Journal of Biology, Agriculture and Healthcare
ISSN 2224-3208 (Paper) ISSN 2225-093X (Online) DOI: 10.7176/JBAH
Vol.9, No.15, 2019
www.iiste.org

Effect of Striga Infestation on Sorghum Agronomic Traits and Its Breeding Strategy for Resistance in Ethiopia: A Review

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Abstract

In Ethiopia sorghum is a major cereal crop grown in wide agroecology however, in most of moisture stress sorghum growing areas are infested by striga. Striga is an obligate root parasitic and a major biotic constraint to sorghum production in Ethiopia. Farmers sown susceptible sorghum varieties in striga infested field resulted plant height and dray matter and yield components were affected therefore, loss significant grain yield production. Farmers named reduction of sorghum growth and stunting as main indication of Striga infestation. Varieties exhibited lower reduction for these traits in striga infestation was named resistant varieties. In Ethiopian Gobiye, Abshir and Birhan registered as striga resistance, drought tolerant and early maturing varieties. Currently in Ethiopian sorghum national breeding program these resistance varieties utilizing as a source of resistance gene and crossing with landraces and other improved genotypes to develop new high grain yielding and resistance variety with farmers preferred agronomic traits. Also resistance variety SRN 39 and Framida use in breeding program. Resistance varieties also a central components of integrated striga management. The screening techniques is undergoing at major sorghum growing areas and striga infested field however, the striga occurrence is complicated and slow down the development of new resistance variety. Laboratory screening data conceding with field data was a mandatory to developed resistance varieties. Generally, enhancing sorghum grain yield production by developing high yielding stable striga resistance varieties, improving integrate striga controlling managements and distributing resistance varieties to the farmers are unambiguous. The objectives of this paper is to review the effect of striga on sorghum agronomic traits and breeding strategy.

Keywords: Striga infestation, Sorghum, resistance
DOI: 10.7176/JBAH/9-15-06
Publication date: August 31st 2019

INTRODUCTION

Sorghum is native to Sub-Saharan Africa and has been cultivated for centuries in Asia and Africa (Monica *et al*., 2004). The most important and old world cereal crops that was domesticated in Africa (Dahlberg *et al*., 2011). It is an annual crop that is tolerant, making it an excellent choice for dry areas. It has been found as an indigenous crop to Ethiopia with enormous genetic diversity.

The potential productivity of sorghum is reduced due to a number of abiotic and biotic stresses. The problems of various invasive and devastating weeds including striga are the major constraints especially in Africa and Ethiopia in particular (Mekonen, 2007). Striga spp. are obligate hemi-parasitic plants that attack to the roots of their host to obtain water, nutrient and carbohydrates (Ast, 2006). S.hermonthica mainly attacks sorghum, finger millet and maize in tropical and sub-tropical regions spreading across from West Africa to Ethiopia. In Ethiopia striga is a major biotic constraint and a serious threat to subsistence food production. Striga hermonthica, the dominant species which is severe in the highly degraded north, north western and eastern parts of the country vis Tigray, Wollo, Gonder, Gojam, north shewa and Harerghe (AATF, 2011).

Striga (witchweeds), are notorious root hemiparasites on cereal and legume crops grown in the semi-arid tropical and subtropical regions of Africa, the southern Arabian Peninsula, India, and parts of the eastern USA. These weed-parasites cause between 5 to 90% losses in yield; total crop loss data have been reported (Obilana *et al.,* 1992). Striga infests and significantly reduces yields of cereal crops including rice, pearl millet, maize and sorghum (Rich *et al.,* 2004). In Ethiopia, it is widely found in the lowland areas where sorghum is the dominant crop. Based on its infestation level sorghum yield loss due to *Striga* damage varies from place to place. On average sorghum yield losses of 65% were estimated in moderate to heavy infestations (Tesso *et al.,* 2007).

