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Article · May 2011

DOI: 10.5251/abjna.2011.2.5.752.760

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AGRICULTURE AND BIOLOGY JOURNAL OF NORTH AMERICA
ISSN Print: 2151-7517, ISSN Online: 2151-7525, doi:10.5251/abjna.2011.2.5.752.760

Evaluation of ecologies and severity of *Striga* weed on rice in sub-Saharan Africa

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ABSTRACT

Striga spp. is renowned for causing great losses in cereal production in sub-Saharan Africa. Crop competitiveness with parasitic weeds such as *Striga* is an important criterion for selection in an initiative to produce and release rice cultivars to farmers that are able to give high and stable yields under low-input conditions. The symptoms of *Striga* infected rice plants are chlorosis, wilting and stunted growth. Rice yield is reported to be reduced by more than 50% in areas that are infested by the weed. In addition, areas that are heavily infested have been abandoned and rendered unfit for crop production. Notable advances in *Striga* weed control technology have been made, yet the weed continues to be a major cause of low agricultural production. This is an indication of poor linkage between research institutions and agricultural extension which is a bottleneck to research findings to benefit farmers.

Keywords: *Striga* spp., host plants, rice, *Striga* occurrence, tolerance

INTRODUCTION

Parasitic weeds are problematic in Agricultural Production Systems (APS) in the world today. The weeds compete with crops for nutrients, water and harbor disease causing organisms. Root parasitic weeds such as *orobanche* (broomrape) and *Striga* (witchweed) compensates for lack of their own root system by penetrating the roots of host plants and thus depriving the essential nutrients for plant growth. This brings about stagnation of the host plants with the end result of low yield (Watson *et al*., 1998). *Striga* species predominantly found in Africa infest land planted with sorghum (*Sorghum bicolor* [L.]), pearl millet (*Pennisetum glaucum* [L.]), finger millet (*Eleusine coracana* [L.] Gaertn), maize (*Zea mays* [L.]), upland rice (both *Oryza glaberrima* [Steudel] and *O. sativa* [L.]) and cowpea (*Vigna unguiculata* [L.] Walp) (Musselman, 1980; Rodenburg *et al*. 2006; Scholes and Press 2008).

Striga, the parasitic angiosperm weed is said to be the major problem in cereal production causing huge losses in grain yield. The diversity of *Striga* spp. populations in African countries need to be understood to identify the races found in the different agro-ecological zones. This will enable improvement of the existing crop material through breeding that can withstand the stress of the weed. *Striga hermonthica* has particularly assumed economic importance in upland rice growing areas in West and East African countries.

The epicenter of *Striga* is believed to be in the tropical savannah between Semien Mountains of Ethiopia and Nubian hills of Sudan in SSA before spreading to other parts of the continent (Ejeta, 2007). This area is also recognized as the origin of sorghum and pearl millet which are readily infected by *Striga*. Over 70 years, several world institutions both private and public have dedicated substantial amount of money towards developing appropriate mechanisms to control the parasite (Ahmed *et al*., 2001). Despite the efforts made to control the *Striga* problem, farmers have not adopted the control options developed (Oswald, 2005). This is one of the greatest tests to be synthesized by the researchers and unearth the reasons behind the farmers not embracing the preventive measures (Emechebe *et al*., 2004).

Striga seed production paradox need to be underscored as the parasite produces many tiny seeds which are capable of existing in the soil for more than 10 years (Hearne, 2009). This has enhanced the parasites' persistence and increase in magnitude. Therefore, this review focuses on the distribution and effect of *Striga* spp. on cereal production particularly rice. The paper first reviews the importance of rice and the extent of infestation of *Striga* spp. in SSA. Assessment on the occurrence of the parasites in their current habitats is highlighted. Finally, rice cultivars tolerance levels to *Striga* is discussed.

