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Weed Challenging Sorghum Production: The Distribution, Impacts and Possible Management Practices of *Striga* Species in Sorghum Fields

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Abstract: *Striga* is a major limiting factor in the production of cereal crops such as sorghum and maize, sugarcane and legumes in sub-Saharan Africa. *Striga* can cause the complete loss of crops under the worst conditions. The aim of this article was to identify different methods of *Striga* management in sorghum to achieve the potential yields of the crop. High seed production, long seed viability and the subterranean nature of the initial phase of the parasite's movement make control of the parasite difficult, if not impossible, by conventional methods. The increased presence of *Striga* has been attributed to poor soil fertility and structure, low soil moisture, increased land use due to continuous cultivation and the expansion of grain production. Many of the potentially successful methods developed to control this weed include the use of resistant/tolerant cultivars, sowing clean seed that is not contaminated with *Striga* seeds, sowing cereals with trap crops that stimulate unsuccessful germination of *Striga* seeds, catch crops, organic plants and inorganic soil amendments such as manure or fertilizer, soil fumigation with ethylene, the use of post-emergence herbicides, push-pull technology and the use of biological control agents. Based on some studies, the interaction of striga with N fertilizer and resistant cultivars, cereal legumes and N fertilizer showed little striga infection. No single management option has been found to be effective in different places and times. Therefore, *Striga* integrated management approach currently offers the best opportunity to reduce impacts at the farm level.

Key words: *Striga* · Cause · Control · Haustorium · Infestation · Sorghum Seeds

INTRODUCTION

Sorghum is a major cereal crop that serves as an important source of food, feed and bioenergy [1]. It grows well under harsh growing conditions in the arid and semi-arid regions, characterized by low soil fertility and high temperatures, conditions not suitable for other major crops such as maize and wheat [2, 3]. According to Wortmann *et al*., [4], biotic challenges including *Striga* infestations, stem borers and p flies, as well as abiotic stresses like drought and low soil fertility, have an impact on sorghum production. Numerous research found that one of the main production barriers for sorghum in semi-arid regions is the lack of access to production inputs such fertilizers, insecticides, fungicides and herbicides.

Sorghum is cultivated in sub-Saharan Africa under dry land conditions on soils of poor fertility, often with *Striga* spp. [*Striga hermonthica* (Del.) Benth (Sh) and *S. asiatica* (L.) Kuntze (Sa)] [4, 5]. Hence, improved farming technologies that enhance soil fertility are critically required to increase sorghum yields and minimize damage caused by *Striga*. Yield improvement in sorghum fields infested by *Striga* can be realized through the application of recommended levels of inorganic fertilizers based on soil tests. Nevertheless, inorganic fertilizers are unapproachable and too expensive for smallholder farmers, suggesting the need for innovative solutions to boost sorghum productivity under smallholder farming systems by controlling *Striga* damage. Hence, the aim of this article was to identify different methods of *Striga* management in sorghum to achieve the potential yields of the crop.

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Fig. 1: *Striga* infestation in sorghum field [9]

Fig. 2: *Striga hermonthica* attachment to host plant (sorghum) [9]

Distribution and Biology of the Weed

Distribution of *Striga* Weed: *Striga* is one of the primary biological factors limiting sorghum yields in semi-arid regions of the world [6-8]. According to research done by Mrema *et al.* [8], yield losses of up to 100% took place in regions with heavy *Striga* infestations. In Tanzania, for example, a yield loss of up to 9% was experienced due to severe infestations of *S. hermonthica* and *S. asiatica.*

The Biology of the *Striga* Weed: *Striga* species are found in the many semi-arid parts of East Africa where sorghum is majorly produced. Based on research done by Yoneyama *et al.* [10], *Striga* spread effectively due to their capacity to generate 10,000-500,000 seeds per plant, each of which is viable in dry soil for 15-20 years. Wind, water, livestock and human intervention [11] can easily disperse its seeds. Germination is often stimulated by the host plant though some non-host species have been reported to produce stimulus for germination of *Striga* seed [12]. The roots of cotton, a non-host plant, emit *strigol*, which promotes the development of *Striga* seeds [13]. Sorgolactone and alectrol are equivalents of *strigol* produced by sorghum and cowpea roots, respectively, to induce *Striga* germination.

Ethylene triggers *Striga* seed germination and can be used to control *Striga* weed where pre- or post-emergence herbicides cannot be applied to control the weed. After stimulation of germination, *Striga* seedlings die back owing to a lack of host plants [14]. The seeds germinated after a period of primary dormancy, followed by seed preconditioning under warm temperatures (25-35°C) and moderate humidity levels (30-50%) for about two weeks[14]. The other conducive condition for *Striga* germination is secondary metabolites, which are named *xenognosins* released from *Striga* [15]. These substances direct the radicle of *Striga* seedlings towards the host root [16].

