughly 5000 years ago in northeastern Africa. Ethiopia is the origin and diversity hub for sorghum, with a wide range of wild and cultivated varieties [17]. Because of its unusual tolerance to hard and drought-prone settings, it is frequently farmed in the dry and semi-arid tropics [3].

Sorghum is the world's fifth most significant cereal crop, after wheat, maize, rice, and barley, with an area of 42.70 million hectares and a total yield of 62.3 million tons. In Africa, sorghum is farmed on approximately 26.14 million hectares, with total output and average yields of 42.35 million tons and 1.62 ton/ha, respectively [26]. Ethiopia is Eastern Africa's second-largest sorghum producer, after Sudan, and ranks third in terms of area covered, after teff and maize, as well as productivity (2.7 t/ha) [14].

Sorghum is produced for food and feed in dry land agriculture all over the world due to its wider tolerance to drought-prone environments. Because of its short growth time and drought tolerance, sorghum is a popular crop in dry and semi-arid areas [27]. Biofuels, beer, and silage are all made from sorghum. Because it is gluten-free and strong in health-promoting phytonutrients, sorghum is given special attention as a food-grade grain [8]. Sorghum is widely grown as a food crop in developing countries, and grain yields have increased dramatically [2]. Sorghum is the main source of food for about 500 million people in developing countries [13].

2.2. Sorghum Production Constraints

Sorghum agriculture is dominated by subsistence farmers in underdeveloped nations, particularly in Africa, who rarely generate extra to sell, hence production constraints differ from those seen in commercial scale production [51]. Sorghum farming provides income to millions of Ethiopian subsistence farmers. However, at roughly 2 tons per hectare, the country's potential productivity is modest [42].

A multitude of abiotic and biotic stressors have lowered sorghum's potential output. Low soil fertility (nutrient inadequacy) and drought are two of the most common abiotic stressors. The parasitic weed Striga (Striga species), foliar and panicle diseases, stem borers, and shoot fly are all important biotic limitations [75]. Drought and Striga, on the other hand, are the most serious concerns in many sections of the country, particularly in the north, north-east, and east [60]. Sorghum production limits vary by area within the country, but they always result in large grain losses [20].

Drought and sorghum striga are the most serious sorghum production issues in all locations. In many regions of the world, parasitic weeds are a severe problem in agriculture, producing large crop losses. Broomrapes (Orobanchaceae) are holoparasites that get all of their nutrients and water from their hosts via a root link. Striga spp. (witch weeds and Orobanchaceae) are hemiparasites that, while having chlorophyll and basal photosynthetic activity, operate like holoparasites [59]. Striga infests roughly 30% of low altitude (1500 m.a.s.l) areas in Ethiopia where sorghum is the primary staple crop, causing output losses ranging from 50% to 100% [67]. Striga resistant sorghum varieties have recently been introduced and released in the country, ranging from low yielding to high yielding [7].

2.3. Parasitic Weed Plants

The global cost of parasitic species is estimated to be £ 1.5 trillion per year, or about 5% of global GDP. In underdeveloped nations, where agriculture accounts for a bigger percentage of GDP, parasitic species can have an even greater detrimental influence on food security and economic performance, exacerbating poverty [64]. striga is one of the aggressive plant species that are harming and even destroying cereal crop yields because to its tough parasitic property, aggressiveness, high number of seed generation ability, multiple years of seed dormancy, wind dissemination ability, and resistance to drought and soil infertility. Because it has the ability to disrupt the host plant's healthy growth through three processes: nutrient competition, photosynthetic impairment, and a phytotoxic effect within days of attachment [32].

Parasitic weeds, commonly known as angiosperms, are heterotrophic flowering plants that can adhere to their host crop and acquire nourishment and growth nutrients through the haustorium. The parasite and the host plant share a physiological relationship through the haustorium. Hemi-parasites (which have chlorophyll pigments only in the mature stages of their life cycle), holo-parasites (which lack chlorophyll), facultative parasites (which can survive without a host but require one at some point), and obligate parasites (which require the host for maturation) are the four types of plant parasites [52]. Among parasitic plants, the Orobanchaceae family is the most destructive to host plants [73]. Striga is a hemi root parasitic genus of roughly thirty Orobanchaceae species [65].