The striga controlling method such as cultural, chemical, biological, and use of resistant varieties are either impracticable for the majority of small farmers or too expensive or unavailable due to different reasons to reduce Striga damage. No single method of control can provide an effective and economically acceptable solution. Therefore, an integrated control approach is essential, ideal and useful to small-scale farmers, in order to achieve sustainable crop production (Hayelom, 2014). Striga-resistant sorghums can be a major component of integrated striga control approaches if resistance is incorporated into adapted, productive cultivars. Resistant cultivars can reduce both new striga seed production and the striga seed bank in infested soils. However, breeding progress has been limited due to the difficulty of evaluating resistance in the field and inadequate information on the genetics of striga resistance (Haussmanna *et al.,* 2000). In this paper, effect of striga on sorghum agronomic traits under striga infested, breeding for improved integrated striga control mechanisms and breeding for striga resistant in sorghum have been reviewed.

LITERATURE REVIEW

In Ethiopia, sorghum is grown as one of the major food cereals. Annually 1.3 million ha of land is allotted for sorghum production and 1.7 million ton of grain is produced in the country (Tadesse *et al.,* 2008). A number of striga resistant sorghum cultivars developed and released by the Sorghum Research Program at Purdue University. These cultivars were carefully tested for field resistance to striga in collaboration with plant breeders in several countries (Table 1).

Table 1. Striga resistant sorghum cultivars developed and released at Purdue University and countries where cultivars have been officially adopted and widely distributed.

Designation	**Country of release**	**Year of release**	**Local name**
SRN 39	Sudan	1991	Mogawium buda 1
P9830	Sudan	1991	Mogawium buda 2
P9401	Ethiopia	2000	Gobiye
P9403	Ethiopia	2000	Abshir
P9405	Tanzania	2002	Hakika
P9406	Tanzania	2002	Wahi
PSL5061	Ethiopia	2002	Birhan

Source: Ejeta, 2005

Constraints of Sorghum Production in Ethiopia

The major factors that account for low yield in sorghum crop are moisture stress, low soil fertility and pest damages. Among the pests, the root parasitic weed *Striga* is greatest biological constraint to sorghum production. This problem is also common in the eastern semi-arid area which is one of the most sorghum producing areas of the country (Zerihun, 2016). Major Sorghum production constraints naming percentage described by farmers in Ethiopia at Dejen, Bessoliban and Motta was striga infestation than low soil fertility, moisture deficient and lack of production input (Mesfin, 2016).

Distribution and host range of Striga

The parasitic seed plant of most importance in Africa is the genus striga. Members of this genus are obligate annual hemiparasittes; they are chlorophyllous, but require a host to complete their life cycle. The striga flowers are pink, red, white or yellow. There is a considerable variation in flower color. The plant is characterized by herbaceous habit, small seeds and parasitism. The seeds of *S. hermonthica* are extremely small, about 0.2 X 0.3mm, weighing about 0.7µg. The number of seeds per capsule ranges from 700 – 1800 depending on the species. The seeds can remain viable in the field for as long as 14-20 years .The minimal length of the life cycle of the parasite, from germination to seed production comprises an average of 4 months (Babiker, 2007). Since *Striga* is a parasitic weed the seedlings cannot sustain themselves on their own resources for particular long after germination. Therefore, they need to find a host root shortly after germination and the germination needs to be perfectly timed with the presence of a host root.

Striga has been given the common name of "witchweed" because it attaches itself to the roots of the host plant thus depriving it (the host) of water and nutrients. *Striga*, is a parasitic weed belonging to the *Orobanchaceae* (formerly: Scrophulariaceae) family (Matusova *et al.,* 2005). *S. hermonthica* is common throughout northern tropical Africa and extends from Ethiopia and Sudan to West Africa. *S. asiatica* has a wider distribution and is found throughout semi-arid areas of tropical and subtropical Africa, Asia and Australia (Gethi and Smith, 2004). Nigeria, Sudan, Ethiopia, Mali and Burkina Faso are heavily affected counties in Africa (AATF, 2011). The host range is almost wide and besides the cultivated cereals, it attacks many of the wild grasses. The traditional crops in the African savanna attacked by the parasite are sorghum (*Sorghum bicolor* L., maize (*Zea mays* L.), pearl millet (*Pennisetum glaucum* L.), and sugarcane (*Saccharum officinarum* L.) and rice (*Oriza sativa L.*) (Babiker, 2007).

