Striga (Witchweeds) in Sorghum and Millet: Knowledge and Future Research Needs

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Abstract

Striga *spp (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. Immunity in hosts has not been found.*

Past research activities and control methods for Striga *are reviewed, with emphasis on the socioeconomic significance of the species.* Striga *research involving biosystematics, physiological biochemistry, cultural and chemical control methods, and host resistance are considered. We tried to itemize research needs of priority and look into the future of* Striga *research and control In light of existing information, some control strategies which particularly suit subsistence and emerging farmers' farming systems with some minor adjustments are proposed. The authors believe that a good crop husbandry is the key to solving the* Striga *problem.*

Introduction

Striga species (witchweeds) are parasitic weeds growing on the roots of cereal and legume crops in dry, semi-arid, and harsh environments of tropical and subtropical Africa, Arabian Peninsula, India, and a small part of USA. In some parts of Africa the profusion of witchweeds have serious impact on the socioeconomic life of farmers. Heavily infested farms are abandoned and occasional migrations of farming communities because of *Striga* has been reported. The statement that *Striga* is a new threat to Africa's food crops is not so. It is endemic in Africa's cereal and legume food crop production.

The weed is parasitic to cereals and legumes, but there is significant variation in the reaction of different crop species. Because *Striga* has evolved, parallel with sorghum, over the centuries, the indigenous crop has developed the whole spectrum of tolerance (on average about 60%), susceptibility (in about 30%), and resistance (in about 10%). On the other hand, in maize, susceptibility has been the common reaction as resistant varieties are still being identified and confirmed. The reaction of millet is complex, with ecological zone implications. Resistance to *Striga* has not yet been found in millet, even though millet coexists with sorghum in some environments. Reaction of rice to *Striga* is not well known, but indications are that susceptibility to *Striga* parasitism is normal in rice.

The cowpea, *Vigna unguiculata,* is the legume most affected by *Striga* in dry areas of Africa, where it is a common food plant.

Being an obligate hemiparasite, *Striga* causes tremendous damage to the host plants before *Striga* emerges from the soil. Persistent drought worsens the situation. Little attention is paid to it or its control. As a result the *Striga* problem is one of the most serious production problems on cereals and cowpeas south of the Sahara.

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African farmers on impoverished soils in the marginal areas are subsistence-oriented and less resourceful, possibly for survival reasons. They recognize the *Striga* problem, but have no simple control measures to solve it. Costly control methods are available, and are used by farmers in countries like USA. In developing countries, progressive farmers who can afford to apply fertilizers and follow good agronomic practices have fewer problems with *Striga.* Even in this situation, use of excess fertilizers in very dry weather may be impracticable. Therefore, the task ahead, to improve the overall productivity of the farm land and transform subsistence and emerging farmers into entrepreneurs, is tremendous. We believe a good crop husbandry is the key to solving the *Striga* problem.

We review historical developments of formal and informal work on *Striga* reemphasize its socioeconomic implications in terms of its continuous spread and its cost in crop loss, and discuss the latest developments in *Striga* research. The research needs of priority are itemized and the future of *Striga* research and control is considered.

Finally, control strategies particularly suited to the subsistence and emerging farmers' farming systems with some minor adjustments are proposed.

Socioeconomic Implications

Why research on *Striga?* The answer to this question lies in the damage done by *Striga* in terms of the farming systems, crop losses, and farm losses (abandonment) in regions of semi-arid Africa and India where the parasitic weed is endemic. In these Striga-infested regions, the environment is so harsh and marginal for crop productivity that only a few drought-resistant staple crops are grown—sorghum, millets, cowpeas, and some maize—and they are extremely parasitized. Food shortages are routine.

The socioeconomic impact of *Striga* infestation on cereal crops in western Africa was assessed by Obilana (1983a) and Ramaiah (1984).

The success of *Striga* as a parasitic weed is due to several of its characteristics, related somehow with the farming systems in semi-arid areas where its hosts are grown, *Striga* seeds survive in arid soils for 15 years. The number of seeds produced per plant ranges from 40 000 to 500 000 for S. *asiatica* (several authors) and 25 000 for S. *forbesii* (Obilana et al. 1988, pp. 342-364). Seeds, small in size, are efficiently dispersed by man (in use, transport by machinery, and seed movement), by animals (in droppings), and by water (in field erosion). Extensive longevity, together with ability to form "biotypes," "ecotypes," and "crop-specific" types and its ease of dispersal has made necessary serious and significant farming systems changes; several small African tribes and family groups have migrated from location to location because of *Striga.* Several cases of farm abandonment or change in cropping patterns have been reported in southern Africa (Obilana et al. 1988, pp. 342-364). Some 30 to 40% of total farmlands have been abandoned to sorghum or maize cultivation in some countries in western and southern Africa.