Striga species are obligate hemi-parasites that attach to the roots of host cereal crops such as maize (Zea mays L.), millets (Eleusine corocana Gaertn. and Pennisetum glaucum L.), sorghum (Oryza sativa L.), and rice (Oryza sativa L.), synchronizing their life cycles and increasing their competitive ability with the host [30]. In Sub-Saharan Africa (SSA), S. asiatica, S. hermonthica, and S. gesneroides cause major losses in agricultural production [65]. *Striga hermonthica* is typically found in Africa's eastern and western regions, with lavender blooms, but Striga asiatica has red flowers and is a major agricultural production constraint in Southern Africa [74]. Striga is an obligatory hemi-parasite capable of photosynthesizing [65] and causing serious issues for monocots [50].

2.3.1. Origin, Distribution and Economic Importance of the Parasitic Weeds

Striga hermonthica is thought to have originated in the Sudano Ethiopian region, where sorghum first appeared, then expanded throughout Africa and Arabia [76]. Striga are found in tropical and semi-arid regions of Africa, the Middle East, Asia, and Australia, and have been reported in over 40 countries around the world. The parasites have been discovered in 25 African countries, with Sub-Saharan Africa and India being the most badly afflicted [20, 58]. Striga was thought to have originated in Sudan's Nuba Hills and Ethiopia's Simien Mountains, according to Mohamed et al. [47]. This area has also been reported as the origin of domesticated sorghum.

Sorghum and pearl millet are the most parasitized hosts in Africa and India, according to Striga distribution in relation to ecological zones [57, 58]. Striga is said to have infested 50 million acres of agricultural fields in Sub-Saharan Africa beneath the cover of cereals [73]. Striga has contaminated 17.2 million hectares in West Africa, accounting for roughly 64% of the total area of major millets including sorghum and pearl millet, and the parasites have been reported to have expanded their infection range. In extreme years, yield loss in Striga-infested areas could be as high as 90% (total crop failure) [29]. According to reports [9], farmers have been forced to abandon significantly Striga-infested farms as a result of this. Striga is most known for its dominance in low-fertility, low-organic-matter marginalized soils, but it can be found in a wide range of soils [50].

Cereal crops are grown all around the world, and the weed has spread to other parts of SSA due to continual cultivation by men. As a result, at least twenty-five African countries have reported Striga infestations in agricultural crops, putting half of the continent at risk from the parasitic witch weed [15]. Striga species are noxious and persistent weeds that have a negative impact on grain productivity all over the world [69]. Exudation of germination stimulants, soil nutritional status, and temperature all influence the distribution of these Striga species [65].

Striga can successfully dwell and inflict damage in a wide spectrum of hosts [41]. Striga has formed attachments with non-traditional host crops such as barley (Hodeum vulgare) and wheat (Triticum aestivum) in a few unusual occasions, resulting in detrimental rotational impacts [30].

2.3.2. The Ontogeny (Life Cycle) of Striga

Striga are root-parasitic, annual, chlorophyll-bearing plants that require a host plant to complete their life cycle. The latter is intricately linked to the host's and the climate, particularly during the post-ripening period [33]. Plants in the Striga genus have a high reproductive capacity and are quickly dispersed [59, 33]. Striga seeds can yield 100,000 to 200,000 very small (0.15B0.30 mm in diameter) seeds per plant, which require pretreatment and conditioning in a wet warm environment (300C in germination [59]. After this phase, Striga seeds will only germinate after being exposed to bioassays for 2 to 16 days before gaining the ability to germinate [43]; induced by certain chemicals secreted into the rhizosphere by the host roots, such as strigolactones.

The life cycle of Striga is divided into two parts: the subterranean phase and the above-ground phase. The aerial phase refers to operations that take place above ground, whereas the subterranean phase refers to activities that take place below the soil surface [19]. There are a number of systems in place to keep the parasite's life cycle in sync with the host plant's. Striga has many stages of development, but the most important ones are germination, radicle growth, haustorium production, and attachment to the host plant [49].