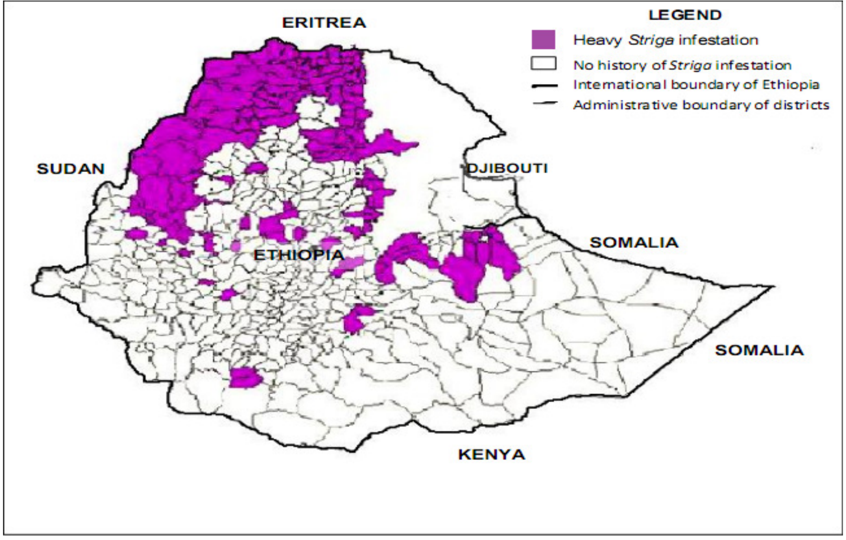
Table 2. Degree of Striga infestation on crops in SSA

Striga species	Crops						
	Maize	Sorghum	Rice	Pearl millet	Finger millet	Cowpea	Sugarcane
S. hermonthica	Xxx	Xxx	Xx	Xx	Xxx	–	Xx
S. angustifolia	–	Xx	–	–	–	–	Xx
S. asiatica	Xxx	Xxx	Xx	Xx	Xx	–	X
S. forbesii	X	X	X	–	–	–	X
S. aspera	Xx	X	Xx	–	X	–	X
S. gesnerioides	–	–	–	–	–	xxx	_
S. latericea	–	–	–	–	–	–	X
S. pubiflora	–	–	–	–	–	–	X

xxx-Serious infection, xx-Moderate infection, x-Less infection, --No infection
Source: Parker and Riches, 1993

The Striga species are among the most specialized of all root-parasitic plant parasites (Parker and Riches, 1993). In Ethiopia, it is widely found in the lowland areas where sorghum is the dominant crop (Figure 1). Based on its infestation level sorghum yield loss due to Striga damage varies from place to place. On average sorghum yield losses of 65% were estimated in moderate to heavy infestations (Tesso *et al.,* 2007).

Figure 1. Historically known areas with heavy Striga infestation in Ethiopia



Source: Tesso *et al.,* 2007

Effect and Loss due to Striga

Striga damage is caused by parasitism, reduction in photosynthesis and increased partitioning of photosynthates to the roots of host plants. It attaches itself to the host plant roots and in doing so, it weakens the crop plant by robbing carbon assimilates, water, nutrients and amino acids from its host (Pageau *et al.,* 2003).

Yield losses caused by Striga are often significant and infestation by Striga usually results in substantial yield reduction often surpassing 65% in heavily infested fields. As indicated by Haussmann *et al.* (2000) grain yield losses of up to 100% are possible on susceptible sorghum cultivars under high Striga infestation levels. Ejeta *et al.* (2002) indicated that in countries such as Ethiopia and Sudan, losses of 65-100% are common in heavily infested fields but total loss can occur when Striga attack is compounded by drought. In some areas, the attack is so severe that farmers cannot grow sorghum anymore; they have either abandoned their land or switched to other less important crops (Fasil and Parker, 1994).

