Striga

Proceedings of the Second International Workshop

International Crops Research Institute for the Semi-Arid Tropics

Proceedings of the

Second International Workshop on *Striga*

Ouagadougou, Upper Volta
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Remerciements

Les organisateurs expriment leur reconnaissance au Centre de recherches pour le développement international dont le soutien financier a permis l'organisation de cet atelier international sur le *Striga* et la publication de ce volume, ainsi qu'au Ministère des Affaires extérieures et au Ministère de l'Enseignement supérieur et de la Recherche scientifique de la Haute-Volta qui ont autorisé la tenue du colloque.

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Contents

Foreword

More than 1800 phanerogamic parasites have been recorded throughout the world. Among the most important are the parasitic figworts or Scrophulariaceae, which are economically damaging root parasites. The genus *Striga,* with more than 50 species, belongs to this family; however, only a few are completely parasitic and damaging to their hosts. Undoubtedly, the major species are S. *hermonthica—a* widespread and important pest of cereals in Africa—and S, *asiatica,* an important pest both in Asia and in eastern and southern Africa.

Although precise estimates of crop loss are difficult to make and data are incomplete, it is well known that severe losses, amounting in many seasons to total crop failure, are caused by these parasitic weeds. However, there is still a general lack of awareness of the magnitude and importance of the problem. These Proceedings bring together the results of discussions held at Ouagadougou, Upper Volta, in October 1981, where the latest research findings and proposals for further research were presented. They highlight the important advances made in knowledge of the pest species, methods of control, and techniques for breeding for resistance to these noxious weeds. It is hoped that this publication will prompt increased effort to be focused on methods of combating *Striga* and reducing the serious losses it causes to cereal production, and on strengthening links between scientists working in numerous programs to produce solutions to outstanding research problems.

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Opening Session

Chairman: K.V. Ramaiah **Rapporteur: Z.G. Roger**

Introduction

D. J. Andrews*

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has a mandate for improving and stabilizing the grain yields of sorghum, millet, pigeonpea, chickpea, and groundnut in the semi-arid tropical (SAT) regions of the world. Considerable progress has been made at ICRISAT Center in developing high-yielding cultivars of these crops, particularly sorghum and millet. Unfortunately, their introduction into the Sahelian countries is limited by problems that are specific to the region. Stabilization of grain yields in this region may be achieved by building up resistance to various yield reducers, such as drought, insect pests, diseases, and the root parasites, *Striga* spp.

Striga is a serious problem of the African continent, although it exists in a less severe form in southeast Asia and the United States of America. ICRISAT recognized this problem in 1974, soon after the establishment of the Institute in 1972 in India, and started work on developing resistant cultivars of sorghum. The results of international Striga-resistant sorghum trials conducted in Africa in 1977 indicated large differences in virulence between Indian *Striga* (*Striga asiatica)* and African *Striga* (*S. hermonthica*). It was also realized that development of cultivars resistant to S. *hermonthica* cannot be accomplished by working in India. Strict quarantine regulations on the movement of *Striga* from one place to another compel research in the area where the problem exists. Because of the severity of the *Striga* problem in Africa, ICRISAT decided to shift the main work to the African continent.

Thanks to the timely financial support from the International Development Research Centre (IDRC) and to the ready agreement of the Government of Upper Volta to the proposal, we began our *Striga* work at Kamboinse Agricultural Experimental Station in 1979.

This program in Upper Volta was for 3 years, to the end of 1981. During this phase, attempts were made to understand the problem and to explore various possibilities of controlling the parasite, with the major emphasis on developing host-plant resistance.

This workshop during the final year of the project provided a timely opportunity to review our work with *Striga* specialists from other parts of the world to determine what should be done in the future. Research efforts should be oriented to finding simpler, cheaper, and easier solutions that are sociologically acceptable to subsistence farmers in Africa.

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Objectives of the Workshop

K.V. Ramaiah*

The first International *Striga* and *Orobanche* Workshop was held in Khartoum, Sudan, in 1978. The present workshop is limited to *Striga* only, to allow for more discussion. During the last 3 years considerable interest has been created in the *Striga* problem, and several national and international institutions have started working on it. As a result, many data, both basic and applied, have accumulated. There are also several basic problems that are not clearly understood and need further research. This workshop is aimed at bringing together for detailed discussions researchers from the African countries where the problem exists and those from the developed nations and international organizations where research is being carried out. We hope this exchange will lead to some conclusions for *Striga* control in Africa. Other objectives of the workshop are:

1. To discuss the severity of the *Striga* problem.
2. To review the variability that exists in *Striga* species and the implications for developing appropriate control strategies.
3. To understand the geographical distribution of *Striga,* the basis for location-specific adaptation of different strains, and implications for determining breeding territories.
4. To discuss the possibilities of basic investigations on mechanisms of resistance; i.e., factors that influence *Striga* seed germination, etc., which may lead to new control strategies.
5. To consider resistant cultivars and the problems involved in developing new stable resistant cultivars in particular. This discussion should include laboratory and field-screening techniques, selection criteria, and breeding strategies.
6. To discuss the scope of agronomic research in *Striga* control, including effects of soils and rainfall; cropping systems to alleviate *Striga* damage; and effects of fertilizers, *Striga* seed germinators, herbicides, etc.,
7. To determine priorities in future *Striga* research.

Unfortunately, only a few scientists are working on this problem compared with its magnitude. The problem is very complex and needs a multidisciplinary approach to find solutions. I am glad we have at this workshop plant breeders, agronomists, botanists, and physiologists, and I hope that by the end of the workshop we will arrive at some guidelines for immediate *Striga* control and for future research efforts.

*ICRISAT/UNDP, Ouagadougou, Upper Volta.

Discours d'ouverture

Djigma Albert*

Permettez-moi tout d'abord, de souhaiter au nom de Monsieur le Ministre de l'Enseignement supérieur et de la Recherche scientifique, la bienvenue en Haute-Volta, aux chercheurs venus d'Afrique et d'autres continents pour participer à l'atelier international sur le *Striga*.

En Haute-Volta, le *Striga* est assez bien connu et pose de graves problèmes dans les cultures de sorgho, de mil, de maïs et de niébé. C'est donc toute la gamme de nos cultures vivrières pluviales qui est concernée par cette plante parasite. Les pertes de rendement peuvent atteindre 100% dans certains champs. Le parasite est observé sur toute l'étendue du pays.

C'est pourquoi nous nous réjouissons de savoir que depuis quelques années, il s'est développé à travers le monde un intérêt pour cette plante parasite. Plus particulièrement en Haute-Volta, les chercheurs de l'ICRISAT à Kamboinsé ont lancé un programme visant à développer les moyens de lutte permettant de réduire l'incidence du *Striga* sur le sorgho et le mil.

Les recherches menées par des scientifiques à travers le monde ont abouti à une accumulation considérable de données tant fondamentales qu'appliquées, qui méritent d'être soigneusement examinées et discutées. C'est pourquoi cet atelier, deuxième après celui tenu à Khartoum en 1978 qui marqua en quelque sorte le démarrage des actions concertées, constitue une étape très importante.

Vos travaux vous permettront de réaliser un premier bilan, de proposer des solutions économiquement et sociologiquement acceptables et d'orienter les programmes futurs.

Je voudrais, au nom des autorités voltaïques, remercier l'ICRISAT et le CRDI pour l'organisation de cet atelier.

Je voudrais aussi vous assurer que nous serons très attentifs aux résultats du présent atelier, résultats que nous espérons les meilleurs possibles.

Messieurs, je souhaite plein succès à vos travaux et déclare ouvert le deuxième atelier international sur le *Striga*.

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Welcome

Djigma Albert*

Please let me welcome, on behalf of the Minister of Higher Education and Scientific Research, all the scientists coming from different countries of Africa and other continents to participate in this very important Second International *Striga* Workshop being held here in Ouagadougou.

In Upper Volta *Striga* is observed in all the ecological zones and is known to pose serious problems to sorghum, millet, maize, and cowpea cultivation, thus limiting grain yields of all the important food crops in the country. In extreme cases, the yield losses can be 100%.

We are very happy to see that an interest is developing throughout the world in control measures for this parasite. More particularly, in Upper Volta, the scientists of ICRISAT started a program to develop means of reducing the incidence of *Striga* on sorghum and millet.

The research conducted so far on *Striga* worldwide has resulted in an accumulation of data, both basic and applied, which need careful and detailed discussion. The first workshop on *Striga* was held in Khartoum in 1978, and this Second International *Striga* Workshop now is very timely.

Your work will permit us to draw certain conclusions on the control of *Striga* in future.

I would like, on behalf of the Voltaic authorities, to thank ICRISAT and IDRC for sponsoring this workshop. I would also assure you that we will try to make use of recommendations or suggestions that emerge from this workshop.

Ladies and gentlemen, I wish you full success in your work and declare open the Second International Workshop on *Striga.*

Session 1

Setting the Scene

Chairman: L.J. Musseiman **Rapporteur: W.R. Root**

Striga—Analysis of Past Research and Summary of the Problem

C. Parker*

Abstract

The history of research on Striga *spp is surveyed from 1900 to date. The value of rotations, trap cropping, fertilizers, and resistant varieties was recognized quite early during this period. Though recent research has shown further possibilities for control of the parasite by herbicides and artificial stimulation of germination, no method is yet fully effective and suitable for the majority of small farmers. Further research needs are discussed, and the need for more data on crop loss as a means of quantifying the problem is emphasized in relation to funding needs.*

Résumé

Striga-*Analyse des recherches faites antérieurement et sommaire du problème : L'histoire de la recherche sur les* Striga *spp est tracée depuis 1900 jusqu'à nos jours. Très tôt, on a reconnu la valeur des rotations, des cultures pièges, des engrais et des variétés résistantes. Bien qu'elles offrent de nouvelles possibilités de lutter contre ce parasite, les découvertes récentes, à savoir l'emploi des herbicides et la stimulation artificielle de la germination, n'ont pas abouti à des méthodes efficaces qui conviendront aux petits agriculteurs. D'autres recherches à entreprendre sont définies, en soulignant le besoin de données plus amples sur les pertes de rendement permettant une quantification nécessaire à la détermination des besoins financiers.*

Survey of Past Research

Thanks to the useful publication commissioned by the United States Department of Agriculture (USDA 1957), which summarized literature on *Striga* up to 1956 in faithful detail, it is possible to follow the history of research on this problem at least from the beginning of the 20th century.

The Earliest Research

Striga spp were already clearly recognized as parasitic weed problems before 1910 in both India (Barber 1904) and South Africa (Burtt-Davy 1905). Experimental work on control methods began about the same time, and a series of experiments in Burma between 1913 and 1920 was reported by Sawyer (1925). This work revealed yield losses of 4 to 46% in sorghum (*Sorghum bicolor* [L.] Moench) from *Striga asiatica* (L.) Kuntze and demonstrated the benefits of close row spacing, good cultural practices, fertilizer use, burning of stubble, and crop rotation. The work was discontinued when it was realized that no more direct methods of control were feasible (common salt, sodium nitrate, etc., had been tried for direct chemical control but had failed).

In South Africa, similar studies on *S. asiatica were* conducted, and similar conclusions arrived at on the value of rotation, catch cropping with sorghum,

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and fertilizer, particularly nitrate (Pearson 1911, 1912,1913).

South Africa

In South Africa, the 1920s saw the start of Saunders's classical studies on *S. asiatica,* culminating in his excellent thesis (Saunders 1933), which clarified the biology of the parasite, explored the use of trap and catch crops, and made the first attempts at selecting resistant sorghum varieties. This last work led to the eventual release of several resistant varieties (Saunders 1942). The main one, cv Radar, unfortunately failed to maintain its resistance, apparently due to outcrossing and loss of purity (Grobbelaar1952).

Meanwhile, work in Rhodesia concentrated on the *concept* of catch *cropping* with sudangrass (*Sorghum sudanense* [Piper] Stapf) grown twice in a season, 6-8 weeks each time, then plowed in as a green manure. That was thought to reduce the problem 75% (Timson 1931). Timson also tested the range of inorganic herbicides available at that time and found that 1.5% sodium chlorate as a directed spray in maize gave selective kill of *S. asiatica* (Timson 1934).

India

Research on *Striga* in India apparently did not get under way until the 1930s, when studies on the germination of *S. asiatica* (Kumar 1935) were done and selection of resistant sorghum varieties (Kumar 1940,1952; Jenkins 1945) was initiated.

The selection of resistant sorghum varieties was then taken up by Rao at Coimbatore, starting with the same resistant material used by Kumar, namely, Bilichigan from Burma and Boganhilo from Africa, but incorporating their resistance into improved varieties by crossing with CO-1, AS-60, N-1, and T-6 (Rao 1948, 1951).

Uttaman (1950), working in Madras, was the first to study in detail *S. asiatica* in rainfed rice (*Oryza sativa* L.). He demonstrated an apparent toxic effect of *Striga* on rice and proposed various cultural methods of control. He did not find useful differences among rice varieties.

Other useful studies in India during this period included the determination of chromosome numbers of the four main Indian species of *Striga*—*S. asiatica, S. densiflora* Benth., *S. euphrasioides* Benth. (= *S. angustifolia* [Don] Saldanha), and *S. gesnerioides* (Willd.) Vatke—all of which were2n = 40 (Kumar and Abraham 1941). Also, while the germination of both *S. asiatica* andS. *densiflora* was confirmed to depend on host-root exudates and tended to be depressed by light, that of *S. euphrasioides* did not require exudate but did require light, suggesting facultative rather than obligate parasite behavior (Kumar and Solomon 1940). Solomon (1952) later showed in sand culture experiments that both *S. asiatica* and *S. densiflora* flourished best and caused greatest damage at low levels of nutrient.

East Africa

S. hermonthica (Del.) Benth. was relatively neglected until the 1930s, when Watt (1936) published recommendations for its control in Kenya by various *cultural* methods such as *rotation, manuring,* and the use of early sorghum varieties, including Dobbs, which could be harvested before most of the *Striga* matured. It was made compulsory for *Striga* to be pulled, and as it became habitual for farmers to make it obvious that they were obeying the regulations, it is still customary to spread flowering *Striga* on the road before officials or other important visitors arrive. Detailed biological studies of *S. hermonthica* were first made by Andrews (1945), in Sudan, who made useful observations on the ability of different crops to act as trap crops. He also pointed out the large proportion of *Striga* plants that do not emerge from the soil in dense infestations.

Doggett, continuing work in East Africa, showed the particular advantage of the variety Dobbs, with its partial resistance and apparently greater tolerance than other varieties to *Striga* attack (Doggett 1954a, 1954b, 1965). He summarized valuable observations on the difficulty of interpreting the magnitude of *Striga* populations from the numbers emerged (Doggett 1965). He also was able, to deduce that each 1000 emerged *Striga* plants/ha caused a grain yield loss of 2 to 3 kg and he showed that although trap cropping could be worthwhile, it took many years to reduce dense infestations.

Andrews's work in Sudan was followed by Wilson Jones, one of the first to demonstrate the value of 2,4-D and MCPA, not only for selective kill of emerged *S. hermonthica,* but also as a treatment a few weeks after sowing to prevent, or at least reduce, germination and attachment of the parasite (Wilson Jones 1953,1956). He was also the first to draw attention to the existence of physiological strains of *S. hermonthica* with different abilities to attack sorghum and millet (Wilson Jones 1955).

West Africa

Work on *S. hermonthica* in West Africa was strengthened when Okonkwo (1964) studied the physiology of the parasite and showed that after the very early stages of germination and plumule development, only sugars and mineral nutrients were required for development up to flowering. Later in the 1960s and 1970s, a considerable research effort on *Striga* was based at the Institute of Agricultural Research, Samaru, Nigeria, with two main approaches. One approach was to screen the then world collection of sorghum varieties for resistance to *S. hermonthica;* initially this work was done by S.B. King, and later by N. Zummo and El Rouby (largely unpublished but usefully summarized by Obilana at this workshop). This screening led to the selection of the low-stimulant variety SRN-4841 (closely related to Framida), which is still one of the most reliably resistant varieties in Africa. The other approach was to work with agronomic techniques, and particularly with the herbicides suitable for spot spraying in both sole and mixed sorghum crops (Ogborn 1972).