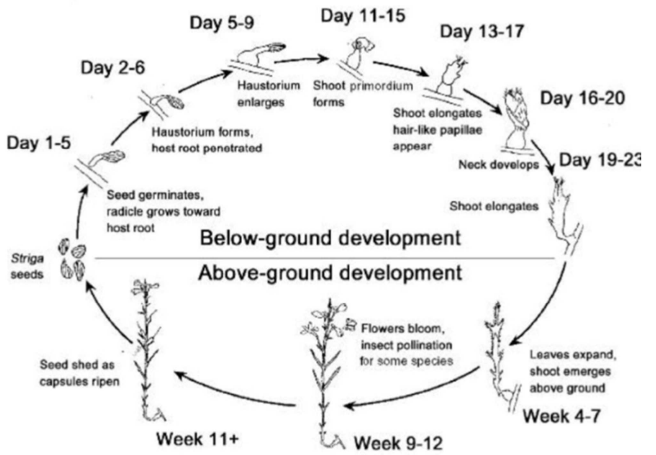

Figure 1. *Life cycle of striga.*

2.3.3. Germination

Striga may develop thousands of seeds with a lifespan of up to 20 years, but they will only germinate if a chemical cue is released from the host plant's roots [44]. Studies on a variety of germination stimulants recovered from the root exudates of various hosts have revealed that they all belong to the same chemical class known as strigolactones [48]. An after ripening period is required for the Striga seed to germinate, which is the time during which the viable seed does not germinate in order to complete the physiological processes and reach full maturity [12]. The time after ripening varies according on the Striga species and geographical region, and can range from a few days to two years. Striga seed that has been conditioned will germinate after the ripening phase has ended. Striga seeds will be exposed to favorable or optimum circumstances during conditioning/preconditioning. Seeds will absorb water for 14 to 21 days at temperatures between 30 and 40 degrees Celsius during this procedure [47]. The purpose of pre-conditioning is to remove chemical inhibitors from the seed that could prevent it from germinating [59].

2.3.4. Haustorium Formation and Attachment

After the Striga seeds have germinated, the Striga seedling's radicle begins to develop chemotropically toward the roots of the host plant [5]. When the radicle comes into contact with the roots of the host plant, it swells up at the tip to form a haustorium, which then penetrates the host plant's roots [65]. The haustorium is in charge of transferring carbohydrates and nutrients from the host plant to the Striga plant. Striga will grow underground for six to eight weeks before emerging from the ground if the parasite and its host plant form a fruitful association [49].

2.4. Effects of Striga Infection the Host Plant

Striga is fully dependant on the host plant for carbon while below the soil surface [72], and infected plants lose 80 percent of their carbon due to the parasite's impaired photosynthesis [63]. Striga has a detrimental impact on biomass allocation as a result of the redirection of water and photo-assimilates as the parasite becomes the sink, resulting in stunted plant growth and reduced yield [65]. Plants infected with Striga have a higher root to shoot biomass, according to Umehara [71], because the roots act as a sink for the photo-assimilates that the parasite need to thrive. The content of abscisic acid (ABA) in xylem sap rises in Striga-infected plants, owing to wounds induced by the parasite's penetration of host roots [66].

2.5. Economic Importance of Striga

Infection with Striga has resulted in a total loss of 30-50 percent of Africa's agriculture on 40 percent of its fertile area (Amudavi et al., 2007). Striga infestations often result in significant yield reductions, with yield reductions exceeding 65 percent in heavily infested fields. According to Haussmann et al. [31], high Striga infestation levels can result in grain production losses of up to 100% on vulnerable sorghum cultivars. According to Ejeta et al. [22], in extensively infested areas in Ethiopia and Sudan, losses of 65-100 percent are normal, but total loss might occur when striga infection is worsened by drought. Farmers in some locations have been unable to grow sorghum because to the severity of the infestation; they have either abandoned their land or moved to less vital crops [61].

Striga causes damage to host plants by parasitism, reduced photosynthesis, and greater partitioning of photosythates to the roots. By allelopathy, competing for nutrients, and inhibiting the expression of sorghum plants' full genetic potential, the weed reduces crop output. It attaches itself to the roots of the host plant, weakening the crop plant by robbing it of carbon assimilates, water, nutrients, and amino acids [56]. Furthermore, striga lowers water use efficiency [28] and has a significant impact on the host plant's water economy due to its high transpiration rates, rendering the crop particularly vulnerable to drought.

2.6. Control and Management of Striga

Striga can be defeated in a variety of ways. For weed management, Joel [36] recommends using appropriate agricultural technology such as refilling soil fertility, using certified seeds, following good agricultural practices (GAPs), and minimizing weed soil seed banks. Several approaches have been used to control Striga, according to Kinde [41], including those that lower the amount of Striga seed in the soil bank, inhibit the generation of new seeds, and prevent the transmission of infested to non-infested soils. Striga damage and infestation can thus be reduced by using management methods and procedures that halt the spread of the fungus at various phases of growth. When multiple management methods are used together rather than separately, they work well. The following are some of the various control and management measures:

2.6.1. Cultural Control Methods

Crop rotation (intercropping [70]; transplanting [54]; soil and water management; application of fertilizers [35]; and hand weeding are some of the cultural methods that have been advocated for Striga control. These techniques should also help to minimize the number of Striga seeds in the soil seed bank. Some of these approaches increase soil fertility, which helps the host grow faster but has a negative impact on the juvenile Striga plants' germination, attachment, and subsequent development. However, small-scale farmers have had limited success with this strategy, owing to socioeconomic and budgetary constraints that impede appropriate nitrogen fertilization [46].