Effects of *Striga* infestation on sorghum height, Leaf numbers and Sorghum dry matter

Plant height of uninfected sorghum was significantly different from that of infected plants. Effect of Striga infestation on Sorghum height reported by Samia *et al.,* 2014 at 8 weeks after sowing infection of sorghum variety 1, variety 3 and variety 5 by Striga at the highest level (4mg) resulted in 51, 62 and 35 %, lower plant height than uninfected plants, respectively. However at 10 week after sowing results displayed that uninfested sorghum variety 3 sustained the highest plant (80cm). Striga inoculation at 2 and 4 mg reduced Sorghum variety

3 height by 59 and 67 %, respectively as compared to uninfested control. In sorghum variety 1 *Striga* reduced sorghum height by 71 and 74%, respectively. Therefore, research reported by Samia *et al.,* 2014 indicated that Striga, irrespective of the levels used, reduced sorghum growth significantly, in comparison to the respective Striga free control.

Samia *et al.,* 2014 research result displayed no significant difference in leaf number in each sorghum cultivars treated with each of the two Striga levels, irrespective. This result indicated that generally, Striga infestation had no significant effect on sorghum leaf numbers.

Total dry matter accumulation was most affected by striga infestation. Reduction in total dry matter weight under infestation was more pronounced in cultivars variety 6 and variety 5. However, sorghum variety 5 had the lowest total dry matter, irrespective to Striga level. Cultivar variety 3 also showed no decrease in biomass or plant height on infection, but relatively high Striga emergence (Samia *et al.,* 2014). The aboveground shoot weight and plant height of resistance varieties to the parasite were least affected by striga infestation (Bayu *et al.,* 2001). Generally, these varieties would be interest if good yield potential were associated with their low susceptibility to striga attack.

Breeding for Durable Resistance to Striga in Sorghum

If sources of resistance have been identified, they can be incorporated for agronomic performance. Alternatively, the resistance gene in these sources can be incorporated for agronomic performance. Alternatively, the resistance genes in these sources can be obtained by pyramiding resistance genes. Crop genotypes that possess multiple genes for Striga resistance, based on distinct mechanisms, are likely to have genetic resistance that is durable across several environmental conditions as well as across ecological variants of the parasite. It has also been emphasized that breeding programs should target sources of resistance at different areas and understand the nature of resistance required (Koyama, 2000). Suggested breeding methods include: early generation selection for individual resistance mechanisms; use of recurrent selection procedures to develop breeding populations with multiple sources of resistance; lines with different resistance mechanisms are combined to form hybrids or synthetics, to increase durability of resistance and the use of marker-assisted selection techniques for the development of broad-based, quantitative resistance to witch weeds under field conditions (Haussman *et al.,* 2000b).

Breeding for Improved Integrated Striga Control

Soil fertility

Striga is more favor in less fertile soil, a system that would improve soil fertility to increase yield as well as reduce Striga infestation (Vogt *et al.,* 1991). Severity of infestation of Striga is reported to correlate negatively with soil fertility. Nitrogen proved to be an essential element for reducing Striga infestation and mitigation of its adverse effects on crops. The suppressive effects of Nitrogen on Striga infestation were attributed to delayed germination; reduced radical elongation, reduced stimulants production and reduction of seeds response to the stimulants (Hassan *et al.,* 2009). Good soil management practices involving the use of crop residues and organic manure have been effective control measure against Striga (Vogt *et al.,* 1991). Result reported by Zerihun, 2016 indicated that interaction effect of nitrogen rates by variety on number of S. hermonthica at 10 and 12 weeks after planting was number of striga in variety Gubiye, Hormat and Teshale decreases respectively when the nitrogen rates increases. This result concluded that Striga infestation decreased with increasing nitrogen rates. In addition, resistances variety hosting number of striga more decreases than other varieties when nitrogen rate increases.