In terms of crop yields, *Striga* damage has been most significant. In the eastern African region, grain yield loss for susceptible sorghum varieties was estimated to be 59% (Doggett 1965). For western Africa, Obilana (1983b) and Ramaiah (1984) recorded actual yield losses in sorghum due to *Striga* damage. Obilana reported 5% loss of potential yield in resistant cultivars, 95% in susceptible varieties; and 45-63% in tolerant sorghums. Ramaiah (1984) reported yield-loss estimates of 10-35% in experimental plots. Where *Striga* infestation is intense and varieties are susceptible, 100% crop losses in farmers' fields are common. However, in most farmers' plots with mostly tolerant sorghums and millets, these crops coexist with *Striga.* In terms of actual monetary values, Striga-caused losses between U.S. $28 million and $87 million annually, are suffered by western African farmers (Obilana 1983a). Although actual values have not been reported for southern Africa, estimated grain-yield losses due to *Striga* could reach between 15 and 95% in sorghum, millet, and maize varieties and hybrids.

Sorghum, millets, and maize are principal staple foods in most countries of Africa. Considering that cultivation of these three cereals occupies 54.6 million ha and produces 54.3 million t of grain the approximate value of these crops (in U.S. dollars) is about $12.438 billion (Ramaiah 1984). As these three crops are major hosts of *Striga* in Africa, and it is known that *Striga* can cause yield losses of 100%, this figure could represent the cost of *Striga* infestation in all African maize, sorghum, and millets fields. Recently, Vasudeva Rao et al. (In Press) estimated mean grain yield loss in sorghum in India to range from 14.7 to 32.0% in the rainy season and 21.9 to 84.5% in the postrainy season. They write that potential loss could be total for the crop, with average of 19.7% grain yield loss in hybrid sorghums due to S. *asiatica.* Assuming only 10% of the hybrid sorghum crop is affected, losses of about 75 000 tons, valued at about U.S. $7.5 million occur annually.

It is possible that *Striga* could spread to additional areas, especially with the persistent occurrence of drought. The parasitic weed is not yet present everywhere. Unless effective integrated control measures are taken as soon as possible, *Striga* could become a serious threat to the cultivation and productivity of all rainfed cereals in the semi-arid tropics (SAT) of Africa.

Similarly alarming is the prospect for legumes—especially cowpeas. The threat posed to cowpea by *Striga* is most serious in the semi-arid savannas of western Africa and the dry arid lands of southern Africa. Although exact values of economic losses due to *Striga* in cowpeas have not been recorded, guestimates and visual observations indicate 50-100% yield loss in severe infestations (Obilana 1987). Spread of the cowpea *Striga* into wetter grassland and veld areas has been rapid, confounding the situation, and causing much concern. Economic implications of *Striga* damage on cowpeas becomes more significant in view of the role of the crop in mixed-cropping systems used in the semi-arid and arid savanna and veld regions of Africa.

Striga Research and Control

Early research

Several species of *Striga* were recognized as serious parasitic weeds as early as 1900 in India, Africa, and parts of USA. Parker (1983) traced the research history of this parasitic weed, and summarized part of the problem.

As early as 1905, Burtt-Davy in southern Africa described witchweeds in the Botanical Notes of the Transvaal Agricultural Journal, recognizing the species as parasitic. Within a decade, experiments with *Striga* were conducted in the region. Work on control methods—including agronomic and cultural practices, e.g., fertilizer use and crop rotations, were reported by Pearson (1913). The earlier works concluded that crop rotations, catch cropping using sorghum and sudangrass (Timson 1931), and nitrate fertilizer were valuable in controlling *Striga.*

Saunders (1933) classified the biology of *Striga asiatica,* studied the use of catch crops (including the trap cropping), and pioneered the selection of resistant varieties in sorghum. This last activity identified several "resistant" varieties, including "Radar" (Saunders 1942). The resistance in "Radar" was complex, as it was reported to break down, and then again *Striga*-free in recent studies (Riches et al. 1987, pp. 358-372).

The use of chemicals to control witchweeds was an early objective. Inorganic herbicides, like sodium chlorate, were found to selectively kill *S. asiatica* in maize (Timson 1934).

Present research

Current research into *Striga* has sought using improved techniques to update and confirm earlier findings; come up with the biosystematics and classification of all types of *Striga* in Africa; continue surveying spread of known types and possible new types; and continue studies seeking environment-specific integrated *Striga-management* procedures.

Following the findings of earlier workers, after a lull of about two decades, Visser and Botha (1974), in their chromatographic investigations on *Striga* seed germination, found that crop-root exudates stimulate germination of *Striga* seeds, and that the stimulant substances can be separated readily by high-pressure chromatography. Their work illustrated the involvement of several stimulant substances, which need to be identified and characterized.

Latest Achievements

Musselman's recent book on *Striga* (1987) provides "state of art" knowledge on various aspects of the parasitic weed. The attempt here is only to highlight the latest developments, rather than to undertake an extensive review.