Experiments by Hess *et al.* [17] indicated that the amount and effects of exudates produced by sorghum genotypes could be studied using agar-gel assays. The method involves preconditioning *Striga* seeds, followed by growing them on agar in petri dishes. The maximum germination distance between the sorghum seed and a far-off *Striga* plant is calculated shortly after five days. Genotypes with a marginal growth distance below 10 mm are classified as *Striga*-resistant owing to their capacity to suppress *Striga* germination. This technique is helpful in displaying sorghum genotypes for *Striga* resistance.

Striga is a parasitic weed that depends on nutrients produced by its host to survive [18]. Host plant exudates initiate *Striga* seed germination. The radicle of the parasite seedling contacts the host root and enlarges to form a haustorium. Haustorium provides attachment to the host and establishes a channel for extracting nutrients and metabolites [18]. Failure of haustorium formation or its development leads to the death of the parasite due to a lack of water, mineral nutrients and synthesized photosynthate [19]. The physiological process, like the transpiration rate of *Striga* that is greater than that of the host, speeds up the flow of food, water and nutrients into the parasite. *Striga* also produces an allelopathy toxin that retards the growth and development of sorghum. Production of the toxin is associated with decreased cytokinines and gibberellin concentrations and a substantial increase in abscisic acid levels in damaged host tissues, causing a reduction in the rate of ribulose biphosphate carboxylation [20].

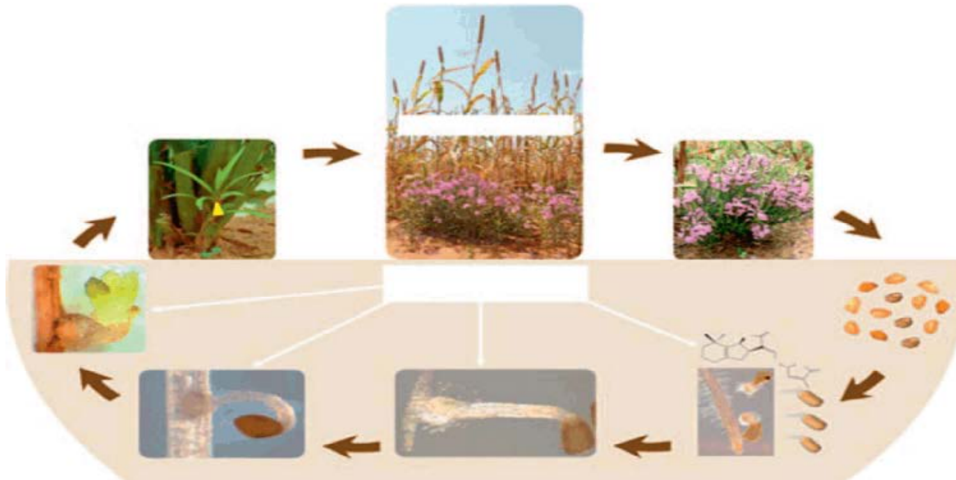

Fig. 3: Life cycle of *Striga*

In conclusion, *Striga* invasion of sorghum fields slows the growth rate of the crop and causes yellowing and wilting of the host plant. This results in poor plant growth and development, leading to a failure of panicle formation and yield loss. Understanding the conditions required for *Striga* seed dispersal, germination, infestation and parasitism will allow plant breeders to develop suitable crop varieties. Knowledge of the association of the parasite with the host and non-host species will also help in designing cropping patterns and crop choices.

Management Methods: There are several *Striga* management methods available, including traditional practices, chemical control, biological control and host plant resistance. However, their adoption depends on the availability of resources and skills among smallholder farming communities.

Cultural Practices: Many cultural control approaches have been suggested to manage *Striga* in sorghum fields. The control techniques help reduce the buildup of *Striga* seeds in the soil and thereby improve soil fertility [19]. Cultural practices slow the parasite *Striga* seed germination and seedling development while accelerating sorghum growth [20]. Among these, include crop rotation, mixed cropping, water management, fertilizing [21] and weeding [22]. Early planting following the onset of main rains minimizes *Striga* in the semi-arid regions because it allows escape from heavy *Striga* infestation, which often happens almost two months after planting.

Cultural methods of *Striga* management have been poorly adopted by smallholder farmers due to limited accessibility and knowledge. Furthermore, their implementation is costly in terms of resources, time and labor. Adoption of proper fertilizer application, rates and timing remains a challenge among sorghum growers in developing countries. The development of a viable integrated *Striga* management program aimed at minimizing *Striga* infestation and improving sorghum yield will require an understanding of the potential and limitations of the currently available management approaches.