Significance of rice production : Rice is a major staple food for approximately half of the world's population. It is one of the major food crops in SSA with an estimated cultivated area of about 6.8 million hectares. The total rice production in the region is about 21.6 million tons in 2006 (FAO, 2007). The demand of rice has been increasing at rate of 4.4% per annum since 1970s which is as result of dietary shift from conventional foods, brought about by urbanization and increase in population (Jones, 1999). Production has also been growing at rate of 5.1% per year with approximately 70% due to increased area under cultivation and 30% on yield. Upland rice has been leading on expansion in the area under production particularly with the incoming of New Rice for Africa (NERICA) (Otsuka and Kalirajan, 2006).

Rice is slowly becoming one of the most important crops in the continent both for food and cash. Obilana and Okumu (2005) reported that upland rice has brought remarkable impact in farmers' livelihoods on poverty reduction, improved nutrition and increased cash income generation. In addition, reduction of the growing period of NERICA rice has bridged the gap of hunger and brought about saleable products. This implies that there is availability of ready cash for household use. Research has also shown that a hectare of rice can sustain 5.7 persons per year as compared to 5.3 and 4.1 for maize and wheat respectively. The world food total calorie out-put is approximately 3119 k cal. /person per day at farm gate, with rice accounting for 552 k cal. /person per day or 18% of the total (De Datta, 1981). However, one of the major constraining factors in production of upland rice in sub-Saharan Africa is weed infestation especially *Striga* spp. The problem of weeds in upland rice is exacerbated by delayed and poor land preparation as well as inefficient weeding associated with broadcast sowing, random transplanting and lack of appropriate agricultural implements.

DISTRIBUTION AND INFESTATION OF *STRIGA* IN SSA

***Striga* weed infestation and occurrence:** There are 28 *Striga* species occurring naturally, infecting grasses and legumes in SSA. Most of the crop host species for *Striga* are cereals which Africans depend on as food (Table 1). The parasite infests some 40% of the cereal-producing areas of SSA resulting to crop losses estimated at US$7 billion annually, affecting livelihoods of approximately 300 million people (Ejeta, 2007). The most affected are subsistence farmers losing about 20–80% of their yield (Gethi *et al*., 2005).

It has been reported that five of the *Striga* spp. cause devastating effects on crops: *S*. *hermontica, S*. *asiatica, S*. *forbsii, S*. *aspera* and *S*. *gesnerioides* (Berner *et al*., 1997). Table 2 shows the distribution of *Striga* in Africa and *S. asiatica* is said to have a wide world geographic distribution as compared to others (Cochrane and Press, 1997). Dugje *et al*. (2006) stated that in Nigeria three major *Striga* species have been found to be infecting crops: *S. hermonthica* (sorghum, rice and maize), *S. aspera* (rice) and *S. gesnerioides* (cowpea). In the savannas of guinea, *S*. *aspera* occurs in the hydromorphic areas where rice is grown, while *S*. *hermonthica and S. asiatica* are found in the free draining upland areas and are regarded as the most infectious (Johnson *et al*., 1997). Notably *S. aspera* is predominantly found in West Africa and sporadically exists in Ethiopia and Tanzania overlapping with *S. hermonthica*.

Table 1. 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

Generally *Striga* spp. grows in areas with annual rainfall ranging from 25-150 cm per year with decrease in severity of infestation in areas of high rainfall (Mohamed *et al*., 1998). However, *S. forbisii* mainly occurs in wet areas and even in water logged conditions infecting wild grasses in swamps and irrigated crops (Mohamed *et al*., 2001) in Cote d'Ivore and Tanzania. There are records indicating *S. hermonthica* and *S. aspera* infections on rice in Northern Cameroon, Northern Nigeria, Benin, Togo and westwards. It has also been reported that *S. hermonthica* infects upland rice in Western Kenya (Harahap *et al*., 1993) and *S. asiatica* causes serious losses in upland rice along the Indian Ocean Islands.