Taxonomy and biosystematics

In spite of the economic importance of this genus, relatively little is known about its taxonomy and biosystematics. The number of species is not known. According to Raynal-Roques (1987) there are about 36 species. Musselman (1987) described 30 species, of which 24 are found in western and central Africa alone (Raynal-Roques 1987). Earlier Musselman (1987) indicated 23 *Striga* species, suggesting that the African region may be its center of diversity. Lesser centers are the southern Arabian Peninsula and India. In a recent summary of herbarium documents, Riches et al. (1987, pp. 358-372) and Obilana et al. (1988, pp. 342-364) found reports of nine of the African *Striga* species to be occurring in southern Africa. The distribution and possible hosts of *Striga* spp found in Africa are listed in Table 1.

Table 1. Distribution and possible hosts of African species of *Striga*.

Species	Distribution	Host	Remarks
S. *hermonthica* (Del.) Benth.	Western Africa (especially in Nigeria, Ghana, Burkina Faso, Niger, Chad, Mali, Senegal, and Mauritania); Eastern Africa (especially in Sudan, Ethiopia, Yemen, Kenya, and Uganda); and the SADCC (especially in Angola, Tanzania, and Mozambique)	Sorghum, pearl millet, maize, and wild grasses	
S. *asiatica* (L.) Kuntze	Eastern Africa (Ethiopia, Kenya), more countries in the SADCC region. Very limited occurrence in western Africa, Burkina Faso (yellow type)	Sorghum, pearl millet, finger millet, maize, upland rice, sugarcane, and wild grasses	Red-flowered types mainly, with occasional orange and yellow forms
S. *gesnerioides* (Willd Vatke = (S. *orobanchioides)*	Western Africa (Nigeria, Niger, Burkina Faso, Mali, and Senegal); SADCC region (Botswana, Malawi, Swaziland, Tanzania, Zimbabwe, and Angola?)	Cowpea, tobacco, convolvulaceae, and fabaceae	
S. aspera (Willd) Benth	Malawi, Tanzania, Mozambique, Burkina Faso, and Nigeria	Rice, wild grasses, and occasionally maize, sorghum, and sugarcane	
S. *euphrasioides* Benth =(S. *angustifolia* (DON) Saldanha)	Malawi, Tanzania, Zimbabwe, Zambia, and Mozambique	Sorghum, maize, sugarcane, upland rice, and wild grasses	
S. forbesii Benth	Tanzania, Botswana, Zimbabwe, Swaziland, and possibly in Angola, Zambia, and Mozambique	Soxghum, maize, rice, and a few wild grasses	

Continued

Table 1. *Continued*			
Species	Distribution	Host	Remarks
S. bilabiata (Thunb.) Kuntze	In the eastern African lakes region and across western Africa in the Sahel and Sudanian zones; Zimbabwe	Mostly on wild grasses	
S. elegans Benth	Tanzania, Kenya, Botswana, South Africa, Zimbabwe	Wild grasses	
S. *macrantha* Benth	Sudan, Zimbabwe and Sudanian zone of western Africa	Wild grasses	
S. *aequinoctialis* Chev. ex Hutch, and Dalz	Burkina Faso, Mali, Nigeria, Niger, and Chad (western Africa)	Wild grasses	
S. klingii (Skann) Engler = (S. *Dalzielii* Hutch.)	Burkina Faso	Sorghum, millet, and wild grasses	With small bluish flowers
S. *junodkii* Schinz	Southern Africa, including Mozambique		
S. *hallaei* A. Raynal	Gabon, Zaire		
S. *fulgens* Hepper	Tanzania		
S. *elegans* Benth	Tanzania, Kenya, Botswana, and South Africa	Cereals and wild grasses	
S. *chrysantha* A. Raynal	Zaire and Central African Republic		
S. *brachychalyx* Skan	Sahelian and Sudanian zones of Africa	Cereals and wild grasses	
S. *baumanii* Engler	Zaire, Kenya, and western Africa		
S. *latericea* Vatke[3]	Kenya, Tanzania, Ethiopia, and Somalia	Sugarcane and cereals	With vegetative propagation
S. *ledermannii* Pilger	Cameroon		
S. *linearifolia* Hepper (Schumach et Thona.) =(S. *strictissima* Skan) = (S. *canescens* Engl)	Western Africa		
S. *primuloides* Chev	Cote d'Ivoire		
S. pubiflora Klotzsch (=S. *agnustoifolia?)* (=S. *zanzibarensis* Vatke?)	Ethiopia and Somalia		Status not confirmed

Information about this genus is not sufficient to provide comprehensive keys or descriptions, but Raynal-Roques (1987) has made an excellent attempt for the species found in western and central Africa. A *Striga* identification booklet, describing the species of agronomic importance, was earlier published (Ramaiah et al. 1983), followed by a recent pamphlet (Obilana et al. 1987). There is considerable confusion in distinguishing closely related species complexes such as *Striga hermonthica* - S. *aspera* - S. *curviflora;* and *Striga euphrasioides* - S. *angustifolia* - S. *pubiflor* - *S. zanzibarensis.* Fairly detailed work and discussions on taxonomic and biosystematic issues of *Striga* species in southern Africa have been presented by Ralston et al. (1986), Riches et al. (1987, pp. 358-372) and Obilana et al. (1988, pp. 342-364).