Chemical Control: The chemical weed control method involves the use of herbicides for the control of *Striga.* According to Kanampiu *et al.* [23] reports, many herbicides are available for controlling *Striga* infestations in sorghum. Selective herbicides are the best option for controlling *Striga* in sorghum fields. In the report of Kanampiu *et al.* [23], 2, 4-D and MCPA are among the selective herbicides used in sorghum fields. These selective herbicides kill weeds before attachment to the host, which would be extremely valuable for controlling the weed. A study conducted by on sorghum and maize showed that treating seeds with 2, 4-D provides effective control of *Striga.* Furthermore, Kanampiu *et al*. [23] have studied the development of transgenic herbicide-resistant sorghum genotypes is an alternative approach that allows the use of herbicides without damaging the crop. They report the effectiveness of a sulfosulfuron weed seed coat applied to mutant sorghum lines in *Striga* control. Seed coating with herbicides is the cheapest method of treatment due to the requirement of only a small amount of the herbicide for seed dressing. High prices of herbicides, limited availability and a lack of technical knowledge on the use

Fig. 4: Untimely control of *Striga hermontica* [9]

Fig. 5: Adult of *Juonia* sp. pollinating *Striga hermonthica* flowers [9]

of agrochemicals to control weeds and pests are the main reasons for their low use in sorghum production [24-26]. It is necessary to create a *Striga* management program that is affordable for smallholder farmers to follow in order to increase sorghum yield within their circumstances.

Biological Control: Biological control is the use of living organisms that are useful in suppressing parasitic weeds, including *Striga* speciest hat are available in ecosystems [27]. According to Abbasher *et al.* [28], *Fusarium oxysporum* (FOS) isolates were highly pathogenic against *Striga.* These isolates often overwinter in the soil even in the absence of their host by colonizing crop debris and producing chlamydospores, which are the dormant resting propagules [29]. Studies conducted by Ciotola *et al.* [29] point out that *Fusarium oxysporum* f.sp. *strigae* is described as controlling *Striga* invasion in sorghum by about 90%. These isolates grow in the rhizosphere of the sorghum plants, parasitize them and inhibit the germination, emergence and development of *Striga* [29]. The bio-control fungus destroys *Striga* plants before they penetrate sorghum roots. Recent studies have indicated a significant reduction in *Striga* numbers as well as the number of days after flowering and ripening in FOS-coated sorghum seeds [30, 31].

The use of FOS for *Striga* management in East African sorghum fields has not yet been reported or implemented. Therefore, there is a need for integrated management of the parasite through host resistance and the application of FOS to enhance the production and productivity of sorghum and related cereals affected by *Striga.* There are no reports of negative effects of FOS on sorghum or related cereal crops. In fact, FOS has been reported to promote the abundance of arbuscular mycorrhizal fungi in the sorghum rhizospheres, which improves crop growth and development [31, 32]. Further, FOS has a very narrow host range, which is restricted to *S. hermonthica*, *S. asiatica* and *S. Gesneroides*.

Host Plant Resistance: Resistant cultivars reduce *Striga* emergence and *Striga* seed production. These genotypes support fewer *Striga* plants and yield better than their susceptible counterparts under *Striga* infestation [33].

Striga in sorghum has been controlled by a number of resistance mechanisms, including mechanical barriers, inhibition and reduced germination stimulant production of germ tube exoenzymes by root exudates, phytoalexine synthesis, incompatibility, antibiosis, insensitivity to *Striga* toxin and avoidance through root growth habit [34]. In addition to these resistance strategies, hypersensitive reactions, necrotic tissue development and phytoalexin production by sorghum plants also confer *Striga* resistance. Tissue surrounding the point of attachment of the parasite forms necrotic spots that limit food, water and nutrient supply to the parasite. Necrosis is reported to accompany phytoalexin secretion that kills the parasite [35]. Genes for hypersensitive response and phytoalexin production under *Striga* attack are reported in some sorghum genotypes [36]. A wild sorghum genotype, P47121, has been reported to have a better hypersensitive response to *Striga* infestation than cultivated sorghum genotypes and could be a useful genetic resource for resistance breeding [37].

Incompatibility with *Striga* has been reported in some sorghum genotypes under *Striga* infestation [38]. Incompatible genotypes do not show any response to *Striga* infestation and the parasite dissociates from the host immediately after penetration [39]. In this case, *Striga* seedlings die before the formation of the first leaf or show signs of stunted growth and death. Sorghum varieties differ in root morphology, the amount of lignin [40], cellulose deposition [41], encapsulation [42] and others. Haustorium fails to penetrate tougher roots in resistant sorghum genotypes than in susceptible cultivars with tender root tissues. Developing sorghum genotypes