England

In England there were prolonged attempts to isolate and identify the stimulant substances responsible for germination of *S. asiatica.* Much was learned of the factors influencing germination, but no positive identification of the stimulant was achieved (Brown and Edwards 1944,1946; Brown et al. 1949,1952). Later, detailed studies were made on the germination behavior of *S. hermonthica* (Vallance 1950, 1951 a, 1951 b), which revealed that prolonged preconditioning could lead to "wet dormancy."

United States of America

The discovery of *S. asiatica* in the USA in the early 1950s stimulated an unprecedented volume of research on the problem. Previous studies on trap cropping, fertilizers, etc., as well as biological studies on germination, were confirmed and reinforced in the early years, but the more important advances included: (1) development of a herbicide to control the weed not only in maize but also in other crops, where it otherwise grew on wild grasses, especially *Digitaria sanguinalis* (L.) Scop. (Eplee 1973); (2) isolation and eventual identification of at least one of the natural stimulant substances, strigol (Cook et al. 1972); and (3) the discovery that ethylene could stimulate *Striga* seed germination (Egley and Dale 1969).

More recently, there have been further valuable contributions from the USA in techniques of field study of *Striga,* allowing for exposure of retrievable bags of *Striga* seed to different conditions and treatments in the field, and for the separation of natural *Striga* seed from soil. The techniques have yet to be adequately exploited in the study of the natural behavior of *S. hermonthica* in Africa. A further discovery of probably more than academic importance is that *S. asiatica* seeds exposed to either natural or artificial stimulant (GR7) during the preconditioning period fail to germinate so readily as seeds preconditioned in water (Hsiao et al. 1979; Pavlista et al. 1979).

Current Programs

Centers of *Striga* research in the past 20 years, other than the USA, have included the UK, South Africa, India, Upper Volta, and Sudan. The work in the UK has been mainly at the Weed Research Organization (WRO), Oxford, where the possibilities of selective control of *S. hermonthica* by herbicides have been explored but without real success (Parker 1974). Observations on host-parasite relations have included the interesting discovery of a pronounced influence of *Striga* on the root:shoot ratio of the host, the roots being significantly stimulated in infested hosts, while shoots are inhibited (not fully published, but see Parker 1976). These observations led to a detailed study at Reading University on the influence of *S. hermonthica* on the natural growth substances in xylem exudates of sorghum (Drennan and El-Hiweris 1979). Cytokin--s and gibberellins were drastically reduced, and inhibitors increased in infected plants, providing ready explanation of the damaging effect, though not explaining exactly how *Striga* causes the changes. Another study in the UK was that by Teferedegn (1973), who showed that at least one of the effects of nitrogen was to decrease stimulant exudation from the host.

Other studies at WRO have helped define optimum preconditioning for different *Striga* species (Reid and Parker 1979) and have shown that the specificity of strains of *S. hermonthica* to millet and sorghum is based on different stimulant requirements (Parker and Reid 1979). Incidentally, this also demonstrated that the best trap crops for the millet strain are quite different from those for the more widespread sorghum strains. WRO was also involved in the testing of synthetic analogues of strigol, a project sponsored by the International Development Research Centre (IDRC) and carried out at the University of Sussex. This project led to the discovery of a number of compounds with very high activity as germination stimulants but considerably cheaper to synthesize than strigol (Johnson et al. 1976). There has been further work with these compounds (especially GR7 and GR24) in Nigeria, Sudan, India, and the USA, but their commercial development is still in some doubt.

In South Africa, Visser and Botha (1974) showed that the stimulant substances in crop root exudates could be readily separated by high pressure liquid chromatography (HPLC) and that each crop demonstrated at least three "peaks," as shown by a *Striga* germination assay. This illustrates that many stimulant substances are involved, and a great deal more work is needed to identify them or at least characterize the sensitivity of different *Striga* species and strains to each stimulant substance.

The most intensive *Striga* research effort outside the USA has been the ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) program, devoted mainly to the development of *Striga*-resistant varieties of sorghum and, to a lesser extent, millet. The work was based initially at ICRISAT headquarters at Patancheru, A.P., India, and in the early stages took the form of a systematic screening of the world sorghum collection for ability to stimulate the local Indian S. *asiatica* strain (ICRISAT 1977). Selections from this screening have been field-tested in India and in Africa and are now being used in breeding programs in both continents. Meanwhile, the main effort has been moved to Ouagadougou, Upper Volta, so that work can be concentrated more on the African S. *hermonthica.* Up-to-date reports on this program are presented at this workshop (Ramaiah, these Proceedings; Vasudeva Rao et al., these Proceedings).

A crucial question in relation to resistance breeding is that of different strains of the parasite; these have to be identified in order to determine the cause or failure of resistance in particular localities. The ICRISAT program has involved multilocation testing, which has sometimes indicated differential behavior of varieties at different sites, but whether this is due to the behavior of the local *Striga* strain, or a more complex interaction with the site, is not yet clear.

From the beginning of the ICRISAT work, WRO also has been involved in developing techniques (Parker et al. 1977) to determine the significance of any strain differences, especially within S. *hermonthica* (Parker and Reid 1980) and, most recently, in trying to understand the resistance mechanisms in stimulant-positive varieties such as N-13.

Apart from the work at ICRISAT, there have been continued studies in India by other bodies, including independent efforts to develop resistant sorghum varieties (Kumaraswamy et al. 1979), and some intriguing observations that *Striga* resistance might be increased by suitable "seed-hardening" treatment with phenolic substances (Bharathalakshmi and Jayachandra 1980) have been reported.

In Sudan an active research program sponsored by the IDRC is still in progress, involving agronomic studies (Bebawi 1981; Bebawi and Farah 1981) and the strigol analogues GR7 and GR24 (A.G.T. Babiker, personal communication).

Limitations of Available Control Methods

The above survey of *Striga* research over the past 80 years perhaps emphasizes the extreme complexity of the problem. Dedicated efforts and considerable resources have been devoted to it, yet the problem today remains virtually as serious and insoluble as ever. It may be useful to consider the main control methods that have been researched, the reasons they do not provide adequate answers, and the future research and development that is needed for further progress.

Resistant Varieties

These should provide the simplest solution for the typical small farmer but they take many years to develop and need to be well adapted to each locality. We have seen that varieties have been developed at various times and in various localities in Africa and India, yet they have not had a long-term impact on the problem. In South Africa we know that cv Radar lost its resistance. What happened to the other promising varieties? Did they also lose resistance or were they not popular for other reasons?

There is the possibility of a good resistant variety losing its resistance with the buildup of a more virulent *Striga* population, and research could be done on that, but so long as resources are limited, effort is probably more usefully devoted to breeding work. Breeding is a slow process, and very few good sources have yet been identified. Screening methods are also imperfect and can only be improved by better understanding of resistance mechanisms and factors influencing resistance.

Cultural Methods

Rotation, trap cropping, catch cropping, hand-pulling, and hygienic procedures of various sorts all have been shown to help, but the choice of crops available is often too limited, or the cropping season too short, or labor unavailable or unwilling for hand-pulling work. The benefits are gradual and cumulative, and effort has to be sustained over several years. Technically, there is still inadequate understanding of the behavior of trap crops and the response of *Striga.* Only with much better monitoring of *Striga* seed population in the soil over a period of years can the best regime be defined, and then it has to be effectively demonstrated to farmers before they can be expected to respond.

Artificial Stimulation of Germination

Though the expense of any chemical is likely to be beyond most farmers, artificial stimulation of germination (by ethylene or strigol analogues) remains one of the most direct control measures available. With a government subsidy or contract it should be possible to use chemical stimulation methods in many areas. The expense and difficulty of ethylene application has seriously delayed even its experimental use in Africa and its use is likely to be complicated by "wet dormancy" or other factors influencing the responsiveness of *Striga* seed in the soil. The strigol analogues could be simpler to apply, but are likely to be expensive, and their full development is still in doubt.

Herbicides

In general it has proved difficult to find good selective prevention of *Striga* attack at whatever expense, and the likelihood of herbicides providing fully effective control is small. Use of 2,4-D and other compounds could, however, be part of an integrated program on larger farms.

Nitrogen

High and expensive nitrogen rates are needed for really good suppression of *Striga,* and although lower rates are almost certainly beneficial under the right conditions, nitrogenous fertilizers are often not available, or conditions do not allow their uptake by the crop, and hence their beneficial effect is not realized. More work is needed on the exact mechanism by which nitrogen works, and on the optimum timing and form of application, so that effectiveness can be achieved reliably at minimum expense. The role of nitrogen-fixing legumes as companion crops also deserves more study.

Biological Control

No true research has been conducted as yet on biological control of *Striga.* Surveys (Greathead and Milner 1971) and observations have suggested some possibilities, but there has been no real effort to exploit them. More effort is certainly justified to clarify the possibilities, since "natural" control is already being achieved by *Smicronyx* sp and other insects in parts of West Africa. Studies on the pollination biology of S. *hermonthica* also could be relevant in this context.

The Future

So, finally, the problem remains, and the work needed for further progress is almost certainly beyond the resources available. More manpower is needed to intensify the selection and breeding effort; to study the way *Striga* seed behaves in the soil, especially in West Africa; to define the best agronomic and cultural practices for different cropping zones; to explore the potential of ethylene in Africa; to improve our understanding of the effect of nitrogen; and to explore the potential for biological control of *Striga.*

The scale of the problem certainly deserves increased research effort, but what is the exact scale? Can we say how much yield is being lost? In the past, any efforts at estimating yield losses depended on indirect statistical procedures and the results have not been dramatically convincing. With ethylene and/or methyl bromide, we could now make more direct determinations of yield loss, and it may be necessary to divert some of our current research efforts to collecting this information as a means of convincing funding agencies of the importance of the problem.

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Discussion

Lanting:
Is ferulic acid a toxic substance for human beings?

Parker:
It is present in most plant tissue, sometimes at quite high levels, and I am almost certain there would be no toxicological hazard from its use as a seed treatment.

Perey:
Can you describe in more detail the technique of imbibition and eventual hardening of sorghum?

Parker:
Seeds are soaked in solution of ferulic or other phenolic acids at 25 ppm for 4 hr, then dried. This procedure is repeated three to four times on successive days, then the seed is planted.

Session 2

Taxonomy and Morphology

Chairman: C. Parker Rapporteur: P.C. Matteson

Biosystematic Research in the Genus *Striga* (Scrophulariaceae)

Lytton J. Musselman and C. Parker*

Abstract

The genus Striga *consists of about 25 species of root parasitic herbs, reaching its greatest diversity and causing greatest yield losses in the semi-arid tropics. Greenhouse studies indicate that two distinct reproductive strategies may be operating in the genus.* Striga hermonthica *appears to be an outcrosser, as crosses between plants of the same population produce no seed, while S.* gesnerioides *and S.* asiatica *are self-fertile and always set seed even if flowers are bagged. Field studies on S.* hermonthica *are scanty, but suggest involvement of insect vectors for seed set. Studies on the variation within the three species and the development of distinct strains* (*morphotypes*) *in S.* asiatica *and S.* gesnerioides *revealed that the last species exhibited remarkable host specificity. Funher work is needed to elucidate the relationships within the S.* hermonthica *"complex"* (*S.* aspera, *S.* brachycalyx, *S.* passargei). *Taxonomic characters, both classical and ultrastructural, are evaluated.*

Résumé

Recherche biosystématique sur le genre Striga *(Scrophulariaceae) : Le genre* Striga *comprend environ 25 espèces d'herbes parasites des racines, dont on trouve la plus grande diversité et qui provoque les plus importantes pertes de rendement dans les zones tropicales semi-arides. Les études en serre indiquent que deux stratégies de reproduction distinctes peuvent s'opérer sur ce genre. Le* Striga hermonthica *est issu d'une pollinisation croisée étant donné que les croisements entre plantes de la même population ne produisent pas de graines, alors que le* S. gesnerioides *et le* S. asiatica *s'autofécondent et donnent des graines même lorsque les fleurs sont ensachées. En ce qui concerne le* S. hermonthica, *bien que les études sur le terrain manquent, on pense que des insectes vecteurs sont nécessaires à la formation des graines. D'autres recherches étudient la variation entre les trois espèces et le développement de souches distinctes (morphotypes) du* S. asiatica *et du* S. gesnerioides, *ces espèces présentant une spécificité d'hôte remarquable. Un travail plus poussé est nécessaire pour élucider les rapports qui existent à l'intérieur du "complexe" du* S. hermonthica (S. aspera, S. brachycalyx, S. passargei). *Les caractères taxonomiques aussi bien classiques qu'ultratructuraux sont évalués.*

Striga is a paleotropical genus of root parasites that reaches its greatest development in the grasslands of Africa, where three species may be very serious yield reducers of subsistence grains and legumes: *Striga hermonthica* (Del.) Benth., *S. asiatica* (L) Kuntze, and *S. gesnerioides* (Willd.) Vatke. Several other less important species occur in the Sahel region, including *S. macrantha* Benth., *S. passargei* Engl., *S. brachycalyx* Skan., and *S. aspera* (Willd.)

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Benth. The last two are sometimes implicated in yield reduction.

Hepper (1963) has given useful descriptions for identifying *Striga* species found in Africa. Characters of diagnostic value in separating species include number of ribs in the calyx, indumentum, relative sizes of calyx and of corolla tubes, size of the bract subtending each flower, and flower color. As in several other genera of parasitic angiosperms that exhibit reduction of vegetative parts, floral characters are the main basis of taxonomic differences in *Striga.* Yet certain species are often confused in the field, e.g., S. *aspera* and S. *hermonthica.* Despite its agronomic importance, very little descriptive information is available for the genus, especially for those species that are not serious pathogens.

Likewise, little is known about patterns of genetic interchange in *Striga* species. An understanding of the relationship of its floral biology to breeding and genetic systems is important when considering the actual and potential adaptability of the parasite to new hosts. Much work remains to be done along this line, and this area of research deserves the attention of workers, particularly in the developing countries.

This paper briefly reviews our observations on the biosystematics of *Striga* species, especially, S. *asiatica, S. hermonthica,* and S. *gesnerioides,* including field and greenhouse work on morphology, ultrastructure, floral ecology, and breeding patterns. Much of the information presented here is based on our work that has been recently published or is in press (Nickrent and Musselman 1979; Musselman et al. 1979; Musselman 1980; Musselman and Parker 1981 a, 1981 b; Musselman et al. 1981).

Materials and Methods

All species of *Striga* used in this study are under a federal noxious weed quarantine, making it illegal to transport and grow these species in the USA. Therefore, all plants were grown at the Weed Research Organization, Oxford, UK, where long-range studies on the biology and control of *Striga are* being conducted. *Striga* grows best in a low-nitrogen soil, so it was necessary to prepare a special soil, using for each 45.36 kg (100 lbs) of soil, 120 g superphosphate, 60 g potash, 18 g sulfate of ammonia, 9 g fritted trace elements, 40 g DDT, and 85 g magnesium sulfate.

Seed was sown in the following manner: 5-inch (12 cm) plastic pots were half filled with soil. *Striga* seeds were mixed with soil by adding approximately 1000 seeds to the soil in a plastic bag, mixing thoroughly, and then filling each pot. Host seeds were then put into the pots, which were maintained in greenhouses at a daytime temperature not exceeding 30°C.

Striga species are protandrous, so pollen was collected by excising the anthers from unopened flowers and then releasing pollen onto a clean glass slide. This pollen was then applied to flowers of various ages. As a test for possible parthenocarpy, the stamens and stigma of several flowers of each species were removed in the bud stage. No seed developed in such flowers.

At the conclusion of experiments, pots were disassembled and herbarium vouchers prepared. Vouchers are deposited in the herbarium of Old Dominion University (ODU); the British Museum, Natural History (BM); and the Tropical Weeds Herbarium, Weed Research Organization (WRO).

A cross was considered successful if the ovary swelled noticeably more than the controls. In most cases, of course, seed production was the measure of a successful cross.

The observations reported here are based on our field work during the past 5 years.

Striga asiatica

This is the most widespread of all *Striga* species, distributed from southern Africa (with reports of its presence in West Africa) across the Arabian peninsula, Indian subcontinent, Indonesia, and the Philippines. Several species occur in Australia but their taxonomic position is not clear and they also may be segregates of S. *asiatica.* The species is quite variable; populations in West and southern Africa have red corollas with a very small percentage of yellow corollas. Most of the corollas of S. *asiatica* on the Indian subcontinent are white; those in Indonesia are yellow or, in some extreme forms, very small and pink or purple.