The chromosome number of *Striga* species is not well studied. Interspecific relationships and the origin of different species are yet to be understood. Electrophoretic studies, chromosome studies, and interspecific hybridization should provide useful information on these aspects (Musselman, personal communication). The preliminary results on crosses between S. *hermonthica* and S. *aspera* indicate that each is cross-compatible in either direction. The sympatric nature of S. *asiatica* (red-flowered) and S. *forbesii* observed in the southern African region needs study.

The floral biology of these *Striga* species needs more study. There are two distinct reproductive systems—autogamy and allogamy—in this genus (Musselman and Parker 1983). Autogamy appears to be widespread compared to allogamy. Autogamy characterized by a mass of pollen persisting on the stigma was observed in S. *asiatica,* S. *gesnerioides,* S. *bilabiata, S. angustifolia,* S. *forbesii, S. passargeii* and S. *densiflora* (Musselman 1987). Allogamy appears to be restricted to *S. hermonthica* and S. *aspera,* the two closely related species. In recent field surveys in Burkina Faso, we observed several pollen vectors—butterflies, bee flies, and moths—on these two species. They are now being identified at the Commonwealth Institute of Entomology. Though we (Obilana et al. 1988, pp. 342-364) confirmed autogamy in *S. forbesii* by field-cage studies, the exerted stigmas observed in few plants seemed to be persistent. This characteristic, in addition to 5. *forbesii's* bright long-lasting corollas, can be considered evidence of outcrossing (allogamy).

Physiology

Many aspects of *Striga* biology are not fully understood. They include the physiological processes of photosynthesis, respiration, transpiration, water relations, cause of heavy crop-yield reductions, morphology, and analoging of the haustorium in relation to its function. The overall physiology of resistance or tolerance to *Striga* in cereal species is included.

Some understanding of these aspects is provided by the excellent work of Stewart's group in University College, London (Press and Stewart, In Press; Shah et al. 1987; Press et al. 1987a,b). The rates of photosynthesis of *Striga* species were found to be very low in contrast to the respiration and transpiration rates of higher plants. Stomata of drought-stressed *Striga* plants were found to be open in darkness and their control is poor. This high rate of transpiration is interpreted as a means of maximizing solute transfer from host to parasite. Such reliance on high rates of transpiration has suggested use of antitranspirants in *Striga* control.

Field experiments in Sudan, using Synchemicals' antitranspirant wilt proof S600 spray, were very encouraging. Aerial shoots of treated *Striga* plants turned black after a few days and collapsed. On newly emerged shoots, the spray treatment caused blackening and collapse within 24 h. The straw and grain yields of sorghum increased by 25% and 18%, respectively. *Striga* yields were markedly reduced by 40% in 1985 and 20% in 1986. These results, if confirmed, will be very valuable; antitranspirants could effectively replace herbicides, and they are less hazardous to the environment.

Press and his colleagues demonstrated that sorghum varieties infected with *Striga* show massive reduction in photosynthesis and that *Striga* plants derive more than 35% of their carbon from the photosynthetic activity of the host plant. The loss of a substantial portion of the host plant's photosynthetic production and drought stress account for the reduction in grain and stover yield attributed to *Striga.* The reduction in photosynthetic activity of the host in the presence of *Striga* may be useful as a screening indicator of susceptibility.

Control Approaches

Cultural

Several cultural methods were reported to be efficient in controlling *Striga* species (Ramaiah 1987; Bebawi 1987; Ogborn 1987). Some include use of costly inputs such as fertilizers, some are labor-intensive, like hand weeding, and some involve minor adjustments in the cropping systems-such as crop rotations. Among these, hand weeding is most often recommended to Third World farmers and is also the one often rejected, mainly because of its low cost-benefit ratio. Extension workers emphasize the importance of hand weeding as soon as the *Striga* plants emerge, but most of the damage to the host has occurred while the *Striga* is still in the soil. Hand removal of *Striga* helps reduce population buildup, and thus is helpful in the long run, but farmers seldom think beyond 2 or 3 years ahead. In most nations of western and southern Africa, land ownership is nonexistent. Farmers seldom undertake long-term strategies to control *Striga* or improve the soil by anti-erosion measures, crop rotation, or trap cropping.

Recent experiments on farms in northern Burkina Faso have produced encouraging results on a single hand-weeding of *Striga* in millet fields just before harvest (Ramaiah 1985; ICRISAT1986). The dramatic reduction of *Striga* populations in the following 2 years provided evidence that a majority of the seeds still on the *Striga* plants were destroyed when the plants were pulled and burned. Significant increases in millet yields occurred in the two cropping seasons that followed. Verification is expected in experiments now underway in Mali, Cameroon, and Ethiopia; the practice needs testing in Tanzania, Botswana, Malawi, Swaziland, and Zimbabwe. This method along with resistant varieties, fertilizers, and other cultural practices known to reduce *Striga* populations could be used very effectively as a supplementary control method. Hand weeding may then become more practical, and perhaps a common practice.