(1) Hand weeding/Sanitation

Annual weeds can be effectively managed by hand weeding. It is, however, time-consuming, labor-intensive, back-breaking, and frequently more expensive than the chemical process. For resource-poor farmers in developing nations, this is the most practicable of all existing management strategies. It has the potential to lead to a significant reduction in Striga infestation in the long run. The potential benefits of this control system may not be realized for another 4-5 years, and time is crucial for ensuring efficacy. The best time to hand-pull Striga is 2-3 weeks after flowering, with 3-4 week intervals between operations. Infected plants may produce new shoots below the soil surface, necessitating a second weeding before crop maturity. To reduce the possibility of re-infection, uprooted Striga plants must be removed from the field, dried, and burned. Hand weeding is only useful for avoiding parasite seed accumulation in lightly contaminated soil [16].

(2) Soil fertility management - Nitrogen and Phosphorus

Striga species cause more damage in nutrient-depleted soils, hence soil nutrient replenishment will boost the host's growth at the expense of the parasite [40]. The addition of nitrogen (N) to the soil slows the parasite's development while promoting the establishment of the host [6]. Fertilisers such as urea, ammonium sulphate (NH4SO4), nitrogen, phosphorus (P), potassium (K), and calcium ammonium nitrate (CAN) decrease Striga infestations in the field while also increasing host crop grain yields [45]. Ifie [34] also discovered a link between Striga resistance and low-nitrogen soil tolerance. Increasing the availability of nitrogen has a good effect on a susceptible host's performance during severe infestations, but has a detrimental influence on Striga's growth phases [38].

(3) Crop rotations and inter cropping

Intercropping is a low-cost, potentially feasible strategy for addressing two important and interconnected issues: low soil fertility and Striga infestation. When legumes (cowpea or common bean) are intercropped with sorghum, parasitic weeds are reduced while grain yields are increased. Intercropping with non-host plants (trap crops) has been observed to reduce Striga infestation by reducing the soil seed bank due to the promotion of suicidal germination of Striga weed [16].

(4) Trap and catch cropping

For subsistence farmers, trap cropping is a less expensive option to Striga control [4]. Trap cropping [21] is the growing of commercially valuable crops with the goal of limiting the quantity of the soil seed bank. Trap and catch crops such as cowpea, soya bean (*Glycine max* L.), pigeon pea (*Cajanus cajan* L.), sunflower (*Helianthus annuus* L.), and groundnuts (*Arachis hypogaea* L.) have all been demonstrated to control Striga populations. These crops have the unique ability to produce germination stimulants that are specialized for S. asiatica germination, resulting in a smaller soil seed bank [24].

Soya bean and cotton [23] are the best trap crops for Striga management, although sorghum produces strigolactones that are compatible with S. hermonthica [25]. Suicidal germination is a strategy used in trap cropping to minimize the quantity of the soil seed bank. Suicidal germination occurs when Striga or parasite seeds are forced to germinate in conditions that are detrimental to their growth and survival. Because it is incompatible with seedling attachment, the soya bean crop causes suicidal germination of Striga seeds [45].

Catch cropping is a control approach that involves sowing host crops that encourage germination of Striga seeds, which are subsequently ploughed down before the weed flowers, according to Esilaba [24]. Catch cropping is usually done with vulnerable crop species that can release the right kind of germination stimulants for Striga species [74]. This has a deleterious impact on the Striga weeds' seed bank population dynamics [24]. The only drawback to employing catch cropping is that it does not generate a profit for the farmer [25].

2.6.2. Chemical Control

Chemical control, according to Esilaba [24], can be performed through herbicide applications such as dicamba, as well as the use of germination stimulants like as ethylene and strigol, which encourage Striga germination. Pre-emergence herbicides are the most effective control technique for root parasites when using herbicides [23]. The use of a mixture of chlorosulfuron, dicamba, and urea to control Striga has been reported to be effective. The selective phenoxy herbicide 2.4D, according to Nickrent and Musselman [52], is effective in suppressing Striga in cereal crops. Striga's parasitic effect on crops is reduced when 2.4D is applied (Mahmoud et al., 2013). To minimize the amount of the soil seed bank, germination stimulants such as Nijmegen 1 and GR24 might be used [23]. The use of germination stimulants and N supplementation is not possible due to a shortage of resources.