Conditions favoring *Striga* growth: *Striga* infestation is steadily increasing as a result of continuous cultivation of cereal crops. Overused, depleted and infertile soils have resulted to high infestation of *Striga*. Pressure on land for continuous cropping of high yielding cereal crops without rotation or moving to other new areas has resulted to exhausted soils. These are the soils that favor *Striga* infestation in addition to soil moisture stress conditions (Khan *et al*., 2007). Less shading due to poor growth of the host crop on poor soils contributes to heavy infestation. This has compounded the problem for small-scale farmers who can least afford inputs on unproductive land, and thus continues mono-cropping (planting of the same crop on the same area) for several years. Infestation in some areas has reduced yield to the extent that abandonment and migration is necessary. Improper management of *Striga* weed has contributed to its existence in SSA for a long time.

Poverty level of small scale farmers has enhanced the spread of *Striga* through sharing of seeds collected from the previous crop harvest. In addition, *Striga* pandemic in SSA has increased due to non advocacy of nutrient replenishment of the soils as a result of mono-cropping, a factor for increased infestation of the weed in size and severity (Woomer, 2004).

Striga produces several seeds, and during tillage the seeds are incorporated into the soil where they can be dormant for many years. Over time they are spread to new areas by human beings through the tools used for land preparation and weeding (Oswald, 2005). The seeds are also spread by animals moving from one field to another for grazing purposes (Hearne, 2009). This has culminated to a complex system of spreading the weed to new areas thus reducing crop yield of farmers who are not aware of the devastating effect.

Soil fertility and *Striga* weed: Parasitic weeds such as *Striga* establish preferentially in poor nutrient fields which have been exhausted by continuous cropping (Kim, 1997). Most *Striga* infested areas are characterized by APS exhibiting low productivity. These areas tend to be managed traditionally with low inputs and continuous cereal cropping without crop rotation. The use of inorganic nitrogen and organic fertilizers such as manure and compost has been reported to reduce *Striga* infestations (Kuiper, 1998). Manure applications have been shown to be as effective as fallowing in maintaining soil productivity. The positive benefits of applying manure include an increase in pH, water holding capacity, hydraulic conductivity, infiltration rate and decrease in bulk density. Manure is also an important source of N, P and K (Kim, 1997). To enhance the quality and effectiveness of traditional soil fertility maintenance strategies such as manure application, a fertilizer augmented soil enhancement strategy need to be adopted to reduce the infections of *Striga*.

Field trials conducted in the dry and wet seasons in the northern Guinea Savanna ecological zone to study the effect of nitrogen rates on upland rice (*Oryza sativa* L.) varieties to *Striga hermonthica* indicated that FARO 48, a variety normally susceptible to *Striga hermonthica* exhibited resistance, FARO 11 exhibited tolerance, while FARO 38, FARO 46 and FARO 45 exhibited susceptibility. The application of 90 and 120 kg N ha^{-1} delayed and reduced *Striga* emergence on the crop, induced a low crop reaction score and produced grain yields that were significantly high. Significant differences in *Striga* infestation were observed between nitrogen rates of 30-120 kg N ha^{-1} (Adagba *et al*., 2002).

The significant interaction between upland rice varieties and nitrogen rates indicates that the susceptible varieties require higher rates of nitrogen to ameliorate the effect of *Striga* compared with the resistant varieties. In addition, Johnson *et al*. (1997) showed that the proportion of *0*. *glaberrima* and *0*. *sativa* plants that appear stunted, is related to the number of *Striga* plants present. The increasing incidences and severity of *Striga* damage is linked to poor soil fertility which is due to lack of farm yard manure and inorganic fertilizers (Emechebe *et al*., 2004).