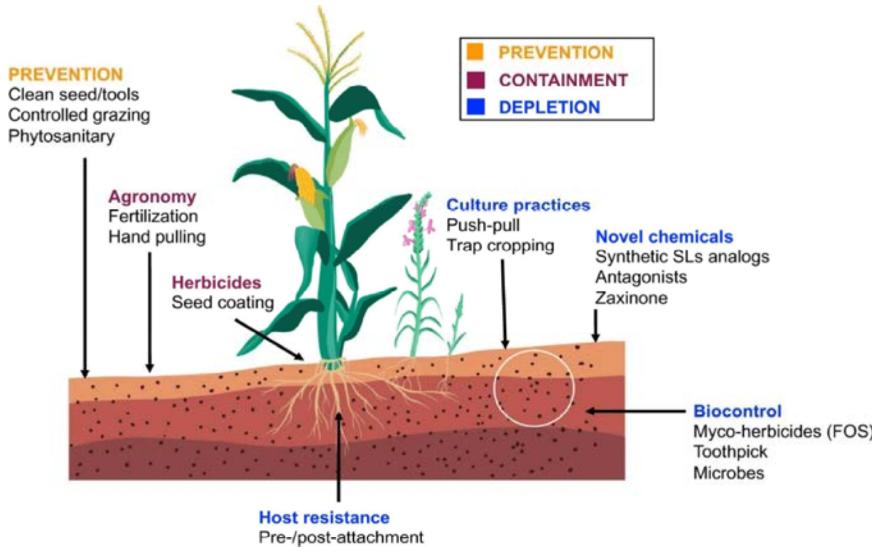

Fig. 6: *Striga* control approaches [50]

with tougher root systems that act as developmental barriers in addition to other resistance mechanisms reduces *Striga* infestation. The use of low haustorium initiation factors (LHF) present in some sorghum genotypes is an effective method of suppressing *Striga* [43]. The presence of LHF (sorgolactones) among sorghum genotypes has been reported from agar gel assays. A recessive gene conditioning LHF was reported in a wild sorghum accession, P47121, in which resistance was manifested before parasite attachment. Haussmann *et al*. [44] reported a set of genes controlling LHF. A single dominant gene was also reported to control LHF by Haustoria do not form when the sorghum root with the LHF gene blocks the parasite from feeding on the host. The LHF gene can be introgressed into high-yielding and broadly adapted sorghum cultivars [45]. Exploring the mode of gene action and inheritance of candidate *Striga* resistance genes is imperative to developing promising sorghum genotypes with multiple resistance genes adapted to the semi-arid environments of sub-Saharan Africa.

Integrated Management: *Striga* management using a single control method is less effective. A combination of several options can be efficient and economical with better control of *Striga* [46]. The use of trap-cropping, fertilizer application and resistant genotypes are some of the effective tools that need to be integrated for effective *Striga* management [46]. Several *Fusarium* spp. and vesicular arbuscular mycorrhizal fungi have been reported to control *Striga* and enhance biomass production in compatible hosts when integrated with resistance genes [47]. Integrated use of *Striga*-resistant sorghum genotypes with FOS treatment enhances the effectiveness of the biocontrol agent, with ultimate yield benefits. Therefore, integrated *Striga* management (ISM) should be promoted as an effective way of managing *Striga* in smallholder farming systems. An ISM strategy that combines the use of *Striga*-resistant sorghum varieties compatible with FOS is cost-effective, environmentally friendly and can easily be adopted by smallholder farmers [48,49].

Future Works for *Striga* Management: The development of sorghum varieties with traits that reflect farmers' preferences requires farmers' involvement in any breeding stages. Involvement of farmers' in a breeding program may assist breeders in gathering current constraints affecting sorghum production, trait preferences and strategies for effective *Striga* management in the major sorghum production areas. Understanding the current farming systems, including the prevailing farming practices, production constraints and overall socio-economic aspects, is critical when devising strategies for managing the parasite. Successful development, release and adoption of new sorghum varieties are highly dependent on farmer and stakeholder engagement. It is therefore important to investigate farmers' production constraints and their traits of preference before initiating variety development. This will also enable breeders to acquire adapted and *Striga* resistant landraces to incorporate into current breeding programs.

CONCLUSION

Although controlling *Striga* is difficult due to its complex life cycle, various control options have been developed. However, control of this poisonous parasitic weed is still inadequate. Integrated management practices have great potential to reduce *Striga* infection compared to a single control method and attention should be given to testing and identifying promising and compatible control methods by integrating *Striga* resistant varieties with fertilizers, myco-herbicides, crop rotation, intercropping/pushing and control methods. Push-pull, herbicide-based seed coating or synthetic germination stimulants are effective for *Striga* control. So far, only a few maize varieties with resistance against *Striga* have been developed through conventional breeding and the genetic resources for resistance genes are insufficient. Therefore, more research is needed in order to breed crops with persistent resistance. The use of biotechnological tools such as marker-assisted breeding, targeted gene editing or mutational breeding and RNA interference (RNAi) can enable the development of *Striga* resistant maize genotypes.

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