2.6.3. Use of Resistant Genotypes and Tolerance (HPR)

In the smallholder farming community, genetic defense has been considered to be the most successful and promising method of controlling Striga. Host plant resistance (HPR), according to Beyene et al. [11], is a biological strategy that gives resistance to parasitic weed infection and is an important characteristic that should be integrated in seed provided to subsistence farmers. According to Karaya et al. [39], host plant resistance prevents the hemi-parasite Striga from attaching to the crop. In exchange, smallholder farmers in the SSA region will benefit from a more effective, long-term, and cost-effective control method [39]. The addition of HPR to the crop genome has the potential to increase production by lowering reliance on agrochemicals as well as losses caused by parasite infection. The HPR method is a more practical control method that can be used on a modest scale [11].

According to Haussmann et al. [31], HPR is an important component of the integrated weed management program (IWM). Tolerance and resistance are the two mechanisms that make up host plant resistance. Tolerance refers to a crop's ability to produce under heavy Striga infestations, whereas resistance refers to the crop's ability to prevent infection by the Striga parasite. However, there hasn't been any evidence of total resistance to striga. In cereal crops, tolerance is the sole genetic Striga resistance reserve [65].

2.6.4. Integrated Striga Management

The various Striga control systems discussed above provided varying levels of Striga control and did not prove to be as effective, cost-efficient, or practical as intended [37]. Several control approaches have been created and widely used for a few crops in recent decades; nevertheless, when implemented individually, the control method has been influenced by the diversity of agricultural systems and environmental conditions, and has had mixed results. Furthermore, while these strategies helped to reduce parasite damage to host crops, it was discovered that they did not sufficiently address the long-term management of root-parasitic weeds, as this necessitates the eradication of the Striga seed bank. There appears to be no single control approach capable of adequately resolving the Striga problem [37, 55]. As a result, the most complete and long-term solution to the Striga is undoubtedly an integrated approach that incorporates a variety of interventions in a coordinated and intelligent manner [55, 20].

According to Haussmann et al. [31], an effective integrated control approach must contain at least one (if not all) control mechanism from each of the authors' three key categories. Oswald [55] proposed a combined approach that included confinement and sanitation, as well as direct and indirect strategies to mitigate Striga's harm and methods to remove the Striga seed bank in contaminated soils. Striga control measures must boost crop output, preserve soil fertility, and be practicable in order for farmers to embrace the integrated Striga control system [10]. Tesso and Ejeta [68] proposed an integrated management method that included the use of sorghum-resistant varieties, tied-ridge tillage, and nitrogen fertilizer. ICRISAT and its collaborators recently conducted participatory research on integrated Striga management through farmer field schools, resulting in practical integrated Striga and soil fertility management strategies for pearl farming.

Regardless of the global context of climate change, which will undoubtedly have an impact on Striga infestation, the persistent seed bank appears to be the main obstacle in the long-term management of Striga in infested fields, with only a small annual depletion percentage induced by the current integrated approach. The necessity to use parasite control methods will exist as long as the Striga seed bank is not successfully controlled. The ideal solution for seed bank demise has been proposed to be a combined approach that incorporates genetic resistance and suicidal germination components. If suitable synthetic SL candidates are identified, this strategy may be appropriate and perhaps more efficient. As a result, very effective synthetic germination stimulant analogs have been developed that are both cheaply and environmentally benign and may be utilized to stimulate suicidal germination of Striga seeds [77].

3. Conclusion

Sorghum is very important crop among the cereals especially in semi-arid areas of the world. However its production is hindered by different biotic, socioeconomic, and abiotic constraints. The parasitic weed *Striga hermonthica* the most damaging sorghum productivity among the biotic factors. Striga parasitizes host plants, causing reduced photosynthesis and increased photosythate partitioning to the roots. Striga infection has resulted in the loss of 30-50 percent of Africa's agricultural production on 40 percent of the continent's rich land. Striga can be defeated in a variety of ways. Some of the recommends are using appropriate agricultural technology such as refilling soil fertility, using certified seeds, and minimizing weed soil seed banks. When multiple management methods are used together rather than separately, they work well. Striga species cause more damage in nutrient-depleted soils, hence soil nutrient replenishment will boost the host's growth at the expense of the parasite. Crop rotations and intercropping could help solve two major and interconnected issues: low soil fertility and Striga infestation.

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