Autogamy

The populations we have examined are autogamous. The following is a description of self-pollination in the U.S. strain of S. *asiatica,* based on Nickrent and Musselman (1979). For the sake of this discussion several stages in flower maturation can be distinguished. The first is an immature calyx totally enclosing the corolla. In the axil below, the corolla just protrudes from the calyx. The style has not yet begun its rapid elongation and its size matches that of the corolla tube. At the next stage the corolla elongates to about 1 cm. A dissection of the flower at this stage shows that the stigma (with its glandular upper end) is distal to the two anterior stamens. On dehiscence of the anthers, pollen is deposited en masse onto the retrose hairs that line the corolla throat. This "pouch" region, where pollination occurs, can easily be recognized macroscopically. Further growth of the style outstrips that of the corolla, pushing trhe stigmatic surface upward through the pollen mass. As this growth continues, the corolla lobes begin to open and the two anterior anthers dehisce, depositing more pollen into the hair-lined pouch. The opening of the corolla throat is less than 3 mm wide and occluded by numerous hairs. Pollen from both anthers germinates quickly and masses of pollen tubes advance through the style and enter ovules.

Striga gesnerioides

This species has developed specialized strains that are host-specific. Some are discussed in Musselman and Parker (1981 a). *Striga gesnerioides* is also a strongly autogamous species with very sticky pollen that coheres as a single lump in the corolla. The corolla tube is lined with upward-pointing hairs similar in structure to those described for S. *asiatica.* These hairs serve to position the pollen mass in the tube so that it is picked up by the elongating style and caught in the forked stigma. The pollen mass is so sticky and gum-like that it is retained on the style even in the developing fruit.

Crosses

Five host-specific strains of S. *gesnerioides* were grown and crosses were made between several of them. The results indicate interfertility between strains (Table 1). However, fertility appears to be lower than that in flowers of S. *gesnerioides* that were selfed. Thus, while the number of crosses is small, it does appear that some isolating mechanism might be operative in the different morphotypes. One of the more interesting aspects of this work is likely to be the host specificity of the F_1 .This must wait for sowing as *Striga* seeds need about 1 year afterripening before they will respond to the required germination stimulant. Such studies should provide valuable data on inheritance of host specificity.

Host Tests

Host specificity in this species is strongly correlated with morphotypes, although such variation has not previously been recorded. While the tobacco strain has corollas with distinct color and plicate lobes,

Table 1. Results of crosses between different strains of *Striga gesnerioides.*[1]

Pistillate parent	Staminate parent	Number of crosses made/Number of capsules developed
77-4 (cowpea)	78-1 (tobacco)	3/3
78-1 (tobacco)	77-4 (cowpea)	12/2
78-1 (tobacco)	79-1 (indigo)	6/4
79-1 (indigo)	78-1 (tobacco)	8/?[2]
79-1 (indigo)	77-4 (cowpea)	5/0
77-1 (cowpea)	77-1 (cowpea)	2/2

1. Origin of seeds: 77-4, Niger; 78-1, South Africa; 79-1, Florida; 77-1, Upper Volta. 77,78,79 refer to year of collection. Host crop named in parentheses.
2. Nonexperimental capsules included in collection envelope, so precise number of capsules impossible to determine.

Table 2. Number of emerged stems of five strains of *Striga gesnerioides* 8 weeks after sowing.

	S. *gesnerioides* from				
Test host	*Indigofera hirsuta*	Cowpea	Tobacco	*Jacquemontia*	*Tephrosia*
Indigofera hirsuta L.	10(1)[a]	0	0	0	0
I. suffruticosa Mill.	11(1)	0	0	0	0
Cowpea	0	23(3)	0	0	0
Tobacco	0	0	31(2)	0	0
Jacquemontia tamnifolia (L.) Griseb.	0	0	0	8(1)	0
Tephrosia pedicellata Bak.	0	0	0	0	0

a. Figures in parentheses are numbers of replicates that showed emergence.

variation between the indigo and the cowpea corollas is not striking. Vegetatively, the cowpea form is very branched and more hairy than any of the other strains. A sixth strain of *S. gesnerioides* that is host-specific for *Euphorbia* sp, is reported to be unique in having very little chlorophyll.

In greenhouse studies, the American strain of *S. gesnerioides* was potted with a wide range of potential hosts, including some that we know it parasitizes elsewhere, and with agricultural and ornamental crops of importance in the southern United States. The results (Table 2) suggested that the American indigo strain of *S. gesnerioides* was extremely host-, specific, only the two *Indigofera* species being parasitized. This strict specificity was not unexpected in view of the behavior of the three African strains, each of which attacked only the host from which the seed was collected.

Striga hermonthica

Taxonomy

The *Striga hermonthica* "complex" in West Africa includes four species of *Striga* that are often confused and frequently misnamed: *S. brachycalyx, S. aspera, S. passargei,* and *S. hermonthica.* Bentham recognized a narrow-leaf form of *S. hermonthica* as *S. senegalensis* Benth., but it is not now considered a distinct species. The name is now most often mistakenly applied to *S. aspera.*

The technical features used to distinguish these species are given in Hepper (1963) and are based largely on bract size and shape and calyx length. S. *aspera* is readily confused with both *S. passargeisnd S. hermonthica. S. passargei* is less well known but in general has narrower leaves than the other two species. *S. aspera* and *S. hermonthica* are likewise superficially quite similar and can be found growing together. They may be readily separated, however, on the basis of bract size and corolla pubescence. The bract subtending the flower of *S. aspera* is narrow compared with that of *S. hermonthica.* The entire external portion of the corolla of *S. aspera* is covered with glandular hairs, while the corolla tube of *S. hermonthica* lacks glands. Additional differences include the more abrupt angle of the corolla tube of *S. hermonthica* close to the tip of the calyx, and the larger lower leaves. The two species also differ somewhat in ecology, *S. aspera* being more commonly found in natural grasslands and *S. hermonthica* as a parasitic weed in sorghum. However, *S. aspera* has also been reported to parasitize sorghum (Porteres 1948) and to be a serious parasite on findo (*Digitaria exilis* Stapf.) or "hungry rice" in the Gambia (Terry 1981).

S. hermonthica is a strikingly beautiful species with large pink flowers. Of the *Striga* species we have examined, only *S. hermonthica* and *S. aspera* have more than two corollas open per inflorescence branch and flowers that last more than 1 day. Corolla variations include: upper lobe entire to almost bifid, orifice of throat white or pink, and lower lobes deeply toothed to entire. The extent of this variation among populations remains to be determined, as does its source. Preliminary work indicates that *S. hermonthica* may exist as at least two strains—one attacking millet, the other sorghum (Parker and Reid 1979). In the present study the millet strain of *S. hermonthica,* examined at a number of sites, was morphologically distinguishable from that growing on sorghum. Little is known regarding floral biology, despite the potential value of such work on a parasite that reproduces entirely from seed.

S. hermonthica appears to be an outcrosser. Its pollen is light and powdery—unlike that of the other species—and is not picked up by the elongating style. Several preliminary self- and cross-pollinations were made. In no instance did any of the self-pollinations produce seeds, but the cross-pollinations were fertile. Very recently, sporophytic incompatibility has been indicated, involving a lack of pollen growth on the stigma of selfed plants (Glynn Jones, personal communication).

Scanning Electron Microscopy of Seeds

Seeds of nine species of *Striga* were examined by scanning electron microscope. All species have aereolate surfaces with prominent ridges that are always ornamented with bilobed protuberances near the crest of the ridge. Less prominent secondary ridges run at various angles between primary ridges. Secondary ridges may lack ornamentation. There appears to be little correlation between surface features and host-specific morphotypes, although surface features may be of some taxonomic value in certain species complexes.

Only in *S. asiatica* was it possible to discern differences in surface features of seed from different geographical origins. In general, seeds from Asia are more highly ornamented. Such seeds have more protuberances and distinctly angled secondary ridges.

It is not possible to distinguish the various morphotypes/geographical strains of the other two wide-ranging species (*S. gesnerioides* and *S. hermonthica*) on the basis of seed surface features. Strains of *S. hermonthica* from sorghum and from millet are indistinguishable on the basis of seed-coat characteristics, both having variable ornamentation.

However, surface features of seeds may have taxonomic value. Seeds of *S. angustifolia* (Don) Saldanha (= *S.euphrasioides* Renth.) were distinct among those examined. They were significantly larger (0.5 mm) than those of other species and had characteristic sculpturing. The differences correlate well with the distinct morphology of this species and with reports that it is a facultative parasite, able to establish without a host. *S. forbesii* Benth. has a distinct ridge ornamentation where the protuberances are unequal in spacing and size. Furthermore, this species has distinctive leaves and prefers much wetter habitats than most species.

Seed surface features may also be of value in studying such species complexes as the *S. hermonthica/S. aspera/S. passargei* group. *S. aspera* closely resembles *S. hermonthica* in overall morphology and is also sympatric with it in distribution. However, seeds of *S. aspera* have prominent ornamentation of the secondary ridges, where the protuberances are larger than those on the primary ridges of some strains of *S. hermonthica.* Surface features of *S. passargei are* not distinct enough to separate it from *S. aspera* or *S. hermonthica.*

The surface features of neither *S. densiflora* Benth. nor the insufficiently described Australian species, *S. parviflora* Benth., are sufficient to separate them from *S. asiatica.*

Discussion

This work clearly indicates that two different but highly successful reproductive strategies are operational in *Striga.* The first is obligate outcrossing as exemplified in S. *hermonthica.* We do not yet know the pollen vector in this species. No insects were apparent on *Striga* in about 100 pots in our greenhouse, and no seed set was observed. There is neither obvious scent in S. *hermonthica* nor copious nectar in the ovarian nectary; however, the powdery pollen suggests an insect vector in *S. hermonthica.*

The second strategy is that of autogamy as in *S. asiatica* and *S. gesnerioides.* The distinct morphotypes in these species may have been genetically fixed by continual inbreeding. Associated with some morphotypes in *S. gesnerioides* is a distinct and narrow host range (Musselman and Parker 1981a). Under greenhouse conditions all flowers were autogamous, suggesting that these two species are obligately self-pollinating. However, careful field studies are needed to determine which, if any, insects visit flowers of *Striga* spp. No data on insect visitors have been recorded, except for visits by *Eurema* sp to *S. asiatica* in South Carolina (USA) and South Africa (J.H. Visser, personal communication). These butterflies are frequent visitors of genera related to *Striga* in southeastern United States.

Future Studies

Field, laboratory, and greenhouse studies are necessary to delineate species more clearly, especially in the *S. hermonthica* complex, to facilitate simple and accurate determination of the reproductive biology. Scanning electron microscopy of seeds has not proven as useful a taxonomic aid as hoped. Sorely lacking is information on chromosome numbers. Alloenzyme analysis with electrophoresis may help to identify adaptive radiation in morphotypes of *S. gesnerioides* or *S. asiatica* and host-specific strains of *S. hermonthica.*

Acknowledgments

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Discussion

Vasudeva Rao:
We too have noticed, in S. *asiatica* in India, the kind of variation you referred to in S. *hermonthica.* I agree that there could be species complexes. Could the differences noticed between plants in the same *Striga* populations stem from developmental differences? Such differences may not be heritable, and heritable variations in the *Striga* complexes would be more important in their contribution as a source of variation.

Musselman:
The variation among plants readily observed in any S. *hermonthica* field no doubt results mainly from nonselection. There is probably some variation in corona size, for instance, due to inflorescence position.

Obilana:
What is the implication of interfertility among S. *hermonthica* strains?

Musselman:
Two points: (1) The strains are interfertile and (2) the genetics need to be studied to determine whether the F_1 of a sorghum-specific S. *hermonthica* x millet-specific S. *hermonthica* is germinated by millet, sorghum, neither, or both. The implication is that genetic interchange might overcome resistance.

Root:
Does *Striga* form free roots? Does photosynthate from *Striga* plants nurture host roots?

Musselman:
No, *Striga* does not form free roots, except when lateral roots are unattached. We do not know whether photosynthate from *Striga* nurtures host roots.

Ba Khalidou:
Will *Striga* regenerate from its roots after the rains? If not is *Striga* propagated by seed only?

Musselman:
Striga is propagated by seed only.

Les especes de *Striga* en Haute-Volta

H. Reneaud*

Résumé

Les espèces de Striga *en Haute-Volta : Le* Striga *pose un problème majeur en Haute-Volta. Dans une première approche pour arrêter la prolifération du parasite dans les terres neuves, l'Aménagement des Vallées des Voltas (AVV) a recensé les différentes espèces de* Striga *sur ces terroirs et dans les régions limitrophes. Cette communication présente une description des sept espèces déjà répertoriées.*

Au sein de l'Aménagement des Vallées des Voltas (AVV) dont le rôle est de mettre en valeur les terres neuves nouvellement libérées de l'onchocercose, le service expérimentation s'est vu, entre autres problèmes, devoir résoudre celui du *Striga* pour éviter et arrêter la prolifération du parasite.

Une première approche du problème conduisit tout d'abord au recensement des différentes espèces de *Striga* sur les terroirs et dans les régions limitrophes. Ce travail a montré que la famille des Scrofulariacées est bien représentée en Haute-Volta.

En effet, en plus des espèces déjà connues, deux nouvelles espèces ont été répertoriées en 1978 et vraisemblablement une troisième en 1981 (en cours de détermination). La détermination des *Striga* énumérés dans ce texte a été effectuée par Mme Ranal et M. Floret, botanistes au Muséum de Paris.

Au total, sept espèces dont quatre jouant ou pouvant jouer un rôle néfaste à l'économie voltaïque :

1. *S. hermonthica* (Del.) Benth.
2. *S. gesnerioides* (Willd.) Vatke
3. *S. klingii* (Skann)
4. *S. asiatica* (L.) Kuntze
5. *S. aspera* (Willd.)
6. *S. aequinoctialis* - A. Chev.
7. *S.* Sp détermination en cours

*Projet AW, B. P. 633, Ouagadougou, Haute-Volta.

1. *S. hermonthica*

Sur l'ensemble des terres neuves mises en valeur dans les trois vallées rouge, blanche et noire, l'espèce la plus répandue est de loin *S. hermonthica*. Cette plante de 20 à 60 cm de haut, bien ramifiée, au port robuste est très reconnaissable par sa fleur mauve.

Cette espèce parasite le sorgho, le mil et le maïs. Elle présente des densités d'infestation différentes dans les blocs de culture suivant l'année de mise en culture et le précédent cultural antérieur à l'ouverture des terres.

Après ouverture sur friche ancienne, terre anciennement cultivée ou jamais cultivée, *S. hermonthica* n'apparaît pratiquement pas. Aussi les parcelles de sorgho de première et deuxième année sont-elles indemnes ou presque. Le parasite commence à apparaître en quatrième année de culture sur le sorgho rouge et le mil.

Par contre, sur toutes les parcelles ouvertes sur friche récente les infestations sont importantes. Il semblerait d'ailleurs que l'abandon de ces terres à la friche soit lié au *Striga*. Cette situation est visible à Tiébélé (zone sud Volta Rouge) où certains blocs de culture sont inaptes à la culture du sorgho et du mil. Des comptages effectués sur ces parcelles accusaient 42 levées en moyenne au m^2 avec des maxima de 112 levées/m^2.

2. *S. gesnerioides*

Cette espèce également bien connue joue encore un rôle économique assez faible au niveau de l'AVV; le niébé (*Vigna unguiculata*) n'intervenant

International Crops Research Institute for the Semi-Arid Tropics, 1983. Proceedings of the Second International Workshop on *Striga,* 5-8 October 1981, IDRC/ICRISAT, Ouagadougou, Upper Volta. Patancheru, A.P., India: ICRISAT.

qu'une fois tous les six ans et sur une faible superficie (10%).

On le trouve surtout sur les cultures associées des paysans en parcelle de cases et sur les champs limitrophes de l'AVV.