Incidence and severity of *striga* on rice: Johnson (1996) reported that 20-100% of yield loss in rice fields depend on the farmers' control of weeds. *Striga* is a common parasitic weed which alone reduces yields of cereal crops such rice more than 50% (Johnson *et al*., 1997). As shown in Table 1 there are four known *Striga* spp. that infect rice:- *S. hermonthica*, *S. asiatica*, *S. aspera* and *S. forbesii*. In the rural communities of Northern Nigeria, it has been reported that crop yield losses due to *S. hermonthica* infections were about 70-100% (Emechebe *et al*., 2004). It has also been reported that crops can show resistance characteristic in one area and succumb in another because resistance can be broken by the existing biotypes (Gethi *et al*. 2005). This was observed in Tanzania where sorghum was planted in different locations (Doggett 1952) and similar observations have been made in West Africa (Ramahiah 1987).

Susceptible and resistant rice cultivars*:* Johnson *et al*. (1997) describes two *O. sativa* cultivars, IR47255-B-B-5-4 and IR49255-B-B-5-2, having resistance to *S. hermonthica* and limited susceptibility to *S. aspera* enabling to support 2-3 emerged parasite stems per rice plant compared to over 20 on the susceptible cultivars which are widely grown in infested areas of Cote d'Ivore (Table 3). However, in general cultivars of African rice species, *O. glaberrima* more often show *Striga* resistance as compared to *O. sativa* (Johnson *et al*., 1997). Johnson *et al*. (2000) reported that *O. glaberrima* cultivar CG14 is resistance to *S. hermonthica* and *S. aspera* which is one of the parents of NERICA rice, currently being promoted for food security in SSA for their short maturity period, drought resistance and high yield. However, it has also been shown by some post-attachment studies to be susceptible to *S. hermonthica* (Gurney *et al*. 2006). The screening of NERICAs against *Striga* spp. is necessitated as the most productive areas for upland rice are heavily infested. Furthermore, the contradictory information on CG14 on resistance and susceptibility to *Striga* infections will be confirmed and reported in this journal.

Incidence and severity of *S. hermonthica*, *S. asiatica, S. aspera* and *S. forbesii* (in decreasing order of importance) parasitizing rice are particularly high in the savannahs of West Africa with relatively high

Table 2. Distribution and occurrence of *Striga* spp. in sub-Saharan Africa

***Striga* species**	**Host plants**	**Distribution**
S. aequinoctialis		Guinea, Angola, Liberia, Siera Leone
S. angolensis		Angola
S. angustifolia	Sorghum, Sugarcane	Malawi, Tanzania, Zambia, Zimbabwe
S. asiatica	Rice, Sorghum,	Angola, Kenya, Lesotho, Malawi, Mozambique, Sudan, Namibia, Tanzania, Madagascar, South Africa, Zanzibar, Zambia, Botswana, Burundi, Democratic Republic of Congo
S. aspera	Rice, Maize, Sorghum, Finger Millet, Wild grasses, Sugarcane	Burkina Faso, Cameroon, Central Africa Republic, Ethiopia, Gambia, Guinea, Cote d'ivoire, Nigeria, Niger, Mali, Ghana, Senegal, Sudan
S. bilabiata		Burundi, Guinea Bissau, Niger, Nigeria, Guinea, Angola, Uganda, Democratic Republic of Congo, Mali, Zambia, Malawi, Cameroon, Burkina Faso, Ethiopia, Central Republic of Africa, Cote d'ivoire, Kenya, Tanzania, South Africa
S. brachycalyx		Burkina Faso, Democratic Republic of Congo, Ghana, Cote d'ivoire, Nigeria
S. chrysantha		Central African Republic
S. dalzielii		Guinea, Mali, Nigeria
S. elegans		Angola, Botswana, Kenya, Malawi, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, Zimbabwe
S. forbesii	Sugarcane, Maize, Sorghum, Rice	Angola, Botswana, Democratic Republic of Congo, Ethiopia, Kenya, Malawi, Mozambique, South Africa, Sudan, Swaziland, Tanzania, Uganda, Zambia, Zimbabwe
S. gastonii		Chad, Central African Republic
S. gesnerioides	Cowpeas, Wild legumes	Angola, Botswana, Burkina Faso, Burundi, Cameron, Central African Republic, Democratic Republic of Congo, Ethiopia, Sierra Leone, Senaral, South Africa, Tanzania, Zimbabwe, Gambia, Ghana, Kenya, Malawi, Mali, Mozambique, Somalia, Nigeria, Ruanda, Uganda, Zambia