In Jordan, Syria, and Israel solar energy was used successfully for the control of *Orobanche,* a closely related parasitic species. The process is called soil solarization: it killed *Orobanche* seeds effectively when the soil was covered with polyethylene for about 40 days following summer irrigation. This was found to be very effective, like methyl bromide fumigation, but less toxic. It has been effective on other soilborne pathogens, including the pigeonpea fusarium wilt disease in India (ICRISAT 1987, pp. 177-178). Limitations include availability of water and of the large polyethylene sheets needed to cover the soil for about 40 days. It appears to have potential in countries like Sudan where *Striga* is a serious problem in the irrigated areas, and in the wetter savanna areas of Nigeria and Tanzania; rainfall here may be up to 1200 mm and the sorghum fields become carpeted with *Striga.*

Chemical

Excellent pre- and postemergence *Striga* herbicides are now available (Eplee and Norris 1987a). Goal® and 2,4-D are pre- and postemergence applications, respectively. In addition, fumigants like methyl bromide and germination stimulants like ethylene gas effectively reduce *Striga* seed reserves in infested soils. Fumigants, however, are most expensive for use by the small-scale farmer.

Though herbicides are available to control *Striga* as it emerges or later to prevent seed production, using them does not prevent the damage inflicted by preemergent parasitic attachment. This limitation is now overcome by the discovery of systemic herbicides (Eplee and Norris 1987b). In USA, Dicamba® is used on sorghum and maize to kill *Striga* before crop yields are reduced. Dicamba® sprayed at 0.5 kg a.i. ha^{-1} on sorghum or maize no taller than 1 m gave excellent control of *Striga* without reduction in yield.

Host resistance

Resistant varieties offer an excellent approach to avoiding yield losses to *Striga* in subsistence farmers' fields. Breeding efforts at ICRISAT in Burkina Faso have developed resistant varieties acceptable to farmers. We now have identified a few varieties with very high levels of resistance to *S. hermonthica.* They include IS 6961, IS *7777,* IS 7739, IS 14825, and IS 14928. Grain yields are very low in these varieties, and efforts are underway to transfer their resistance into high-yielding backgrounds. Screening for host resistance in sorghum at SADCC/ICRISAT Sorghum and Millets Improvement Program Bulawayo, found three cvs—SAR19, SAR 29, and SAR 33—to be resistant to S. *forbesii.* These were earlier found resistant to S. *asiatica* (white-flowered) in India. SAR 19 and two others, SAR 16 and SAR 35, were resistant to S. *asiatica* (red-flowered) in Botswana.

Ramaiah (1987) presented a detailed review of host resistance to *Striga.* Except for finding these new sources of resistance, there is no major breakthrough in understanding resistance mechanisms, genetics of resistance, physiological variability within *Striga* species in relation to stability of host resistance, screening/infestation techniques, and evaluation for resistance. Comparison of root-distribution patterns of resistant and of susceptible sorghums (Housely et al. 1987) is of interest. Resistant varieties, like Framida and P 967083, have deeper root systems with significantly less total root length in the upper 30 cm of the soil core than the susceptible variety, Dabar. Babikar et al. (1987) observed that *Striga* seeds buried deeper than 24 cm undergo dormancy not easily broken by normal preconditioning. *Striga* seeds 5 to 10 cm below the soil surface are the most active. Thus host varieties with shallow root systems will be more exposed to active *Striga* seeds than those like P 96083 which have less of the root system in the *Striga*-active soil zone. Breeding for deep-rootedness in sorghum varieties may have an advantage for resistance to *Striga* and perhaps to drought stress as well.

More intensive efforts to develop high-yielding stable and broad-spectrum resistant varieties are desirable. This is possible only if we have reliable screening techniques to identify resistant plants and we know more about the biochemistry of the resistance mechanism, and about other factors conditioning resistance. Meanwhile, we have observed indications of multispecies resistance in some ICRISAT sorghum materials, especially SAR 19 with resistance to S. *asiatica* (white- and red-flowered) and 5. *forbesii* (Obilana et al. 1988).

Control Strategies

It is now well recognized that no single method of control can effectively solve the *Striga* problem. *Striga* species are weeds and they are parasites. As weeds, they appear late in the season, and escape the normal early weeding operations. As parasites, they have the advantage of remaining out of sight (and frequently out of mind) while feeding on the host. The three major principles of *Striga* control are: (1) reduction of seed numbers in the soil; (2) prevention of new seed production; and (3) prevention of movement of seeds from infested to noninfested areas. Any control strategy should include an integration of at least one method from each of these three major principles (Table 2).