3. *S. klingii*

Cette espèce recensée en 1978 est une plante de 20 à 50 cm de haut, peu ramifiée, à fleurs presque bleues qui sévit intensivement dans la région du village de Zabré au sud du pays sur sorgho et mil. Sur maïs le parasitisme n'a pas encore été vérifié. L'infestation est bien limitée par les deux obstacles naturels de la Volta Rouge et Blanche, *S. klingii* n'apparaissant pas sur les terroirs AVV jouxtant l'est et le sud-ouest de cette région. Cette espèce est dangereuse et se développe vers le nord avec l'extension des nouvelles défriches.

4. *S. asiatica*

Cette espèce à fleur jaune, peu ramifiée, de 10 à 20 cm de haut a été trouvée sur maïs en 1978 sur le terroir AVV de la Volta Noire à Djipologo près de la ville de Diébougou. L'attaque était ponctuelle et spécifique au maïs. Cette zone étant à vocation maïzicole, et des projets de culture intensive étant à l'étude, une prospection sérieuse serait à faire dans la région pour déterminer les zones contaminées et l'importance de la contamination.

5. *S. aspera*

Ce *Striga* à fleur rose n'a été trouvé que sur jachère ancienne sur les périmètres de la Volta Blanche (Bané). Il se confond facilement avec *S. hermonthica* et pousse d'une façon assez dispersée. Jusqu'à aujourd'hui, ce parasite n'a jamais été observé sur sorgho ou mil dans les blocs de culture AVV.

6. *S. aequinoctialis*

Ce *Striga* a été découvert en 1978 dans le secteur de la Volta Blanche à Bané, route de Tenkodogo au Togo. C'est un petit *Striga* de 10 à 20 cm à fleur blanc rosé que l'on trouve généralement autour des champs ou dans les allées à couvert herbacé peu dense. Les plantes-hôtes n'ont pu être déterminées d'une façon précise.

7. *S. Sp en cours de détermination*

Le parasite a été prélevé récemment (septembre 1981) dans le sud-ouest de la Haute-Volta sur le papem ORD à Oronkua sur la route de Dano-Pa à 20 km de Dano. C'est également un petit *Striga* de 5 à 20 cm de haut à fleur rouge vif 3 à 5 mm de diamètre, peu ramifié. Il pousse aux abords des champs et dans les allées peu ombragées. La plante-hôte systématiquement identique pour tous les prélèvements est en cours de détermination.

Striga Species in Upper Volta

H. Reneaud*

Abstract

Striga *is a major problem in Upper Volta. As a first step toward checking the spread of this parasite to newly cleared lands, the A VV research group has recorded* Striga *species found in and near these regions. The seven species recorded so far are described.*

The research group of the Volta Valley Development Authority (Amenagement des Vallees des Voltas—AVV), whose aim is to develop the uncultivated lands recently freed from river blindness, found that *Striga* is among the major problems it has to tackle.

The first step towards checking the proliferation of this parasite was to record different *Striga* species in and adjoining the regions to be developed. This survey revealed that the genus *Striga* (Scrophulariaceae) is well represented in Upper Volta.

In fact, in addition to the known species, two new species were reported in 1978; a probable third recorded in 1981 is still being identified. *The Striga* species described in this text were identified by botanists at the Museum de Paris.

There are altogether seven species, including four that are of real or possible economic significance in Upper Volta:

1. S. *hermonthica* (Del.) Benth.
2. S. *gesnerioides* (Willd.) Vatke
3. S. *klingii* (Skann.)
4. S. *asiatica* (L) Kuntze
5. S. *aspera* (Willd.)
6. S. *aequinoctialis* (A. Chev.)
7. *Striga* sp being identified.

1. S. *hermonthica*

S. hermonthica is by far the most widespread species in the uncultivated lands that are being developed in the valleys of the Red, White, and Black Volta rivers. This plant is *20* to 60 cm tall, with good branching and sturdy habit and is easily recognizable by its mauve flowers.

The degree of infestation of this parasitic weed of sorghum, millet, and maize crops varies in different crop fields, depending on the year when the land was first cropped and its crop history.

S. *hermonthica* is almost absent after breaking up of lands that have been fallow for a long period, whether previously cultivated or not. In the first and second years sorghum crops are practically free of this weed. The parasite begins to appear in the fourth year of cultivation on red sorghum and millet.

However, a very high level of infestation was observed when recent fallows were cropped. It appears that *Striga* incidence is closely related to fallowing of these lands. This situation is clearly seen in Tiebele (southern Red Volta region), where some fields are unsuited to sorghum and millet cultivation. A survey of these fields showed an average emergence of 42 *Striga* plants/m^2 with a maximum of 112 plants/m^2.

2. S. *gesnerioides*

This equally well known species is still of minor economic importance in the AVV region because its host, cowpea *(Vigna unguiculata),* is grown only once in 6 years and only over 10% of the cropped area.

This weed is found mainly in intercrops in farmers' house fields and in fields bordering the AW region.

3. S. *klingii*

This species, recorded in 1978, is a plant 20 to 50 cm in height, with little branching and bluish flowers.

*AVV Project, B.P. 633, Ouagadougou, Upper Volta.

International Crops Research Institute for the Semi-Arid Tropics. 1983. Proceedings of the Second International Workshop on *Striga,* 5-8 October 1981, IDRC/ICRISAT, Ouagadougou, Upper Volta. Patancheru, A.P., India: ICRISAT.

Incidence is high in sorghum and millet crops in the Zabre village region in the southern part of the country. Parasitism in maize has not yet been verified.

Infestation is naturally checked from spreading beyond the Red and White Volta rivers and *S. klingii* does not occur on adjoining AVV lands to the east and southwest of this region.

This species is potentially dangerous and it is spreading northward as more lands are being cleared.

4. *S. asiatica*
The species with yellow flowers and little branching, 10 to 20 cm in height, was detected on maize in 1978 on AVV lands of the Black Volta at Djipologo near the city of Diebougou. Attack was sporadic and specific to maize.

As this is a predominantly maize-growing region planned for intensive cultivation, a thorough survey should be undertaken to determine the areas and severity of infestation.

5. *S. aspera*
This species of *Striga* with pink flowers has only been observed on lands left fallow for a long period of time on the outskirts of the White Volta region (Bane). It can easily be confused with S. *hermonthica.* Its occurrence is quite scattered and so far it has not been detected on sorghum and millet in AW crop fields.

6. *S. aequinoctialis*
This species of *Striga* was discovered in 1978 in the White Volta sector (Bane) on the Tenkodogo-Togo route. It is dwarf, 10 to 20 cm tall, with pinkish white flowers, and is generally found around fields or in lightly grassed pathways. Its host plants are yet to be identified.

7. *Striga* sp
This newly recorded species, which is being identified, was collected in September 1981 in southwest Upper Volta on the ORD "papem"' at Oronkua, 20 km from Dano, on the Dano-Pa route. It is also a dwarf *Striga* plant, 5 to 20 cm tall, with bright red flowers 3 to 5 mm in diameter and very little branching. It grows in the area bordering the fields and in uncovered pathways. The host plant common to the collected samples is being identified.

Discussion

Gwathmey:
Since the reason for your keeping a record of *Striga* is to avoid infestation of new land that is being developed in Upper Volta, what recommendations have you drawn from this so far?

Reneaud:
1. On soils severely affected, where yield is nil:

- stop growing susceptible crops;
- grow trap crops of cotton, cowpea, or groundnut.

2. On soils moderately affected:

- follow the recommended crop rotation;
- uproot and systematically burn all *Striga* plants.

Eplee:
Is the *S. asiatica* you described similar to that found in the USA and South Africa, except for flower color? What other differences are there between the *S. asiatica* of Upper Volta and that of the USA?

Reneaud:
I have not seen other publications on *Striga* — I am not sure what the differences are:

'Preextension and multilocational trial base (PAPEM) of the regional development organization (ORD).

Session 3

Germination

and Host-Parasite Specificity

Chairman: R.E. Eplee **Rapporteur: B.B. Singh**

Factors Influencing *Striga* Seed Germination and Host-Parasite Specificity

C. Parker*

Abstract

The general requirements for germination of the most important Striga *species include an afterripening period of some months after harvest; 1 to 4 weeks of imbibition known as "conditioning," "preconditioning," or "pretreatment"; and a germination stimulant, originating under natural conditions from the roots of hosts. These three aspects are discussed, together with the more specific requirements of the individual species S.* euphrasioides *Benth., S.* densiflora *Benth., S.* asiatica *(L) Kuntze, S.* hermonthica *(Del.) Benth., and S.* gesnerioides *(Willd.) Vatke. S.* euphrasioides *is distinctive in not requiring a stimulant and in being able to establish itself without attachment to a host. The role of specific germination requirements has been identified as a factor limiting different strains of* S. hermonthica *to particular host crops, but this has not yet been demonstrated with complete certainty for other* Striga *species.*

Résumé

Facteurs influençant la germination des graines de Striga *et la spécificité des rapports hôte-parasite : En général, les exigences de germination des plus importantes espèces de* Striga *sont : un intervalle de quelques mois après la maturation des semences récoltées; un "conditionnement", "pré-conditionnement" ou "pré-traitement" où les graines sont imbibées d'eau pendant une à quatre semaines; un stimulant de la germination produit sous conditions naturelles par les racines de la plante-hôte. Cette communication examine ces trois aspects ainsi que les besoins particuliers des différentes espèces de* Striga : S. euphrasioides *Benth.*, S. densiflora *Benth.*, S. asiatica *(L.) Kuntze*, S. hermonthica *(Del.) Benth. et* S. gesnerioides *(Willd.) Vatke.* S. euphrasioides *se distingue des autres en ce qu'il peut s'établir sans stimulant et sans s'attacher à un hôte. Les besoins spécifiques de germination limitent les différentes souches de* S. hermonthica *à des hôtes particuliers; ceci n'a pas été confirmé pour les autres espèces de* Striga.

It is generally recognized that the germination of *Striga* seeds depends upon (1) afterripening, (2) preconditioning at a suitable temperature, and (3) exposure to a suitable germination stimulant, also at a suitable temperature, which may differ from that for preconditioning.

This brief review outlines available information on each of these aspects. Relatively little is known concerning the link between germination requirements and host specificity, but the limited information on this is also discussed.

Afterripening

Saunders (1933) stated that *S. asiatica* (L.) Kuntze in South Africa required a resting period of at least 6 months, after which germination would steadily

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improve up to 18 months, when a plateau was reached. Fresh seed would germinate only to about 5%. He did not state under what Conditions of seed storage these observations were made. Kust (1963), however, has published results of detailed tests with *S. asiatica* in the USA, which confirm that freshly harvested seed gives very low germination percentages, and that the length of the afterripening period varies from 4 to 6 weeks at 35°C to about 12 weeks at 24°C, to 40 weeks at 0°C.

Vallance (1950) compared the germination of seeds of *S. hermonthica* (Del.) Benth. of different ages (but from different sources) and concluded that there was some afterripening requirement in this species also. Unpublished observations at the Weed Research Organization have also indicated a tendency for samples of *S. hermonthica* from West Africa to give relatively low germination in the first 6 months after collection, but at least one sample of *S. hermonthica* from Abu Naama, Sudan, has given over 80% germination within 3 months from collection, so no generalization can be made concerning this requirement. Attempts to overcome the afterripening requirement of the West African seed by various temperature and desiccation treatments were not successful (Reid and Parker 1979).

Preconditioning

Several different terms have been used for the requirement of the seed to imbibe for a period before it is exposed to stimulant. "Preconditioning" is perhaps the most frequent, but "pretreatment" and "conditioning" have also been used.

The optimum temperature and length of preconditioning were studied in detail for *S. hermonthica* by Vallance (1950), who showed a temperature of 22°C to be more favorable than 27°C or 32°C. A lower temperature of 12°C resulted in slower conditioning, but eventually gave higher levels of germination than 27°C or 32°C. The preconditioning period was shorter and the germination levels reached were generally greater for older samples of seed. Under the optimum conditions of pretreatment only a few days were required for good germination, and the optimum length of pretreatment time varied from 7 to 21 days. In almost all instances, some decline of germination was observed after 21 days of pretreatment, which Vallance referred to as "wet dormancy." He was able to show that viability was not necessarily lost, as ungerminated seeds could be dried, preconditioned again, and subsequently made to germinate.

Reid and Parker (1979) confirmed that 23°C was a more favorable preconditioning temperature than 33°C for a wide range of samples of *S. hermonthica* from both West and East Africa and from both sorghum and millet hosts. However, for *S. asiatica* from India and South Africa, they showed that the higher temperature of 33°C was more effective. Kust (1963) had used 35°C in his studies, but Brown and Edwards (1945) had for some reason used 22°C. *S. densiflora* Benth. from India and *S. gesnerioides* (Willd.) Vatke from West Africa also showed slightly better response to higher preconditioning temperature, but results were less conclusive (Reid and Parker 1979).

Reid and Parker (1979) confirmed the "wet dormancy" phenomenon for *S. hermonthica,* especially when seed was preconditioned at 33°C for more than 4 to 6 weeks but they did not find a comparable phenomenon in *S. asiatica even* after8 weeks at 33°C.

Some recent results have shown that preconditioning in the presence of either natural stimulant or synthetic (GR7) germination stimulants greatly reduces the capacity of the seed to germinate, even if fresh stimulant is later supplied (Hsiao et al. 1979). This interesting phenomenon has not yet been explained but may have considerable practical importance when or if artificial germination stimulants are used in control systems.

Germination Stimulants

The natural stimulant substances are highly active, but are present in root exudates at such low levels that their separation, purification, and identification have proved extremely difficult. Only two natural stimulant substances (strigol and strigol acetate) have so far been identified (Cook et al. 1972). Strigol can cause 50% germination of S. *asiatica* at a dilution of 10^{-11} M. Both substances were isolated from cotton (*Gossypium hirsutum* L.) root exudates, but strigol is thought almost certainly to be produced also by maize (*Zea mays* L.) and by sorghum (*Sorghum bicolor* [L] Moench). It is clear from the high pressure liquid chromatography work of Visser and Botha (1974) that there are a number of natural stimulant substances—at least three different ones—in the root exudates of a range of host and trap crops.

A number of other natural and synthetic compounds have been shown to stimulate germination of *Striga* species to some extent. Before strigol was identified, it was shown that thiourea and allylthiourea (Brown and Edwards 1945), some coumarin-type compounds (Worsham et al. 1959), and cytokinins such as kinetin and zeatin (Yoshikawa et al. 1978) had some stimulant activity, but none has practical value. Later it was demonstrated that ethylene would stimulate *S. asiatica* (Egley and Dale 1970), and this natural gas is now being used on a substantial scale in the USA at about 1.5 kg/ha, to trigger "suicidal" germination of *Striga* seeds and so deplete the number of dormant seeds in the soil and hasten the eradication process (Eplee, these Proceedings). Ethephon has also been shown to stimulate both *S. asiatica* and *S. hermonthica* (Chancellor et al. 1971), but has not been tried as a practical field teatment.

After strigol was identified and described, the International Development Research Centre (IDRC) sponsored a project to synthesize simpler analogues, and several have proved highly active. GR5 and GR7 were described by Johnson et al. (1976), and recently GR24 has been found to be relatively more active (Eplee, these Proceedings). These compounds are potentially much cheaper to make than strigol, but their commercial production is uncertain at present.

Besides the presence of a stimulant, *Striga* germination also requires a suitable temperature, the optima being generally between 30 and 35°C. Few workers have investigated the influence of light, but Kumar and Solomon (1940) showed that light appreciably decreased germination of *S. asiatica* and, although not completely inhibitory, light tends to depress germination of both *S. asiatica* and *S. hermonthica* when applied either during preconditioning or at exposure to stimulant.

Special Requirements and Host Specificity of Individual Species

S. euphrasioides Benth. (=S. *angustifolia* [Don] Saldanha)

It must be emphasized that most of the above generalizations do not apply to *S. euphrasioides,* which has a larger seed (about 0.5 mm long). This species is able to support its own establishment and behaves as a facultative parasite. Germination does not depend on a host stimulant but does require light (Kumar and Solomon 1940). Preconditioning may not be needed in quite the same way, but germination is improved by prolonged leaching of the seed (Rangaswamy and Rangan 1966).