Table 2. Continued

***Striga* species**	**Host plants**	**Distribution**
S. gracillima		Malawi, Tanzania
S. hallaei		Gabon, Democratic Republic of Congo
S. hermonthica	Maize, Rice, Sorghum, Pearl millet, Finger millet, Sugarcane	Angola, Cameron, Central Africa Republic, Democratic Republic of Congo, Djibouti, Eritrea, Gambia, Guinea Bissau, Ethiopia, Cote d'ivoire, Niger, Kenya, Senegal, Sudan, Chad, Uganda, Tanzania, Togo, Namibia, Nigeria
S. hirsuta		Angola, Burkina Faso, Central African Republic, Democratic Republic of Congo, Kenya, Ethiopia, Mozambique, Somalia, Nigeria, Seychelles,Tanzania, Zambia
S. junodii		Mozambique, South Africa
S. klingii		Ethiopia, Kenya, Tanzania
S. latericea	Sugarcane	Ethiopia, Kenya, Tanzania
S. lepidagathidis		Guinea, Senagal, Guinea Bissau
S. lutea		Burkina Faso, Democratic Republic of Congo, Kenya, Mali, Nigeria, Sierra Leone
S. macrantha		Angola, Central African Republic, Guinea, Cameroon, Liberia, Mali, Senegal, Chad, Sierra Leone
S. passargei		Burkina Faso, Ghana, Guinea, Nigeria, Togo, Sudan, Tanzania, Zambia
S. pinnatifida		Ethiopia
S. primuloides		Ghana, Cote d'ivoire, Mali, Nigeria
S. pubiflora	Sugarcane	Kenya, Mozambique, Tanzania
S. yemenica		Ethiopia

Source: Johnson *et al*., 1997; Khan *et al*., 2002; Mohamed *et al*., 2001; Timko *et al*., 2007

Table 3. Reaction of rice cultivars to *S. hermonthica*, *S.asiatica* and *S.aspera*

Reaction	Genotype	*Striga* spp.	Refs
Resistant	ACC102196	*S. aspera*	5
	B3913F-16-5-ST-42	*S. hermonthica*	3
	Ble Chai	*S. hermonthica*	3
	CG14	‡*S. hermonthica*, §*S. aspera*	2, 6, 7
	FARO 40	*S. hermonthica*	1
	FARO 48	‡*S. hermonthica*	1
	IG10	*S. aspera*	5
	IR38547-B-B-7-2-2	‡*S. hermonthica*	3, 5
	IR47255-B-B-5-4	*S. hermonthica, S. aspera*	3, 5
	IR47697-3-4-1	*S. hermonthica*	3, 6
	IR49255-B-B-5-2	*S. hermonthica, S. aspera*	3, 5
	Jean louis	*S. asiatica*	4
	Nipponbare	*S. hermonthica*	2, 7
	WAB928-22	*S. hermonthica, S. aspera*	6
	WAB935-5	*S. hermonthica, S. aspera*	6
	WAB937-1	*S. hermonthica, S. aspera*	6
Tolerant	Azucena	*S. hermonthica*	7
	FARO 11	*S. hermonthica*	1
	Kasalath	‡*S. hermonthica*	2, 7
	M27	‡*S. hermonthica*, †*S. aspera*	2, 5
	Makassa	*S. hermonthica*, †*S. aspera*	5
	T2	*S. hermonthica, S. aspera*	2, 5
Susceptible	Bala	*S. hermonthica*	7
	Dourado precoce	*S. hermonthica*	3, 4
	Namroo	*S. hermonthica*	2 ,3
	IR64	*S. hermonthica*	7