With minor adjustments in traditional farming

Mixed cropping and rotation. Mixed cropping of host and nonhost crops is a very common practice in western Africa; cereal crops (mostly sorghum) are grown mixed with trap crops such as cowpea, groundnut, cotton, soybeans, field peas, and sesame. Our recent laboratory experiments with these trap crops show that most of these do indeed act as trap crops. These crops are mixed and sown at random, instead of seeding and cultivating them as sole crops on areas of variable length and width in keeping with their importance in the mixture. However, sole cropping would permit application of *Striga* control methods to the cereal row area only, thus reducing the labor required and reducing the possibility of herbicide damage to the associated crops. It will also allow rotation of these strips, which is useful in two ways; trap crops, such as groundnut, will encourage abortive germination of *Striga* seeds in the soil. Secondly soil fertility is improved through fixation of atmospheric nitrogen. Other beneficial effects of trap crops in reducing *Striga* and improving the yields of cereals can be listed.

Subsistence farmers need their cereal staple each year. Crop rotation is an ideal practice; the cereal is grown on a different piece of land each year. This recommendation should meet with least resistance in central and western Africa.

A similar approach, together with crop rotation, could be used for *Striga* control in communal cereal farms in southern Africa where "monocropping" or "double cropping" is more common.

Table 2. *Striga* control methods described under three principles.

I Reducing number of *Striga* seeds in soil	II Preventing production of new seeds	III Preventing spread from infested to noninfested soils
1. Cultural	1. Cultural	1. Cultural
Trap crops Catch crops Deep plowing Soil solarization	Resistant varieties Hand weeding Irrigation/flooding Date of sowing Fertilizers/manures Density of sowing/shading	Antisoil erosion 2. Phytosanitary practices Clean seed
2. Chemical	2. Chemical	3. Feeding only *Striga-free* fodder to livestock
Methyl-bromide fumigation Germination stimulants (Ethylene gas and strigol analogs)	Herbicides	
	3. Biological	

Crop substitution, hand weeding, cattle manure. Sorghum and millet, the most important cereals in the semi-arid tropics, occupy different ecological zones in the sub-Saharan Africa. Sorghum and maize are dominant in the Sudanian and northern Guinean zones and the dry veld where rainfall is relatively high (700-1200 mm) and the soils are heavy and relatively more fertile. Millet is the most important crop on sandy soils of the Sahel and the dry veld. Accordingly, *Striga* has developed extreme crop-specificity in these zones of western Africa (Ramaiah 1984). Therefore, introduction of early-maturing and drought-resistant sorghum varieties adapted to the sandy soils of the Sahel or dry veld will greatly solve the *Striga* problem there. Conversely, cultivation of millets in the Sudanian zone will be advantageous. This practice need not be followed throughout the region, but will be very useful in *Striga-endemic* areas. It may also have limited use in very dry and hot environments, as in Botswana, where the crop-specificity of *Striga* has not been confirmed.

In the Sudan a similar system is followed by the farmers of southern Darfur (Ogborn 1987), where farmers have started to utilize their freedom from the *Striga* menace.

Farmers must be careful not to allow *Striga* on these introduced crops to set seed, as it is common to find that *Striga* populations build up to intolerable levels rapidly Crop substitution should, therefore, be accompanied by hand weeding. As fewer *Striga* plants emerge, the task should not be extensive.

If supplementary control measures are ignored, the substituted crops can succumb to *Striga.* This has occurred in western Africa (Porters 1952) and in the Sudan (Bebawi 1987).

We recommend supplementary hand weeding to prevent *Striga* buildup and the parking of cattle, sheep, and goats in continuously cropped fields in dry season. The manure will help sustain productivity of the soil.

Varietal substitution, hand weeding, and cattle manure. Local varieties of sorghum and millet in Africa have some resistance to *Striga,* though they suffer greatly under heavy infestations. Resistant varieties of sorghum have been known since the 1930s (Saunders 1933), but their use by the farmers was limited because of certain undesirable agronomic traits.

Nevertheless, varieties like Dobbs, Framida, Radar, and Mugd are grown by farmers in eastern and southern Africa. Framida was introduced into western African countries and is doing extremely well in Togo, Ghana, Benin, and Burkina Faso. Under heavy infestations, this variety is known to produce several times more than the local susceptible varieties. In addition to its resistance to *Striga,* Framida is excellent in seedling establishment and resistance to drought, has higher and stable yields, possesses partial photoperiod sensitivity, resists bird damage (due to brown grains), and good food quality when properly processed. Its brown-grain characteristic limits its cultivation to red-sorghum growing areas, and to production for brewing opaque beer in southern Africa.

The use of recent resistant varieties and improved derivatives from older cvs, in place of susceptible cvs, plus hand weeding and cattle manure can reduce significantly the *Striga* menace and increase cereal productivity. Two of the most promising varieties are ICSV 1002 BF and ICSV 1007 BE ICSV 1002 BF combines the additional good characteristics of white grains, lodging resistance (nonsensescence character), and resistance to important leaf diseases. This variety is in the prerelease stage in Burkina Faso and Gambia.