S. densiflora Benth.

Relatively little detailed information has been published on this species. Its host range is comparable to that of *S. asiatica* but experience at WRO suggests that it has different germination stimulant requirements. Varieties of sorghum that stimulate only very low germination of *S. asiatica* and *S. hermonthica* sometimes stimulate *S. densiflora* more (Parker et al. 1977). It is probable that *S. densiflora* will not respond to strigol. Unpublished studies at WRO suggest that a strain from a sorghum host is not responsive to the GR compounds 7 or 24, but does respond to ethylene.

S. asiatica (L.) Kuntze

Most of the observations on *S. asiatica* are based on seed obtained from either maize or sorghum, and no broad differences have been noted in the behavior of samples from India, South Africa, and the USA. As the species is known to respond to strigol, and as both maize and sorghum are presumed to exude this stimulant, it would be expected that the two crops would act as interchangeable hosts.

There is evidence, however, for the existence of host-specific strains. In Botswana it is observed that maize is not attacked at first, when planted into fields where sorghum has been infested by *S. asiatica,* though in subsequent years maize may gradually show increasing susceptibility (C. Riches, personal communcation). In India, there are reports of some degree of host specificity of strains of *S. asiatica* on sorghum, pearl millet (*Pennisetum americanum* [L.] K. Schum), and *Paspalum scrobiculatum* L., the specificity being at least to some extent based on differential germination requirements (Bharathalakshmi, these Proceedings). This evidence is preliminary, and it may be that the specificity of different strains depends more on incompatibility *after* germination rather than on different germination requirements. Further study is needed.

S. hermonthica (Del.) Benth.

Wilson Jones (1955) first demonstrated the existence of physiological strains of *S. hermonthica* in the Sudan, which differed in ability to attack sorghum and millet. He stated that this specificity did not result from differences in germination requirements but he presented no supporting data. Parker and Reid (1979) have since confirmed the existence in West Africa of distinct host-specific strains that attack either sorghum or millet, each strain being almost totally unable to parasitize the other host. The specificity could be explained by *different germination requirements, the sorghum* root exudates failing to stimulate the strain from millet and vice versa. It is possible that the specific germination requirements of each strain are reinforced by an inability to develop on the alternative host even after germination, but this has not yet been confirmed. It appears certain that the strains that attack millet do not respond to strigol, and the work done at WRO (unpublished) suggests that they will not respond to GR7 or GR24 either, although they are stimulated by ethylene.

It is often observed that where sorghum is attacked by *S. hermonthica,* maize also proves susceptible but, as with *S. asiatica* in Botswana, there are some reports that maize may initially be "resistant" to a sorghum strain of *S. hermonthica* but become susceptible after only a few years of repeated cultivation (J. Ogborn, personal communication). The *Striga* virulence trials arranged by ICRISAT over a wide range of sites in Africa have also produced evidence of variation in response by maize, sorghum, and millet to *Striga,* suggesting that there are more than two strains (ICRISAT 1980). Several other crops are attacked in some localities, including finger millet (*Eleusine coracana* [L] Gaertn.), rice (*Oryza sativa* L.), and sugarcane (Saccharum *officinarum* L) but there is no evidence for distinct strains of the weed being specific to those crops.

Work at WRO is aimed at determining the extent to which different strains of *S. hermonthica* vary in their germination stimulant requirements and thus threaten to overcome resistance based on a low-stimulant character (Parker and Reid 1980). Conclusions have not been clear-cut, and there is evidence that strains of *S. hermonthica* from Sudan may respond to a wider range of root exudate substances than those from West Africa, but the differences are not great. Most strains of *S. hermonthica,* however, apparently respond to a distinctly wider range of stimulant substances than *S. asiatica,* so that sorghum varieties selected for low stimulant activity in India, with *S. asiatica* as a test plant, may not retain their resistance against *S. hermonthica* in Africa. There is no evidence as yet that a variety could stimulate *S. asiatica* but not stimulate *S. hermonthica.*

S. gesnerioides (Willd.) Vatke

This species differs from the others discussed in that it attacks mainly broad-leaved species, the most important economic host being cowpea (*Vigna unguiculata* [*L.*] Walp.). Other *hosts* include tobacco (*Nicotiana tabacum* L.) in southern Africa, various wild plant hosts in Africa and India, and, most recently, hairy indigo (*Indigofera hirsuta* L.) in Florida, USA. Parker and Reid (1979) showed very distinct host specificities of the strains attacking cowpea, tobacco, *Jacquemontia tamnifolia* (L.) Grieseb. (Convolvulaceae), and *Tephrosia pedicellata* Bak. (Leguminosae). More recently Musselman and Parker (1981) published further results confirming the strict host range of the indigo strain from the USA. Although quite strictly specific in its hosts, this strain attacks curiously diverse hosts (spread over three botanical families), including *J. tamnifolia* and an ornamental *Nicotiana* sp.

Germination studies with this species of *Striga* have proved difficult, and although there is some evidence for host specificity being due in part at least to differences in germination requirements, it seems mostly based on compatibility factors after germination. *S. gesnerioides* from a cowpea host does not respond at all to GR7 or GR24, but is stimulated to some extent by ethylene (WRO, unpublished).

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Inhibition of Germination in *Striga* by Means of Urea

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Abstract

Striga *is particularly a pest of low-fertility soils, and infestation is less severe on fertile soils. An attempt to understand the basis of the beneficial effects of nitrogenous fertilizers has given some clues. Various nitrogenous fertilizers, such as urea, ammonium sulfate, and sodium nitrate, were used at different concentrations during the* Striga *seed preconditioning period (14 days) as well as during the germination period (2 days).*

Under both acid and alkaline conditions, urea at 200 mg/liter and above markedly inhibited germination as well as length of radicles. At 400 mg/liter germination was as low as 18% under slightly acid, and 23% under slightly alkaline conditions (in the absence of urea, the percentages were respectively 73 and 88). The length of the radicles was only 0.2 mm in the presence of urea, whereas in its absence length was 2.3 mm. At higher concentrations of ammonium sulfate, Striga *seed germination was reduced slightly; the effect on radicle length was more pronounced but less than that of urea.*

Sodium nitrate and sodium chloride had no significant effects at the concentrations tested.

The results suggest that it may be more economical to use urea instead of other nitrogenous fertilizers on Striga-infested fields. It is not clear how urea brings about the reduction in germination and length of radicles, thus reducing the proportion of the germinated Striga *seeds that can successfully establish themselves on the host roots. Experiments on this aspect are being carried out.*

Résumé

Inhibition de la germination du Striga *au moyen de l'urée : Le* Striga *est une plante parasite poussant sur des sols de faible fertilité; l'infestation est moins sévère sur les sols fertiles. Une meilleure connaissance des effets bénéfiques des engrais azotés nous a fourni quelques éclaircissements sur la lutte contre le* Striga. *Divers engrais azotés, tels que l'urée, le sulfate d'ammonium et le nitrate de sodium ont été utilisés à des concentrations diverses, durant la période de pré-conditionnement (14 jours) et de germination (2 jours).*

Placée en conditions d'acidité et d'alcalinité, l'urée, à une concentration de 200 mg/l et plus, inhibe de facon importante la germination et freine le développement des radicules. A une concentration de 400 mg/l, le pourcentage de germination atteint 18% en milieu légèrement acide et 23% en milieu légèrement alcalin (sans urée, ces valeurs auraient été respectivement de 73 et 88). La longueur des radicules est de 0,2 mm avec urée, alors qu'elle atteint 2,3 mm sans urée. A des concentrations plus élevées de sulfate d'ammonium,

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Note: This paper was presented by C. Parker on behalf of the authors. It appears in a more detailed form in Experientia 38:559-560.

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la germination de la graine de Striga *est légèrement ralentie; son effet sur la longueur des radicules a été plus prononcé, mais à un moindre degré qu'avec l'urée. Par ailleurs, le nitrate de sodium et le chlorure de sodium n'ont présenté aucun effet significatif aux concentrations évaluées.*

D'après les résultats des essais, il semble plus économique d'épandre l'urée plutôt que d'autres engrais azotés sur les champs infestés par le Striga.

L'on n'a pas encore élucidé comment l'urée freine la germination et la pousse des radicules et réduit, de ce fait, la proportion des graines de Striga *germées qui peuvent s'accrocher sur les racines de l'hôte. Des expériences sont actuellement effectuées sur cet aspect.*

Discussion

Gwathmey:
Given the nitrogen effect on *Striga* germination, what are your recommendations on: (1) dose of application of urea nitrogen; (2) timing of application; and (3) placement of fertilizer material with respect to host plant?

Parker:
Dose: almost any nitrogen is beneficial to some degree—probably the more the better up to very high levels. Hence the maximum that is economically feasible should be used. Assuming both direct effects on *Striga* germination and indirect effects on the host, applying it a few weeks after sowing probably is best. Again assuming both direct and indirect effects, fertilizer is best placed in two broad bands one on each side of the crop rows.

Gwathmey:
Ammonium sulfate is a strongly acidifyng fertilizer material. Does low pH have an inhibitory effect on *Striga* development or is the effect that of nitrogen?

Parker:
Striga is not much influenced by pH, so the effect is certainly due to nitrogen.

Gwathmey:
Cameroon farmers also use ash for *Striga* control. What salts or soluble compounds interact with *Striga* to account for this folk wisdom?

Parker:
If there is no nitrogen in the ash, then I cannot explain it, as I would not expect any other common salts to have any direct influence.

Evidence of Enzyme Activities in the Haustorium of *Striga gesnerioides* (Scrophulariaceae)

Amadou Tidiane Ba*

Abstract

Acid phosphatase, ATP-ase, peroxidase, succinic dehydrogenase, and cytochrome oxidase activities were demonstrated in the haustorium of Striga hermonthica, *leading us to hypothesize about the involvement of these enzymes in relation to haustorial activity. The same enzyme activities were investigated in the haustorium of* Striga gesnerioides. *In spite of differences in the haustorium structure and organization, enzyme activities tested are positive and present some common traits with* Striga hermonthica *in their localization. Comparison of these enzyme activities in the two types of haustoria confirms our first hypothesis on the close relation between them, mechanisms of penetration of the host, and active transport of metabolites through the haustorium.*

Résumé

Mise en évidence d'activités enzymatiques dans l'haustorium du Striga gesnerioides *(Scrophulariaceae), une phanérogame parasite : Des activités phosphatasiques acides, ATP-asiques, peroxydasiques, succino-deshydrogénasiques et cytochrome-oxydasiques ont été mises en évidence dans l'haustorium du* Striga hermonthica. *Les résultats obtenus nous ont amené à formuler des hypothèses sur le rôle de ces enzymes dans l'activité de l'haustorium. Une analyse identique a été menée sur l'haustorium de* Striga gesnerioides, *d'où il apparaît qu'en dépit de différences de structure et d'organisation de l'haustorium, les activités enzymatiques évaluées sont positives et présentent dans leur localisation quelques traits communs avec le* S. hermonthica. *La comparaison des activités enzymatiques dans les deux types d'haustoria confirme notre première hypothèse sur la relation étroite qui existe entre eux, les mécanismes de pénétration de l'hôte et le transport actif de métabolites à travers l'haustorium.*

Striga gesnerioides is an epirhizoid parasitic weed less well known than other parasitic species of the same family, Scrophulariaceae. Information on its biology is scanty. Tiagui (1956), Ozenda and Capdepon (1972), Okonkwo and Nwoke (1975,1978), and Ba (1977) studied the embryology, morphology, anatomy, and phylogenic position of different *Striga* species. The mechanisms and the structures involved in the fixation and transport processes between the host and the parasite remain to be clearly understood. Results obtained on the studies of enzyme activities in the haustorium of *Striga hermonthica* (Ba and Kahlem 1979) led to further investigation of the same enzyme activities in the haustorium of *Striga gesnerioides* to determine similarities and differences that might indicate the functioning of the haustorium.

Materials and Methods

Striga gesnerioides was grown on *Ipomoea pes-caprae* (Convolvulaceae) in pots. Haustoria obtained

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Table 1. Procedures and conditions used for determining enzyme activities in the haustorlum of *Striga gesnerioides.*

	Acid phosphatase activities				
	Burstone method	Gomori method	ATP-ase	Peroxidase	Succinic dehydrogenase
Fixation at 4°C	Gluta-Caco[1] pH 7.2 30-45 min	Gluta-Caco pH 7.2 30-45 min	Gluta-Caco pH 7.2 30 min	Gluta-Caco pH 7.2 45-60 min	Fresh samples
Rinse	Caco buffer pH 7.2 12 h	Caco buffer pH 7.2 12 h	Caco buffer pH 7.2 12 h	Caco buffer or phosphate buffer pH 7.2 20 h	Rapidly in phosphate buffer 0.2M pH 7.2
Incubation medium	Burstone (1961)	Gomori[2] (1950)	Dauwalder (1969)	DAB 5 mg H_2O_2 1.3 vol. 0.2 ml phosphate buffer 0.1 M pH 7.4 10 ml	Nachlas and Coll (1957)[3]
Temperature of incubation medium	37°C (BM)[4]	37°C (WB)[4]	37°C (WB)	Room temperature	37°C (WB)
Incubation time	30-45 min	30-45 min	30-45 min	15-30 min	60 min

1. Gluta = glutaraldehyde; Caco - sodium cacodylate.
2. Gomori (1950) cited by Martoja and Martoja (1967), p. 271.
3. Nachlas and Coll (1957) cited by Martoja and Martoja (1967), p. 292.
4. WB = BM = Water bath.

from pot culture and from fields at the station at Ngor (a suburb of Dakar) were fixed and prepared as described in Table 1.

Results

A longitudinal section of a mature haustorium is shown in Figure 1. Distribution of enzyme activities was as follows:

Phosphatase

Phosphatase is localized primarily at the contact zone (CZ) of host and parasite tissues and includes meristematic cells (MC) and elongated invading cells (EC). The enzyme is also present at the sheath of elongated cells (SEC) around the xylem, inside and outside the haustorium.

Peroxidase

This enzyme is found primarily at the lateral parts of the contact zone of host and parasite tissues where tissues are under a mechanical pressure. It is also present in the xylem of the haustorium, host, and parasite roots.

Succinic dehydrogenase

This enzyme's activities are localized at the contact zone (CZ), but mainly in the elongated invading cells (EC), in the meristematic-like cells (MC), and also in the cells around the xylem. This localization is the same as that of phosphatase activities.

Discussion

The lack of hyalin tissue and the presence of a branched vascular system (xylem with sheath of elongated cells) are the main features in which the haustoria of *Striga gesnerioides* differ from those of *Striga hermonthica.* Enzyme activities tested on the haustoria of *Striga gesnerioides* show significant similarities for phosphatase and respiratory activities that seem to be related to the mechanism of parasite penetration on the one hand, and to the active transport of metabolites on the other. It is now well known that phosphatases catalyze the breakdown and synthesis of compounds containing energy-rich bonds and are hence connected with the transfer of chemical energy in the cells. This energy might be related to the process and mechanism involved in host penetration by the parasite,

However, differences that appeared in the peroxidase activities are quite closely related to the lack of hyalin tissue in the haustorium of *Striga gesnerioides.* So the exact role of this tissue in the haustorium of *Striga hermonthica* is still to be investigated.