Striga infestation decreased with increasing organic matter of the soil and that organic matter content seemed to be the most important factor which preserved the soil fertility. Since soil microbial biomass flourishes better in a medium rich in organic matter, organic or inorganic soil amendments may increase soil suppressiveness to Striga spp. and also improve soil conditions to increase yield of subsequent cereals (Berhane, 2016).

Inter cropping

Intercropping sorghum with legumes consistently provides significant seasonal control of *Striga* and enhanced grain yields. The overall effect however showed that intercropping sorghum with soybean and groundnut led to a reduction in Striga number at simultaneous intercropping rather than relay cropping. Intercropping with these legumes therefore showed some promise as a suitable component of an integrated Striga management approach for the small holder farmers, but this would need to be combined with other cultural methods such as hand weeding of emerged Striga to avoid replenishment of Striga seed bank in the soil (Fitsum *et al.,* 2016). Some studies indicate that intercropping with cowpeas between the rows of maize significantly reduced Striga numbers when compared to within the maize rows (Odhiambo and Ransom, 1993). Moreover, finger millet intercropped with green leaf desmodium reduced *Striga hermonthica* counts in the intercrops than in the monocrops (Midega *et al.,* 2010). According to (Fasil *et al.,* 2005) also reported related findings on sorghum cowpea intercropping where Striga emergence was lower under intercrops than sole crops. Generally, various studies have shown that intercropping cereals, mainly with legumes such as cowpea, peanut and green gram can reduce the number of Striga plants (Carsky *et al.,* 2000). Potentially they might be acting as traps crops and interfere with Striga germination and development (Parker and Riches, 1993).

Host plant resistance

Striga resistance is the ability of the host root to stimulate Striga germination but at the same time prevent attachment of the seedlings to its roots or to kill the seedlings when attached. The use of resistant crop cultivars is the most economically feasible and environmentally friendly means of Striga control. In East Africa, the most promising new approach to Striga control is the use of resistant cultivars for instance sorghum. Striga resistant cultivars have been bred in a number of crops. However, cultivars with immunity to Striga have not been found in all host crops. The host/parasite relationship is governed by a series of steps involving stimulation of germination, haustorium initiation, penetration of the host root, connection to the host xylem and concurrent growth (Butler, 1993).

Result reported by Gobena *et al.,* 2017 sorghum seedlings with high Striga germination stimulant activity (A) will germinate conditioned S. asiatica seeds cocultured in agar, a centimeter or more from its root as the germination stimulant, 5-deoxystrigol, diffuses through the medium. Low-stimulant sorghum that exudes orobanchol instead of 5-deoxystrigol will not cause S. asiatica seeds to germinate in the agar gel assay, even very near its roots (B). (Scale bars, 1 mm.) The photograph (C) shows an LGS1 WT high-stimulant sorghum (left) growing next to a line (right) carrying the lgs1-1 allele in a field infested with S. hermonthica (purple flowers) in Ethiopia.

Integrated Striga management

No single management option has been found effective across locations and time. An integrated Striga management approach, currently, offers the best possibility for reducing impact at the farm level. (Evans *et al.,* 2011) reported suitable management Striga control strategies aimed at improving and filling in the gaps of the available mechanisms which have not been widely adopted by farmers. Priority should be geared towards understanding the parasite and the farmers farming systems so that any mechanism developed will be able to fit into the farmers' requirements. In addition breeding of cultivars that are resistant to Striga will be cost-effective to control the parasite as cultivation of resistant varieties does not require costly inputs from farmers. If at all resistant genes can be identified, they can be transferred to other cereals such as maize, millet and sorghum by marker-assisted selection.