The second selection, ICSV 1007 BF, proved to be the most resistant variety throughout the *Striga* belts of all continents, and in on-farm tests in heavily infested irrigated areas of the Sudan (Nour, personal communication). In the southern African region, we have found the promising white-grained SARs 16, 19, and 33 to be resistant to species of *Striga.* Their productivity is being evaluated in variety trials in the nine countries of the SADCC.

Another local variety, IS 9830 from the Sudan, has good levels of resistance, is early, and yields well under a range of growing conditions.

Recently a derivative of Framida, SAR1, was released in India for cultivation in *Striga*-endemic areas (ICRISAT 1986).

Varietal substitution should always be accompanied by hand weeding and farm animal manure to sustain long-term productivity of the soil.

Preventing buildup of new strains of *Striga* to levels that overcome the resistance of a new variety is an absolute requirement. Breakdowns in resistance to *Striga* were reported from the Sudan (Ogbom 1984) and southern Africa (Riches et al. 1987).

Date of sowing, land preparation, supplementary hand weeding. Farmers in Africa sow their local varieties following the first heavy rain very early in the season. Early sowing on land not well-tilled, before normal rainfalls begin, exposes seedlings to drought stress. This is known to favor early emergence of *Striga* in western Africa and Ethiopia (Ramaiah 1987) and in the Sudan (Andrews 1945).

.In a delayed-sowing operation, it is advised to prepare the land with first rains and sow improved varieties. The late local varieties suffer significant yield losses if there is an early cessation of rainfall. Early varieties sown early should possess resistance to mold and grain weathering. Early varieties (such as the CK 60 B sorghum), support the emergence of many *Striga* plants, but because grain in these varieties fills and matures quite early, yields do not seem to be reduced significantly.

In the northern Guinean zone of western Africa, the rainfall is greater and the season is relatively longer; relay cropping is traditional. This system could be modified to suit our *Striga* control strategy. In northern Nigeria we have observed a relay-cropping system of three crops: photosensitive sorghum, millet, and groundnut. Millet is harvested at the end of September; sorghum not until the end of November. In September, hardly any *Striga* is seen on sorghum, but by the end of October, it is in full flower and has plenty of time to set seed before sorghum harvest in November. For this situation, we recommend sowing an early- to medium-maturing sorghum that can be harvested by mid-October. *Striga* by this time is only starting to flower, thus preventing to some extent enormous seed buildup. These early varieties have a three-fold advantage—escape damage, prevent *Striga* seed buildup, and act as catch crops. This practice has been recommended in Kenya where the sorghum cv "Dobbs" would be ready for harvest before most of the *Striga* matures.

One practical possibility is to move the photosensitive varieties (flowering in mid-September) from the Sudanian zone into the north Guinean zone, as replacements for the local photosensitive varieties that flower in mid-October. But somehow this did not happen in the traditional system, perhaps because of different local-adaptation requirements. A second possibility is to introduce improved high-yielding varieties for sowing late in the relay-cropping system.

This has produced excellent results, in terms of improved overall productivity in Mali (ICRISAT 1986). We recommend improved resistant varieties, wherever available, for relay sowing on land well-prepared and fertilized, supported by a late hand weeding.

With major adjustments in traditional systems

There are very effective Striga-control methods for farmers who can afford them—costly soil fumigations, herbicides, fertilizers, phytosanitary regulations, and antitranspirants. Some of the control strategies using these methods are listed:

Fertilizers and improved varieties, late-season hand weeding. We recommend the use of fertilizers with input-responsive resistant varieties such as Framida, ICSV 1002 BF, and SAR 19 backed with late hand weeding. In Gambia, Carson (1986) has recommended a similar package for Striga-endemic areas.

Ethylene gas, herbicides, phytosanitary regulations. This method is being successfully used to eradicate *Striga* in USA. It represents the best from each of the three major principles of *Striga* control described earlier: (1) reduction of seeds in infested soils (ethylene gas), (2) preventing new seed production (herbicides), and (3) prevention of spread of *Striga* from infested to non-infested fields (phytosanitary regulations). Each demands a lot of resources and infrastructure to make it effective. A comprehensive review of these methods was recently published by Eplee and Norris (1987b).

Recent research on *Striga* physiology has provided clues for *Striga* control through use of antitranspirants [Press et al. (In press)]. *Striga* plants were reported to have higher transpiration rates, and any action that interferes with its transpiration function restricts cooling, raises internal temperatures, and ultimately causes death of the plant. Antitranspirants are less hazardous than herbicides to humans and the environment, in general, and therefore should be an attractive alternative to herbicides.

It is our hope that extension services in Striga-affected areas will demonstrate these control methods, explaining their potential so that farmers become motivated to use them.

Research Needs

The foregoing shows that *Striga* is not a new problem on cereals and legumes in Africa; some early work was done and much is now being done to understand *Striga* and its control. However, new *Striga* problems are being found, and they need to be researched.