Key

HRS	=	Host root suber
HCP	=	Host cortical parenchyma
HC	=	Host root cortex
HX	=	Host xylem
CA	=	Calcium oxalate
EC	=	Elongated invading cells
MC	=	Meristematic-like cells
CZ	=	Contact zone
NAP	=	Haustorium nonamiliferous parenchyma
SEC	=	Sheath of elongated cells
HBX	=	Haustorium branched xylem
AP	=	Haustorium amiliferous parenchyma
PR	=	Parasite root

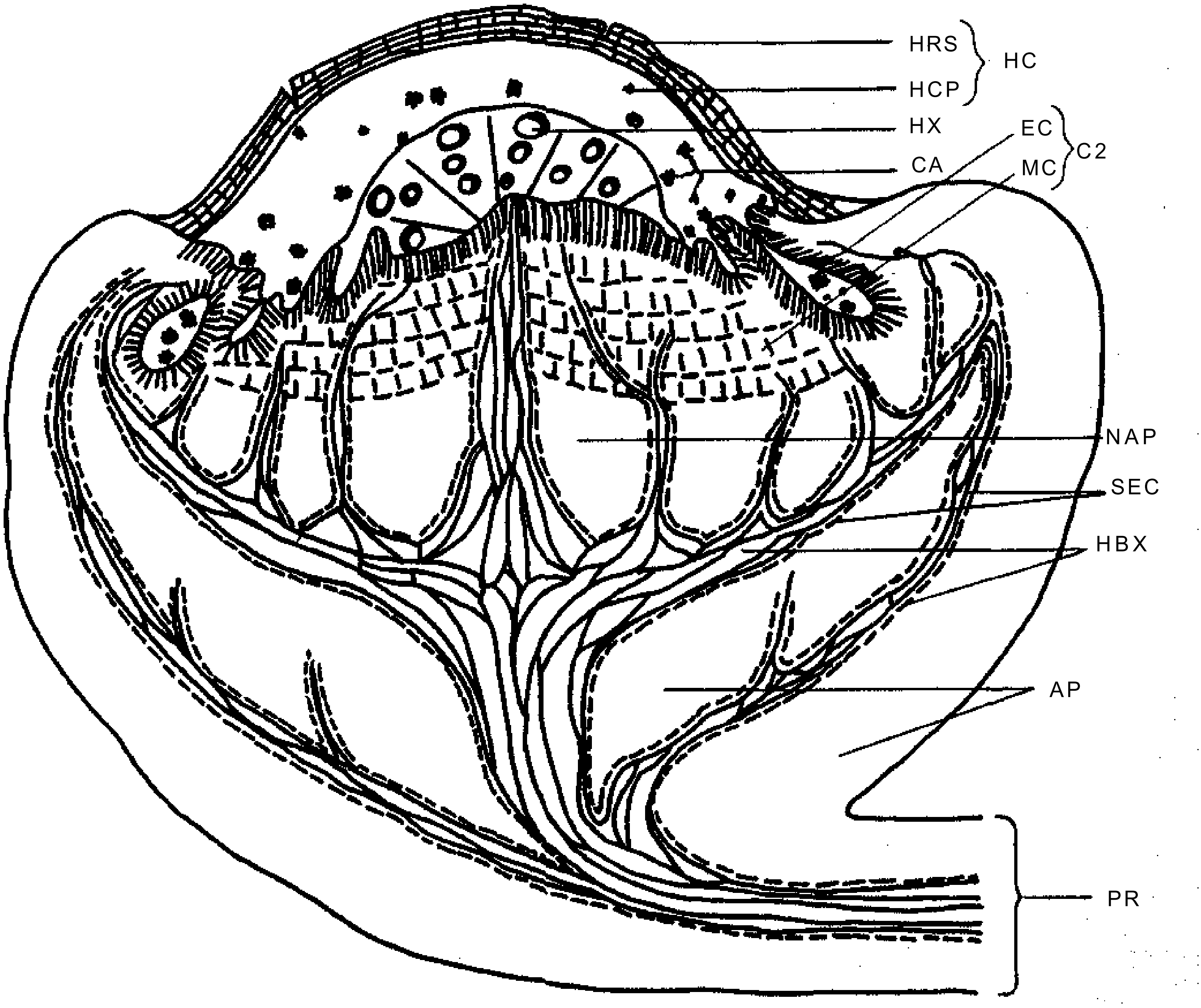

***Figure 1. A longitudinal section of a mature haustorium of* Striga gesnerioides.**

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Effect of Stimulant Plus Herbicide on *Striga* Germination

Rebecca S. Norris and Robert E. Eplee*

Abstract

Research to eradicate Striga *from the United States of America includes development of technologies to stop production of seeds and to devitalize the existing* Striga *seeds in the soil. These functions need to be conducted simultaneously to achieve maximum benefit in the shortest period of time. The use of ethylene gas or a synthesized stimulant along with a foliage-active herbicide showed promise in significantly reducing* Striga *seed populations in soil.*

Résumé

Les effets combinés du stimulant et de l'herbicide sur la germination du Striga : *L'éradication du* Striga *aux Etats-Unis repose sur l'élaboration d'une technologie destinée à arrêter la reproduction et dévitaliser les graines de* Striga *qui se trouvent dans le sol. Ces opérations pour être pleinement efficaces doivent être conduites simultanément, dans un laps de temps réduit. L'utilisation du gaz éthylène ou d'un stimulant synthétique et d'un herbicide foliaire actif permettrait de réduire de façon significative les populations de graines de* Striga *dans le sol.*

The eradication of *Striga* from the United States of America has been the ultimate objective of this research. To achieve *Striga* eradication, it is necessary to: (1) stop its reproduction or the production of seeds and (2) devitalize or kill the seeds already in soil. We have developed various herbicidal and cultural practices that can achieve the first objective; these involve a wide variety of chemicals, application methods, and cropping practices. But devitalization of seeds is complicated by two factors: (1) the seed survives over a long period and (2) seeds will germinate only after a critical period of preconditioning and a germination-inducing chemostimulant is introduced.

The identification of the natural stimulant, strigol, in the late 1960s led to the synthesis of analogues of strigol that had germination-inducing ability. The work on synthetic stimulants was somewhat thwarted in the USA by the discovery, development, and use of ethylene gas as a stimulant for inducing "suicidal" germination. But because of a continued need for greater flexibility in a germination stimulant than ethylene could provide, work on synthetic stimulants continued.

It became apparent from the work with germination stimulants that their effectiveness in seed-population reduction depended upon simultaneous control of parasitic growth. Thus, we centered our investigations on treatments that combined a herbicide and a germination stimulant.

Materials and Methods

Striga seeds were placed in the soil in nylon packets under field conditions to prevent normal preconditioning. The soil surface had a covering of mixed

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grasses 10 to 15 cm high at the time of treatment. The treatments named in Figure 1 were sprayed to the plot by a hand sprayer and water carrier, except for ethylene, which was injected into the soil. The seed packets were retrieved from the field plot 28 days after treatment for determination of germination percentages. During this period the experimental plots received 190 mm of rain.

Results and Discussion

The data presented in Figure 2 show the effect of the treatments on the seed populations in the soil. These data compare the population of seeds before treatment with the number of seeds 28 days after treatment.

GR24 plus paraquat or GOAL was comparable in activity with ethylene in inducing *Striga* seed germination in packets. The same treatments were also as effective as ethylene in reducing seed populations in soil. The compound GR7 was somewhat less effective. The herbicides alone controlled *Striga* but had little commendable effect on seed population. In this test, the grass, which was not controlled by 2,4-D, was perhaps responsible for some seed stimulation.

Thus, the data presented here indicate that soil-surface-applied GR24 plus either of the herbicides, GOAL or paraquat, can significantly reduce *Striga* seed populations in the soil. The compound GR7 is somewhat less effective. These observations are consistent with reports from other workers. Including a contact herbicide facilitates the activity of these surface-applied treatments.

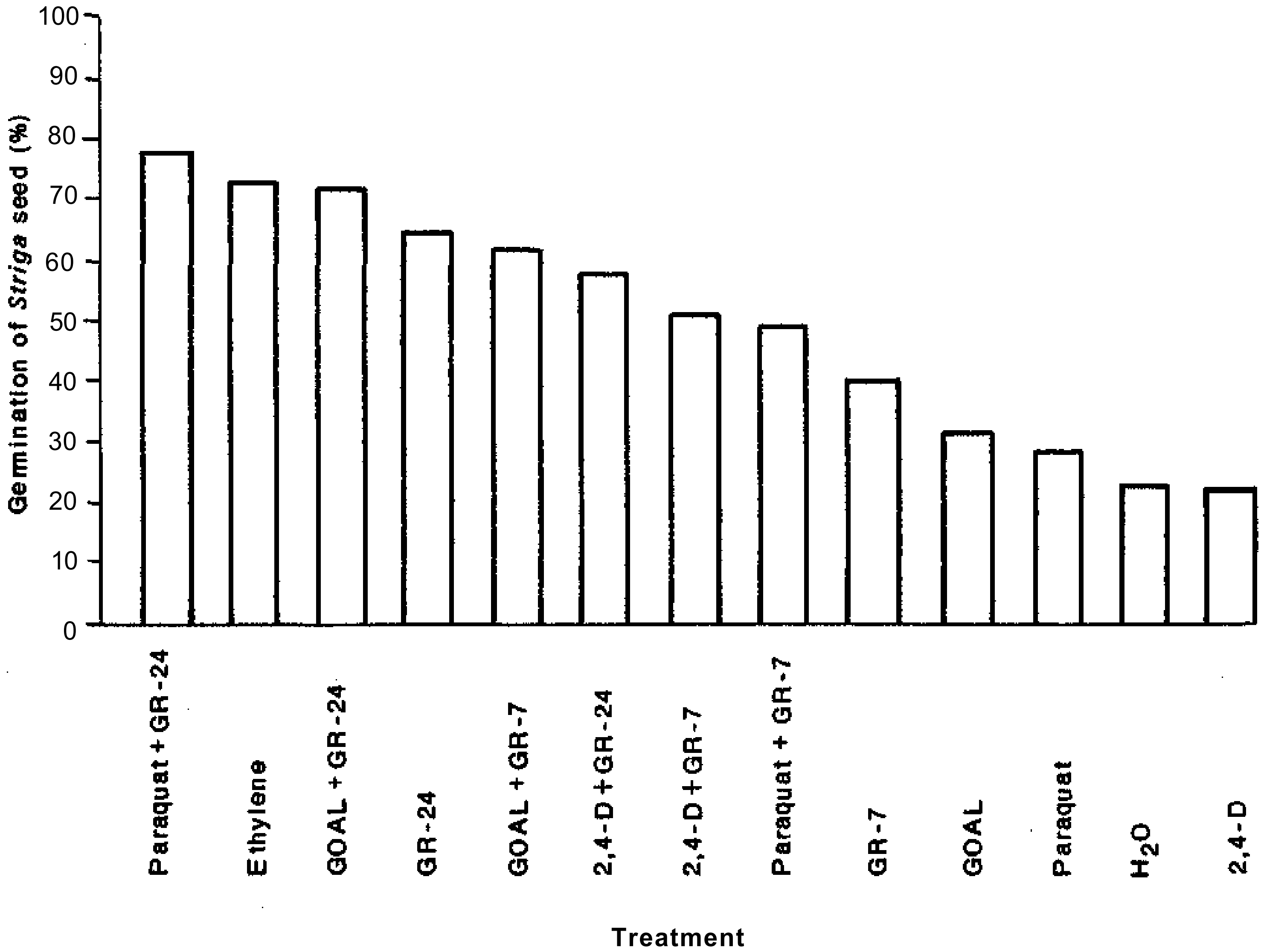

Figure 1. Herbicide/germination stimulant combination: percent germination of* Striga *seeds in containment packets.

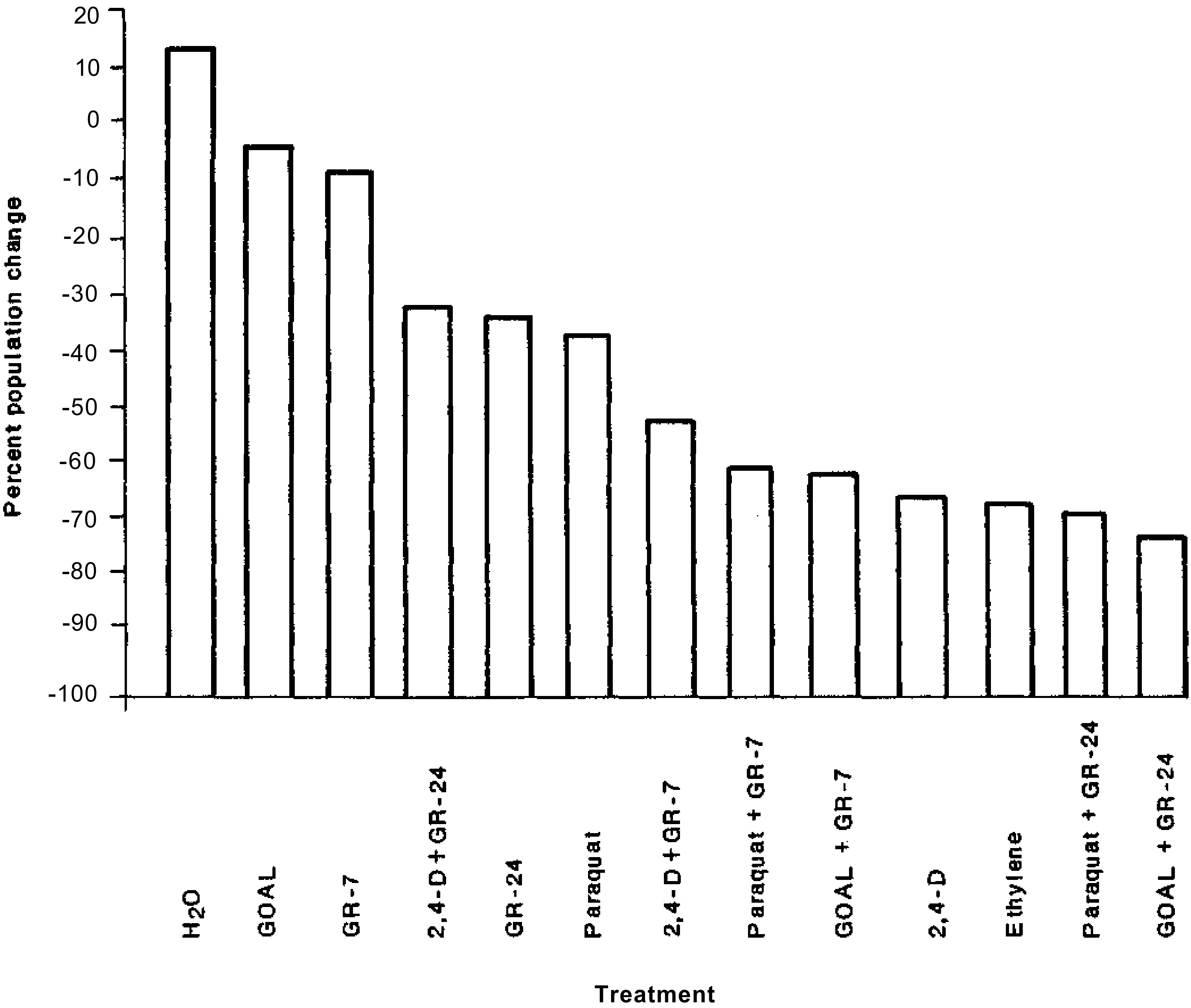

Figure 2. Percentage change of* Striga asiatica *seed population in soil due to herbicide and herbicide/germination-stimulant combinations.

Discussion

Ramaiah:
Did you observe any residual effects of synthetic stimulants? We found them to be active for a few months after application.

Eplee:
Yes. The stimulant will remain active in the soil for4 to 5 weeks, but the seeds do not respond to the stimulant so well if they are preconditioned in its presence.

Sandwidi:
For how long are natural stimulants produced and how long do they remain effective?

Parker:
The natural stimulants will probably be produced by a crop so long as roots are actively growing but the stimulants probably decay within a week or two at most.

Ramaiah:
It is interesting that combined treatment with a stimulant plus herbicide resulted in a greater reduction of *Striga.* How is this reduction brought about?

Eplee:
The herbicide kills weeds that act as intercepts of the spray solution, thus releasing the stimulant to the soil. If the stimulant is applied to bare ground, there is no benefit from the herbicide.

Ramaiah:
Do you see any practical use of the stimulants in tropical conditions? If so, how? We had very disappointing results in Upper Volta soils.

Eplee:
I think it may be a matter of timing. The stimulant must be applied to soil or with a contact herbicide, after the seeds have been preconditioned. It must also receive rain to move it into the seed germination zone. The stimulant may not reduce the number of attachments for the current crop, unless it is plowed after the stimulant treatment.

Vasudeva Rao:
Is there any information on the germinating ability of GR compounds in different types of soils?

Eplee:
There has been some work but not enough. Surface application works in sandy soils. Incorporation may be necessary on heavier soils.