A similar study by (Temam, 2006) pointed out that species of Striga were controlled by using the resistant variety, fertilizer and tied ridges on farms of eastern Ethiopia which had long been abandoned due to Striga infestation. Species of Striga were controlled by using the resistant variety, fertilizer and tied ridges on farms; whereas, the local cultivar had severe infestations. The Striga-infested local varieties died, failed to produce a head or had very small heads. Striga count against treatment and yield against treatment were significant at $p \leq 0.01$. Striga count against location and yield against location were not significant (Temam, 2006).

Field screening

Conventional plant breeding for Striga resistance has traditionally involved field evaluation of germplasm under artificial or natural infestation. The agar-gel assay is an excellent tool to screen host genotypes in the laboratory for low production of the striga seed germination stimulant. Field screening for striga resistance is hampered by high microvariability in African soils, heterogeneity of natural infestations, and concomitant large environmental effects on striga emergence (Haussmann *et al.,* 2000). The efficiency of striga resistance breeding in sorghum could be further increased by combining laboratory assays with the field evaluation, and by the development of marker-assisted selection techniques. For effective striga control, resistant cultivars must be integrated with other control methods such as crop rotation (Haussmanna *et al.,* 2000).

Breeding Strategies

Both interspecific variability among Striga species and intraspecific variation for aggressiveness must be taken into account when breeding for striga resistance (Ramaiah, 1987; Ejeta *et al.,* 1992). In order to obtain stable, polygenic resistance, breeding materials should be evaluated at various locations with different striga populations or host-specific races (Ramaiah, 1987). In doing so, quarantine regulations must be strictly respected, and striga species or strains should not be introduced into regions where they do not already occur. If seed shortage imposes a constraint on progeny evaluation, a reduction in plot size should be preferred over reduction of the number of test locations, since there is always the danger of losing data from one location due to ``non-striga years" or other obstacles. To avoid seed shortage and therefore a trade-off between replications and sites, breeders could use inbred generations as test entries (Kling *et al.,* 2000).

The fact that the low stimulant gene(s) were reported to be recessive renders the back-cross program more complicated and time-consuming. With its high heritability and the possibility to screen large numbers of entries, the in vitro germination distance fulfills two major prerequisites for an indirect selection trait. Coefficients of correlation between germination distance and striga resistance under field conditions are generally positive but vary among genetic materials and test locations (Vasudeva Rao, 1985; Omanya *et al.,* 2000). In trials involving a recombinant inbred population derived from the cross of line IS 9830 (low stimulant) with line E 36-1 (high stimulant), coefficients of correlation between germination distance in the agar-gel assay and striga emergence in the field ranged between 0 and 0.32 (significant at P.0.01) in Kenya, and between 0.29 and 0.64 (both significant at P.0.01) in Mali (Omanya *et al.,* 2000).

3. CONCLUSION

Some sorghum genotypes support significantly fewer *Striga* plants and give higher grain yield than others. Some other genotypes show smaller yield reductions than others under the same level of infestation. Some are highly susceptible and would not give yield at all. The presence of this wide range of variability in Striga resistance and tolerance traits among sorghum genotypes suggests an opportunity to develop high yielding and resistant/tolerant genotypes through hybridization.

Developing Striga resistant genotypes is the most promising, practical, and cost effective approach to reduce effects of Striga. Also, resistance cultivars is a major component of integrated control packages. Therefore, future research efforts should be directed towards understanding host resistance mechanisms, improvement of field screening and infestation techniques, and development of stable high yielding Striga resistant varieties that are acceptable to farmers.

The screening strategy could be to use laboratory assays for individual resistance mechanisms as an initial screening of a larger number of breeding materials, followed by the more resource-demanding field screening. Networking and exchange of useful materials are also important steps towards more efficient breeding programs for resistance to striga in sorghum.

Numerous sorghum cultivars or breeding lines have been reported as resistant to striga. However, Sorghum breeding program finding would not only show how striga reduced the performance and yield of the different sorghum varieties but, also assist farmers in choosing the best variety of sorghum to cultivate under striga infestation.

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