Refs: 1-Adagba *et al.*, 2002, 2-Gurney *et al.*, 2006, 3-Harahap *et al.*, 1993, 4-Itoh *et al.*, 2008, 5-Johnson *et al.*, 1997, 6-Johnson *et al.*, 2000, 7-Kaewchumnong & Price, 2008. Contradictory reaction reported with the same species: †Resistant, ‡Susceptible, §Tolerant.

incidence also in Central, East and Southern Africa. The greatest damage occurs in the sahelian and savanna zones of Africa, which constitute the major rice growing areas where *Striga* problem is most severe. It has already been shown that FARO 48 is resistance to *S. hermonthica* while FARO 38, FARO 46 and FARO 45 are susceptible (Table 3). Studies conducted in western Kenya on rice tolerance to Striga showed that heavy infestation led to complete crop failure (Kuoko *et al*., 1992). *Striga* emergence in the local varieties ranged from 8-18 plants m^{-2}. Gurney *et al*. (2006) reported a robust resistance in Nipponbare rice cultivar to *S. hermonthica* in post-attachment experiment. In this cultivar the parasite failed to form xylem to xylem connection to the host plant root. Other studies have also shown Nipponbare having low numbers of *Striga* and emerging late thus concluding that the variety is resistant (Swarbrick *et al*. 2009).

Striga tolerance and Quantitative trait loci in rice: Gurney *et al*. (2006) screened 31 rice cultivars of *O. sativa*, *O. glaberrima* and wild relatives of rice sourced from different ecologies in the world for *Striga* tolerance. All the cultivars were susceptible except for Nipponbare which exhibited high level of post-attachment resistance to *Striga hermonthica*. The result also showed detection of seven *Striga* resistance quantitative trait loci (QTL) (on chromosomes 1, 4, 5, 6, 7, 8 and 12) for post-attachment in an advanced backcross inbred line (BIL) resource generated from Kasalath and Nipponbare. This result corroborated with the findings of Swabrick *et al*. (2009) who assessed QTL for resistance in rice (Koshihikali-Nipponbare BILs, Nipponbare-Kasalath cross and Kasalath-Koshihikari cross) to *Striga hermonthica* and concluded that chromosome 4 QTL in Nipponbare-Kasalath cross and Kasalath-Koshihikari cross overlapped between 6.5Mbp and 8 Mbp on the physical rice genome. These findings narrowed down the position of *Striga* resistance which had been earlier reported by Gurney *et al*. (2006).

However, in the study conducted by Kaewchumnong and price (2008) on rice cultivars tolerance to *Striga* showed that the QTL for all rice traits in the *Striga* infected were present between position 139 and 169 cM on chromosome 1. The QTL LOD scores ranged from 4.9 to 15.7 and they were significant at 3.2. There were two positions in the studies of Gurney *et al*. (2006) and Kaewchumnong and price (2008) that coincided. First is on chromosome 1 at position 46 cM between marker C1370 and R2417. The second is at position 32 cM at marker R202 on chromosome 8. Kaewchumnong and price (2008) further showed that Chromosome 1 especially marker C1370 of rice seems to control both the establishment of *Striga* and the effect of *Striga* on rice plants. From these studies it can be deduced that there is an indication that genes for *Striga* tolerance exist in rice germplasm and further fine mapping may bring about examination of genes, and then narrow them down to find out their putative functions. This will enable understanding on the nature of tolerance and ultimately breeding for *Striga*-resistant rice plants.

CONCLUSION

Africa has complex systems of agricultural development ranging from bush clearing and cultivation to convectional agricultural production. Rice is slowly becoming food security crop in SSA. With the increasing population, pressure on cultivated land, changes in feeding habits and urbanization, rice consumption is likely to continue increasing. The area under production of upland rice (especially the new cultivars of NERICA) is under threat from *Striga* weed infestation. This therefore calls for 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 through the use of synteny.

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