We recognize three levels of research leading to understanding and control of *Striga:* (1) adaptive, (2) applied, and (3) basic. Adaptive research includes verification of research recommendations through on-farm testing. These recommendations, resulting from applied research are practices that will be suggested to, and hopefully adopted, by farmers. Applied research consists of experiments to determine how the knowledge gained in basic research can be used in practical ways to help solve the *Striga* problem — in other words, to become useful in devising a new control practice. Basic research seeks new knowledge of the *Striga* plant and its hosts. Conducting research into more biological aspects using the latest research techniques are employed. In our view the research needs are as follows.

Host resistance

Adaptive research. (1) Demonstration of host resistance in sorghum to farmers and extension agents through multilocational on-farm testing.

Applied research. (1) Breeding stable high-yielding acceptable (to farmers) resistant varieties of sorghum and millet; (2) screening of wild relatives of pearl millet to find resistance; (3) development of reliable infestation and screening techniques; (4) physiological variability in relation to stability of host resistance; (5) field designs and appropriate statistical analyses.

Basic research. (1) Understanding *Striga* resistance mechanisms active in sorghum and millets; (2) inducting resistance by changing host physiology, increasing lignification in root tissue, root exudation, defense chemicals, seed hardening, etc.; (3) rapid screening techniques, based on "chemical markers" produced in *Striga-infected* plants; (4) application of molecular genetics to isolate resistance genes useful as probes to screen germplasm and varieties.

Agronomic practices

Adaptive research. (1) Demonstrate value of late hand weeding; (2) demonstrate value of fertilizers, wherever available, particularly with maize; (3) demonstrate value of rotating modified mixed and host and nonhost crops.

Applied research. (1) Field experiments to determine optimal crop densities, dates of sowing, etc.; (2) identification of suitable trap crops for different *Striga* species; (3) study *Striga* chasers like coriander, etc.; (4) determine seasonal emergence patterns.

Basic research. (1) *Striga* seed behavior under different conditions in the soil; (2) determine factors such as soil, host, parasite, and climate that dictate narrow and broad spectrum adaptation of *Striga;* (3) develop growth models, etc.

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Chemicals

Adaptive research. (1) Demonstrate value of 2, 4-D in sole crops; (2) demonstrate other herbicides in crop mixtures.

Applied research. (1) Conduct trials with antitranspirants and systemic herbicides.

Basic research. (1) Synthesis of stable stimulants based on strigol, ethylene, or other compounds; (2) study combinations of stimulant and herbicide compounds.

Biological control

Applied research. (1) Controlled exchanges of insects between India and Africa; (2) survey of oxganisms parasitic or pathologic on *Striga;* (3) use of the gall-forming weevil *Smicronyx urnbrinus* in reducing *Striga* seed production.

Basic research. (1) Develop bioherbicides based on biological "enemies" of *Striga;* (2) study taxonomy of African *Smicronyx* spp; (3) study diseases and other pests of *Striga.*

Crop specificity

Adaptive research. (1) Crop substitution (millet in sorghum zones and sorghum in millet zones); (2) crop rotations using nonhost (trap) crops; (3) study socioeconomic implications of these in the respective ecologies.

Basic research. (1) Determine basis for immunity in nonhost (trap) crops.

Taxonomy

Applied research. (1) Sympatric existence of *Striga* species and its implications; (2) clarification of relationships among closely linked species.

Basic research. (1) Genetic diversity and genetic interchanges among and within the *Striga* species by inter- and intra-specific hybridization, chromosome studies, and seed morphology, floral morphology, and breeding systems.

Biology

Applied research (1) Field experimentation with antitranspirants.

Basic research (1) Relationship between *Striga* seed germination and host crop phenological development; (2) photosynthesis; (3) transpiration; (4) water relationships; (5) chemical compounds produced by the host that initiate parasitic shoot growth; (6) Striga-specific herbicides; (7) toxins of *Striga,* and antitoxins of host plants.

Outlook

Striga research in Africa is inadequate, and the volume of work required for rapid progress in *Striga* research is almost certainly beyond present resources. Even so, increased effort is essential if the *Striga* problem is to be managed.

Considerable manpower will be required to intensify work on the series of research and extension needs identified here. Intensive training of national research and extension staff, especially those in endemic areas for *Striga* is essential; involvement with international scientists in this effort for regional cooperation would be required.

Practical research results should be made available to the farmers as soon as practical through pilot projects demonstrating the value of simple recommended cultural practices.

There is need for continued cooperation and collaboration among all groups working on the *Striga* problem in Africa and elsewhere; these include IARCs (International Agricultural Research Centers), NARSs (National Agricultural Research Systems), funding agencies, and coordinating organizations.

A continental-action program in the form of a "*Striga* Research and Control Network" with strong regional components and strong national commitments to research, training, and extension would be of genuine value, with payoff at the farmer level.

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