Striga Resistance Screening of Some Cultivars of Pearl Millet, Sorghum, Maize, and Cowpea

Amadou Tidiane Ba*

Abstract

Cultivars of pearl millet (Pennisetum americanum), *sorghum* (Sorghum bicolor), *and maize* (Zea mays) *were screened for their susceptibility to* Striga hermonthica. *Most of the pearl millet cultivars were susceptible, whereas maize and sorghum cultivars were generally tolerant. All cowpea cultivars were resistant to* Striga gesnerioides. Striga *seeds germinated in response to the presence of roots of cowpea cultivars from Upper Volta, attached themselves to the host roots, but subsequently did not grow.*

Résumé

Criblage de quelques cultivars de petit mil, sorgho, maïs et niébé pour la résistance au Striga : *Certains cultivars de petit mil* (Pennisetum americanum), *de sorgho* (Sorghum bicolor) *et de maïs* (Zea mays) *furent criblés pour leur résistance au* Striga hermonthica. *La plupart des cultivars de petit mil étaient sensibles alors que ceux de sorgho et de maïs étaient en général tolérants. Tous les cultivars de niébé ont été résistants au* Striga gesnerioides. *En ce qui concerne les cultivars de niébé en provenance de la Haute-Volta, les semences de* Striga *ont germé, en réagissant à la présence des racines auxquelles les plantules se sont accrochées, sans pour autant se développer davantage.*

Striga hermonthica is a serious pest of cultivated cereals in Senegal and the Sahel region in general. It is widespread throughout the country, and in the northern and southern-central regions (Thies, Louga, and Diourbel) it causes severe damage to pearl millet. Due to lack of well-tried and inexpensive control methods against this parasite, screening was undertaken to find resistant or tolerant cereal cultivars from Senegal and Upper Volta.

Materials and Methods

A screening trial was undertaken with 13 cultivars of sorghum (8 from Senegal and 5 from Upper Volta) and 8 cultivars of maize (4 each from Senegal and Upper Volta) with *Striga hermonthica* seeds collected from the Bambey (Senegal) area, where it is a parasite on *Pennisetum americanum.*

In another experiment, nine cultivars of cowpea (five from Senegal and four from Upper Volta) were screened against *S. gesnerioides. Striga* seed used was collected from Ngor, a suburb Qf Dakar, where it was found attacking *Ipomoea pescaprae* (Convolvulaceae).

Screening was carried out in pots and fields at the botanical garden of Dakar University. Each test was replicated three times. For each test, seeds of the host were sown in 24 seed holes infested with *Striga* in a volume of soil 25 cm in depth and 25 cm in diameter. Isolated haustoria of *Striga gesnerioides* were fixed, embedded in paraffin, and cut by standard procedures. Sections 15 to 20 μ thick were stained with saf ranin and fast green to detect possible mechanical barriers.

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International Crops Research Institute for the Semi-Arid Tropics. 1983. Proceedings of the Second International Workshop on *Striga,* 5-8 October 1981, IDRC/ICRISAT, Ouagadougou, Upper Volta. Patancheru, A.P., India: ICRISAT.

Results

Results, presented in Tables 1,2, and 3 for *Striga hermonthica* and Table 4 for *Striga gesnerioides,* allowed us to identify resistant, tolerant, and susceptible cultivars. Cultivars on which no *Striga* was found were considered resistant; cultivars on which some emerged plants were found, but where growth, development, and seed production of the cultivars were not disturbed, were considered tolerant. Cultivars that suffered damage resulting in yield loss were considered susceptible.

Sorghum

Five cultivars from Bambey (CEGT, CE-90,51 -59, CE-111-6111-57, and 7531-V-15) and one from Upper Volta (9289) were tolerant. The four other cultivars from Upper Volta (IS-5603, CK-60B, N-13, and IS-8686) were resistant, but this result is still to be confirmed, as these cultivars were screened only once.

Table 1. Screening of sorghum cultivars against *Striga hermonthica.*

Cultivar	Origin	Result
CEGF	Bambey (Senegal)	Tolerant
CE-90	Bambey (Senegal)	Tolerant
51-59	Bambey (Senegal)	Tolerant
CE-111-6111-57	Bambey (Senegal)	Tolerant
7531-V-15	Bambey (Senegal)	Tolerant
51 -59-AT	Bambey (Senegal)	Resistant
7410-KHONE	Bambey (Senegal)	Resistant
51-69-ST	Bambey (Senegal)	Resistant
9289	Upper Volta	Tolerant
IS-5603	Upper Volta	Resistant
CK-60B	Upper Volta	Resistant
N-13	Upper Volta	Resistant
IS-8686	Upper Volta	Resistant

Table 2. Screening of maize cultivars against *Striga hermonthica.*

Cultivar	Origin	Result
ZM-10-SR-II	Bambey (Senegal)	Tolerant
ZM-10	Bambey (Senegal)	Tolerant
BDS-III	Bambey (Senegal)	Resistant
BDS	Bambey (Senegal)	Resistant
Kamboinse local	Upper Volta	Tolerant
Diara	Upper Volta	Tolerant
Saria local	Upper Volta	Tolerant
SYN-B-23	Upper Volta	Tolerant

Table 3. Screening of pearl millet cultivars against *Striga hermonthica.*

Cultivar	Origin	Result
Souna III	Bambey (Senegal)	Highly susceptible
Ankov-Tess-3	Upper Volta	Highly susceptible
Ouahigouya local-3	Upper Volta	Susceptible
Serere 2A-9	Upper Volta	Highly susceptible
CIVT-II	Upper Volta	Susceptible

Table 4. Screening of cowpea cultivars against *Striga gesnerioides.*

Cultivar	Origin	Result
58-15	Bambey (Senegal)	Resistant
Bambey 21	Bambey (Senegal)	Resistant
59-25	Bambey (Senegal)	Resistant
Mougue	Bambey (Senegal)	Resistant
58-75	Bambey (Senegal)	Resistant
KN-1	Upper Volta	Resistant[1]
TVX-309-16	Upper Volta	Resistant[1]
TVX-1193-70	Upper Volta	Resistant[1]
VITA-4	Upper Volta	Resistant[1]

1. Cultivar showed a special reaction that is described in the text.

Maize

Two cultivars from Bambey (ZM-10-SRII and ZM-10) and all four cultivars from Upper Volta (Kamboinse local, Diara, Saria local, and SYN-B23) were tolerant. Two cultivars from Bambey (BDS-III and BDS) were found resistant.

Pearl Millet

All pearl millet cultivars from Senegal and Upper Volta were susceptible and remained stunted by *Striga* attack.

Cowpea

Cultivars from Bambey (58-15, Bambey 21, 59-25, Mougue, and 58-75) were resistant. Cultivars from Upper Volta (KN-1, TVX-309-16,TVX-1193-70 and VITA-4) showed special reaction. Up to 10 weeks

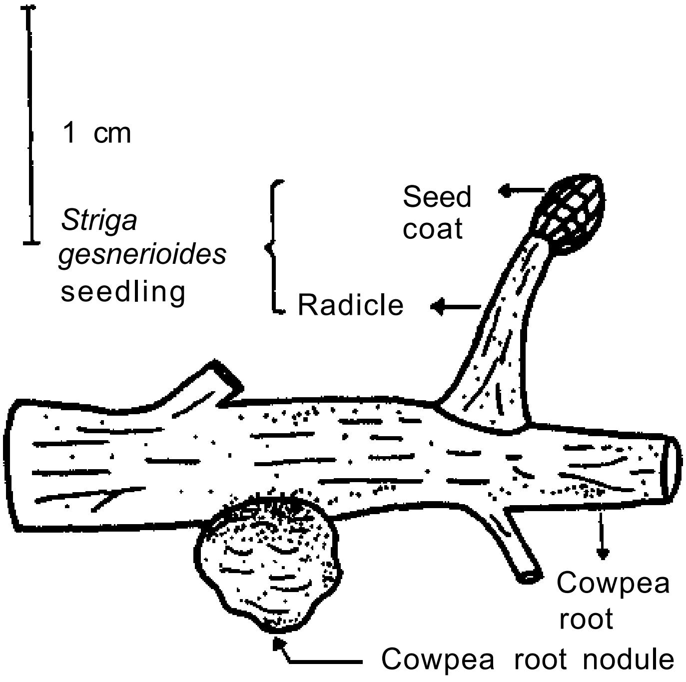

Figure 1. Young seedling of* Striga gesneriodes *on cowpea root.

no emerged *Striga* plants were seen, and cowpea growth, development, and podding were normal. At the end of the cowpea podding period, small seedlings of *Striga gesnerioides* of about 1 cm fixed on cowpea roots were observed (Figure 1). The radicle of germinated *Striga* seeds apparently could not develop. Several dead seedlings were observed on the host roots. Stained cross-sections of cowpea root with host-parasite contact did not show any apparent mechanical barriers.

Discussion

All the pearl millet cultivars tested were severely damaged, whereas sorghum and maize cultivars, irrespective of their origin, were not seriously damaged by *Striga hermonthica,* so they may be considered tolerant to the *Striga hermonthica* strain used.

Screening of cowpea cultivars tested against *Striga gesnerioides* showed more complex results. All cultivars from Senegal were resistant. The ones from Upper Volta stimulated *Striga* seeds to germinate, and the seedlings were able to penetrate the host root, but failed to develop further. It appears that the cultivars that were susceptible in Upper Volta were resistant to the *Striga gesnerioides* strain from Senegal parasitizing *Ipomoea pescaprae.* The precise mechanisms that confer resistance of this kind need further investigation. It is known (Ba 1977) that *Striga gesnerioides* in Senegal attacks some wild leguminous hosts such as *Indigofera diphylla, Indigofera obtusifolia,* and *Tephrosia lupinifolia.* Whether these strains of *Striga gesnerioides* pose any danger to cowpea cultivation in Senegal needs to be examined.

Acknowledgment

We are indebted to K.V. Ramaiah and the National Agronomical Research Centre of Bambey (Senegal) for the seed of cultivars sent us for screening.

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Session 4

Control Methods

Chairman: D.J. Andrews

Cochairman: T. Obilana

Rapporteurs: Owen Gwathmey

Christine Perey

Striga Research at ICRISAT Upper Volta Center

K. V. Ramaiah*

Abstract

The ICRISAT/Upper Volta Striga *program started in the 1979 crop season with the objective of developing cultivars of sorghum and pearl millet resistant to* Striga hermonthica *and assessing the importance of physiological strains in breeding cultivars with broad-spectrum, stable resistance. During 1979 and 1980 considerable progress was made in confirming the resistance of cultivars identified earlier at ICRISA T Center in Patancheru, India. The two most stable resistant cultivars identified so far are N-13 (from India) and SRN-4841, a brown sorghum of Nigerian origin. Both also possess excellent drought resistance in addition to* Striga *resistance. SRN-4841, in particular, is showing promise as it has good seedling establishment and vigor and better yield potential than the local varieties. This variety is in farmers' field trials in Upper Volta and Mali.*

The existence of crop-specific strains of Striga hermonthica *has been confirmed and efforts are being made to demonstrate within-crop strains. The importance of these strains in a breeding program is discussed, and an appropriate control strategy applicable to subsistence farmers is outlined.*

Résumé

Recherche sur le Striga *au Centre de recherche de l'ICRISAT en Haute-Volta : Le programme de lutte contre le* Striga *établi par l'ICRISAT en Haute-Volta a débuté en 1979. Ce programme comporte deux objectifs : la sélection de cultivars de sorgho et de petit mil résistants au* Striga hermonthica *et l'évaluation de l'importance des souches physiologiques dans la sélection des cultivars résistants à plusieurs souches de* Striga. *Depuis lors, on a confirmé la résistance et la stabilité de plusieurs cultivars identifiés au Centre ICRISAT en Inde dont les plus stables sont N-13, originaire de l'Inde, et SRN-4841, un sorgho brun du Nigeria, qui outre leur résistance au* Striga, *sont résistants à la sécheresse. Son bon établissement, sa vigueur à la levée, son haut potentiel de rendement, par rapport aux espèces locales, font de la SRN-4841, une variété prometteuse. Elle est actuellement sous étude dans des champs de paysans en Haute-Volta et au Mali.*

Des souches de Striga hermonthica *spécifiques à certaines cultures ont été confirmées et des études sont en cours afin d'identifier des souches propres à chaque culture. L'importance de ces souches dans un programme d'amélioration est soulignée dans cette communication. Une stratégie de lutte appropriée, applicable sur les champs des paysans, fait aussi l'objet d'une description.*

Striga is a very serious problem of several food crops such as sorghum (*Sorghum bicolor*), millet (*Pennisetum americanum*), maize (*Zea mays*) and cowpea (*Vigna unguiculata*), grown in the semi-arid tropics of the world. The major species that attack the cereal crops are S. *asiatica* in southeast Asia, southern Africa, and the USA; S. *hermonthica* in east and central Africa; and S. *densiflora* in the

*ICRISAT/UNDP, Ouagadougou, Upper Volta.

International Crops Research Institute for the Semi-Arid Tropics. 1983. Proceedings of the Second International Workshop on *Striga,* 5-8 October 1981, IDRC/ICRISAT, Ouagadougou, Upper Volta. Patancheru, A.P., India: ICRISAT.

Indian subcontinent. Cowpea in West Africa is attacked by another species, S. *gesnerioides.* The details of distribution of various *Striga* species are given by Hosmani (1978).

Lighter soils, low soil fertility, and water stress accentuate the severity of *Striga* attack in terms of damage done to the host. On fertile, deep soils *Striga* damage is minimum. Since sorghum and millet are generally grown on relatively light soils and the rainfall in the semi-arid tropics varies in intensity and distribution, with frequent dry spells, *Striga* has been a major yield reducer in these crops.

Because of quarantine restrictions on the movement of *Striga* seed, ICRISAT research efforts on *Striga hermonthica* have been located in Upper Volta since 1979, giving major emphasis to the exploitation of host-plant resistance in sorghum and millet. During the 2-year period under review, efforts were mainly focused on creating a sick plot at the Kamboinse Research Station and screening the resistance source and breeding material developed at the ICRISAT Patancheru Center, in Upper Volta and a few other neighboring African countries. The problems encountered and progress made are briefly reviewed in this paper.

Screening Techniques

Development of reliable screening techniques to identify resistant cultivars in any resistance breeding program needs no emphasis. *Striga* emergence is significantly affected by nonhost factors such as soil type and fertility, rainfall, etc. The situation is further complicated by the possible presence of physiological strains of the parasite. *Striga* incidence is thus a result of complex interactions between *Striga,* host, and environmental factors that call for multilocation evaluation of host resistance.

Laboratory-Screening Techniques

Identification of resistant cultivars in the laboratory under controlled conditions offers excellent scope if it is possible to develop an understanding of specific host-plant resistance mechanisms. There are at least three stages in the process of *Striga* establishment where the host could successfully resist or reduce establishment:

1. *Striga* seed germination factor(s) (produced by the host roots) is required for the *Striga* seed to germinate. Lack of such factor(s) could confer host resistance (Kumar 1940).
2. Antihaustorial factors in the host root can interfere with the penetration and establishment process of the *Striga* haustoria (Saunders 1933,1942).
3. Antibiosis factors in the host plant may operate after the successful establishment of *Striga* on the host root. Though this mechanism is known to exist (Saunders 1933), very little work has been carried out. Our preliminary results (unpublished) indicated the possible role of phenolic acids but this needs confirmation.

Efforts to develop laboratory techniques to identify low-stimulant cultivars (Parker et al. 1977) and antihaustorial factors (ICRISAT 1978) have shown some promise. Screening of the germplasm collection for low stimulant production is being carried out at ICRISAT Center in India. Use of this technique to screen early segregating generations is being explored.

Field-Screening Techniques

Field screening is generally less reliable because *Striga* infestation is seldom uniform. The coefficient of variation for *Striga* resistance as measured by number of emerged *Striga* plants is often very high, thus limiting meaningful interpretation of data. Various factors that need to be taken into consideration for improving the field-screening efficiency are: (1) uniform and assured infestation of *Striga* in the experimental field, (2) soil uniformity in the experimental field, (3) experimental design, and (4) criteria for evaluating resistance.

Uniform and Assured Infestation

Striga infestation in fields naturally infested is nonuniform, and infestation every year is rather uncertain for some unknown reasons. Assured infestation can be obtained by artificial means. Broadcasting *Striga* seed at the end of the season and drilling additional seed with a planter 1 or 2 weeks before planting the test entries has assured higher levels of infestation but did not improve the uniformity across replications. Similar observations were also made in millet (B.B. Singh, unpublished). When the millet and *Striga* seed were planted in the same hill, the differences for the same entry in two replications were quite high.

Soil Uniformity in the Experimental Field

Nonuniformity in *Striga* infestation in an experimental field may result partly from inherent differences in the soil itself. Differences in fertility and moisture-holding capacity of the soil from plot to plot can interfere with *Striga* emergence (personal observation). A careful selection of the experimental field for uniformity in the fertility and moisture-holding capacity is very helpful.

Experimental Design

Soils in West Africa are characterized by inherent macro- and micro-variations that limit the selection of an experimental field. This calls for suitable experimental designs with an appropriate number of replications. The commonest design that is used in Strigra-screening trials is the randomized complete block design (RCBD). Systematic comparison of different experimental designs to reduce the experimental error is lacking. We tried the RCBD with systematic controls at ICRISAT Center without success in reducing the coefficient of variation. Extension of this technique using susceptible controls more frequently was useful (Vasudeva Rao et al. these Proceedings).

Criteria for Evaluating Resistance

Precise evaluation indices for *Striga* resistance have not been worked out. The most commonly used criterion is the number of emerged *Striga* plants. Other useful observations on *Striga* include number of flowering *Striga* plants that reinfest the soil, and weight of *Striga* at the end of the season. Weight of *Striga* was negatively correlated with head weight of sorghum (Ogborn, personal communication). Efforts are being made to select character(s) with high heritability so that resistance can be measured with a reasonable degree of precision.

All these four factors need to be considered for an effective evaluation of field resistance.

Resistant Cultivars

Identification of resistant cultivars of sorghum started in 1975 at the ICRISAT Center in Patancheru against the Indian strain of S. *asiatica* and in 1977 against S. *hermonthica* in a few African countries. It was only in 1979 that work against S. *hermonthica* was intensified, with Upper Volta as the center. The results obtained during the first 2 years of screening work in Upper Volta and a few other African countries are reported here.

International *Striga* Trials

During 1979 two international trials were organized, one on screening of sorghum cultivars for resistance and the second on identifying physiological strains of the parasite. The results from the 1979 trials were confirmed by the 1980 trials, which show great promise for exploiting host-plant resistance. The promising cultivars for *Striga* resistance in eight countries are presented in Table 1. N-13 and SRN-4841 were identified as less susceptible across the countries and across *Striga* species tested. Tests carried out in 1980 on several farmers' fields infested with *Striga* in Upper Volta confirmed these results. *Striga* resistance of the test entries was measured by the number of emerged *Striga* plants expressed as a percentage of the number emerged in a local variety used as a control. N-13 exhibited only 16% susceptibility in comparison with the local variety, but its grain yield was rather low, 22% less than the local. On the other hand, SRN-4841 has shown 60% susceptibility but yielded 20% more than the local (Table 2). These two cultivars show promise as sources of *Striga* resistance.

Table 1. Sorghum cultivars less susceptible to Striga identified in indicated countries.

Country	Cultivar
India	N-13, IS-5603, SPV-103, IS-4202, IS-2203
Sudan	N-13, SRN-4841, IS-9830, IS-9985
Ethiopia	N-13, SRN-4841, SPV-103, IS-12610C
Cameroon	N-13, SRN-4841, NJ-1515, IS-8785
Upper Volta	N-13, SRN-4841, SPV-103, IS-534
Mali	N-13, SRN-4841, IS-2203
Ghana	N-13, SRN-4841, Najjadh
Kenya	N-13, SRN-4841

Table 2. Performance of N-13 and SRN-4841 sorghum cultivars in multilocation trials (1977, T979, 1980).

	N-13	SRN-4841
Mean grain yield (kg/ha)[a]	724	1163
Gain in yield over locals (%)	-22	+20
Range in yield (kg/ha)	314-2292	247-4110[a]
Standard deviation	550	1053
Striga susceptibility (% of local)	16	60

a. Mean grain yield is based on 13 and 12 locations, respectively, for N-13 and SRN-4841.

Stability of Resistance

The *Striga* program is aimed at identifying and developing sorghum cultivars with broad-spectrum stable resistance. The data from sorghum entries in the *Striga* virulence test organized during 1979 were used for stability analysis. The sorghum cultivars tested were N-13, SRN-4841, IS-5603,2219B, 1202B, and CK-60B. The locations were Kamboinse and Farako-Ba in Upper Volta; Abu Naama and Wad Medani in Sudan; Kobo in Ethiopia; Mintimbougou in Mali; and Busia in Kenya. The stability parameters were estimated from $\sqrt{X+0.375}$ transformed data of number of emerged *Striga* plants by Eberhart and Russell's (1966) method. The regression coefficient (b) is the regression of number of emerged *Striga* plants of each variety under different environments of the environmental means over all the genotypes, S_d^2 is the mean square deviation from linear regression. The environmental index is defined as the deviation of the mean of all the varieties at a given location from the overall mean. A stable resistant cultivar is defined as one with a mean value ($\bar{X}$ = mean number of emerged *Striga* plants) and regression coefficient (b) close to zero. N-13 ($\bar{X}$ = 7.1 and b = -0.22) and SRN-4841 ($\bar{X}$ = 7.6 and b = 0.01) were the most stable cultivars tested (Table 3). CK-60B showed the highest susceptibility under less severe *Striga* infestation ($\bar{X}$ =17.7 and b = 0.65), whereas 1202B, 2219B, and IS-5603 showed higher susceptibility under higher *Striga* infestations.

Table 3. Stability parameters for *Striga* resistance in indicated sorghum cultivars.

Cultivar	Stability parameter[1]		
	$\bar{X}$	b	S^2_{di}
N-13	7.1	-0.82	2.2
SRN-4841	7.7	0.01	2.4
IS-5603	12.4	1.87	1.3
2219B	13.2	1.40	1.6
1202B	16.0	1.74	11.2
CK-60B	17.7	0.65	7.3

1 $\bar{X}$ = mean number of emerged *Slriga* plants;
b = regression coefficient.

Striga Resistance vs Drought Resistance

An apparent relationship between *Striga* and drought resistance was observed in our *Striga* trials at more than one location. Two of the *Striga*-resistant lines performed very well under drought stress also. In Kobo, N-13 and SRN-4841 survived the drought stress during the 1979 crop season when the rainfall was only 260 mm as against an annual average of 650 mm. The entries in all other trials failed during that season at Kobo. (B. Gebrekidan, personal communication). We have also noticed in Upper Volta during the 1981 season that SRN-4841 resisted extremely well the seedling drought for 3 weeks immediately after sowing in June, whereas the local variety required repeated sowings to fill the gaps. Similar observations were reported from Sudan in 1978 and Mali in 1979. N-13 came out as resistant in drought-screening trials at the ICRISAT (Patancheru) Center (B.V.S. Reddy personal communication). The observations indicate that N-13 and SRN-4841, which are known for their resistance to *Striga,* also resist water stress. Our field observations were strengthened by laboratory findings at Reading University (Drennan and El Hiweris 1979) that both *Striga* and water stress have similar effects on the host at the physiological/ biochemical level. With both stresses, there was a decrease in the growth-promoting substances (cytokinins and gibberellins) and an increase in the growth-inhibiting substances (abscissic acid and farnesol). This important finding, if confirmed, would indicate the occurrence of sources for drought and *Striga* resistance in the same lines.

Physiological Strains of *Striga hermonthica*

The progress in selection is slowed down when there are virulent physiological strains in a pathogenic organism, and the process of developing resistant cultivars is never-ending, when new virulent strains keep appearing in a pathogenic population. To determine the status of physiological strains in S. *hermonthica* in Africa, a study was undertaken in 1979 with field trials and with pot experiments in 1980.

Striga Virulence Test (STVT)

A *Striga* virulence test consisting of six sorghum, five millet, and four maize cultivars was organized at eight locations in six African countries, three in

West Africa (Upper Volta, Mali, and Niger), and three in East Africa (Sudan, Ethiopia, and Kenya). The mean *Striga* emergence counts transformed into $\sqrt{X+0.375}$ are presented in Table 4.

From these results the locations were divided into two groups based on the host crop that is most parasitized: sorghum *Striga* locations, where *Striga* attacks only sorghum but not millet (Kamboinse, Abu Naama, Wad Medani, Kobo, and Busia) and millet *Striga* locations, where *Striga* attacks only millet but not sorghum (Maradi). Farako-Ba and Mintimbougou, which were classified as sorghum and millet *Striga* locations respectively, are of some interest. At both locations both sorghum and millet were attacked. However, the difference in the infestation levels was statistically significant.

Pot Experiments

During the 1979 crop season several *Striga* seed samples were collected from different host crops grown in various ecological zones of Upper Volta (ICRISAT 1979) for detailed investigations in pots during the 1980 season. The field surveys, field trials, and pot experiments revealed a very interesting distribution of *Striga.* Variations in specificity of S. *hermonthica* to various crop hosts were found in the north-south direction in Upper Volta. Striking similarities in host specificity were observed among *Striga* studied from different sites in the same latitude range. Four distinct zones have been identified in Upper Volta and in West Africa in general, within which *Striga* attacks the same crop(s); these are termed as *Striga* zones (for details see ICRISAT/ Upper Volta 1980):

Zone I:	Drier Sahelian zone (around 500 mm annual rainfall) north of latitude 13°N—millets are the predominant hosts.
Zone II:	Zone around latitude 13°N (about 600 mm annual rainfall)— both sorghum and millets act as hosts.
Zone III:	Zone between latitude 11°N and 13°N (about 750 mm annual rainfall)—sorghums are the predominant hosts.
Zone IV:	Zone below latitude 11°N (more than 1000 mm annual rainfall)— both millets and sorghums act as hosts.

The two interesting Zones are II and IV, where both sorghum and millet are attacked. Our preliminary results from a series of pot experiments indicate that in Zone II the same strain of *Striga* attacks both the crops, whereas in Zone IV the strains are different, one specific to sorghum, another to millet. These results are being verified. Though crop specificity appears to be definite, we need further investigation to see whether the strains that attack the same crop are different.

All the four *Striga* zones cut across country boundaries and follow rainfall, soil, and crop zones across West Africa. Thus it may be possible that resistant cultivars developed in a particular zone of one country can be useful in zones with similar conditions in neighboring countries.

Control Strategy

An effective *Striga* control program should include two aspects: first, elimination or reduction of *Striga* seed number from the heavily infested soils, and second, prevention of further seed multiplication.

Striga seed reduction in the soil could be accomplished by using *Striga* seed germinators like ethylene gas and synthetic strigol analogues (Norris and Eplee, these Proceedings) and by using trap crops (Doggett 1965). Trap crops offer excellent scope because they not only reduce the *Striga* seed reservoir in the soil but also increase grain yields of the succeeding cereal crop through beneficial rotation effects (Ramaiah, unpublished).

Multiplication of *Striga* seed can be controlled in the following ways: growing resistant cultivars, hand-pulling *Striga* before it flowers, cleaning stubble after crop harvest, and using herbicides.

Therefore, appropriate control strategy in subsistence farming should include:

1. Elimination of *Striga* seed from the soil by using appropriate trap crops in rotation with cereals.

2. Prevention of *Striga* seed multiplication by growing resistant cultivars, with supplementary hand-pulling of the relatively fewer emerged *Striga* plants.

3. Use of appropriate cultural practices, such as high crop density, high doses of nitrogen, altered time of planting (Parker, personal observation), etc., to avoid *Striga.*

Table 4. Mean *Striga* counts on sorghum, pearl millet, and maize (Transformed $\sqrt{X+0.375}$) in *Striga* virulence test in six African countries.

	Upper Volta		Mali	Niger	Ethiopia	Sudan		Kenya	
Crop and cultivar	Kamboinse	Farako-Bâ	Mintimbougou	Maradi	Kobo	Abu Naama	Wad Medani	Busia	Grand Mean
Sorghum									
1 IS-5603	2.43	11.71	2.45	0.61	6.60	3.53	4.33	4.43	4.51
2 SRN-4841	4.35	2.35	6.75	1.05	2.92	1.68	5.02	3.18	3.41
3 N-13	1.68	3.14	2.45	0.61	6.70	5.00	6.07	3.20	3.60
4 CK-60B	7.22	11.63	9.86	0.98	8.41	4.25	5.35	4.27	6.50
5 1202B	4.89	13.09	3.41	0.84	10.73	5.70	5.03	7.95	6.46
6 2219B	4.99	7.41	5.86	1.12	8.56	5.48	3.61	5.65	5.30
Mean	4.26 ± 0.37	8.22 ± 0.39	5.08 ± 0.39	0.87 ± 0.31	7.32 ± 0.32	4.27 ± 0.67	4.90 ± 0.35	4.78 ± 0.38	
Pearl Millet									
7 B-282	0.92	7.20	6.81	4.24	0.75	0.83	0.61	0.61	2.75
8 Ex-Bornu	0.61	6.34	7.15	3.50	1.08	1.03	1.41	0.61	2.72
9 J-104	0.61	5.93	3.59	0.75	0.61	1.13	0.61	0.92	1.77
10 D2-Comp	2.83	7.27	7.66	7.21	0.75	0.78	0.75	0.61	3.50
11 CIVT-II	0.92	5.24	9.06	5.68	-	2.58	0.98	0.61	
Mean	1.18 ± 0.40	6.40 ± 0.50	6.85 ± 0.42	4.28 ± 0.38	0.80 ± 0.25	1.26 ± 0.28	0.87 ± 0.38	0.67 ± 0.42	
Maize									
12 D-771	0.61	1.93	1.08	0.85	1.49	0.98	2.55	3.66	1.65
13 Diara	0.80	0.89	1.36	0.75	5.23	0.65	2.90	8.48	2.63
14 Syn-B23	0.80	3.79	1.63	3.79	7.05	0.76	2.87	5.08	3.22
15 L-4	0.80	2.21	1.08	2.24	4.29	0.90	2.29	6.74	2.57
Mean	0.75 ± 0.45	2.21 ± 0.56	1.29 ± 0.47	1.92 ± 0.42	4.51 ± 0.25	0.81 ± 0.32	2.65 ± 0.43	5.99 ± 0.46	
SE ($\bar{X}$)	0.90	1.12	0.95	0.85	1.67	0.73	0.86	0.93	
LSD (5%) for comparing any two cultivars	2.61	3.38	2.88	2.35	4.64	1.75	2.37	2.69	
LSD (5%) Mean Sorghum vs millet	1.12	1.03	0.88	0.99	1.97	0.97	1.01	1.16	
LSD (5%) Mean Sorghum vs maize	1.19	1.54	1.31	1.07	2.10	0.79	1.07	1.23	
LSD (5%) Mean Millet vs maize	1.24	1.24	1.06	1.12	2.20	0.83	1.12	1.28	

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Discussion

Ouedraogo:
What is the relationship between the development of *Striga* and the type of soil?

Ramaiah:
Striga development is favored on light, well-drained soils. On the other hand, *Striga* causes less damage on host plants grown on fertile deep soils.

Gwathmey:
Could you elaborate upon the burning of host-crop stubble in the field after harvest? Does fire consume mature plants of *Striga* and thus destroy some seed? Has not *Striga* capsule dehiscence been completed by this time?

Ramaiah:
By the time the host crop is harvested, a large proportion of *Striga* plants would have completed their life cycle. However, one still finds a good stand of flowering *Striga* after the harvest of the host crop. So burning may help kill *Striga* plants that otherwise would produce more seed.

Sharma:
What is the effect of burning the stubble on the next season's *Striga* populations?

Ramaiah:
No definitive studies have been made. Probably it has beneficial effects in reducing *Striga* seed buildup to some extent.

Lanting:
In the southern zone the *Striga* strains attacking millet and sorghum are different. Does this offer a possibility for a rotation? Is it advisable for farmers not to grow a mixture of sorghum and millet to prevent a buildup of both strains in the same field?

Ramaiah:
It is advantageous to rotate sorghum and pearl millet, as many farmers do in Strga-infested areas, not only to check *Striga* buildup but also for other beneficial rotation effects.

Reneaud:
Can pearl millet be used as a trap crop for the physiological strains of *Striga* which are specific to sorghum?

Parker:
As the specificity of sorghum and millet strains of *Striga* depends on different germination stimulants, it is almost certain that millet will not act as an effective trap crop for the sorghum *Striga;* conversely, sorghum will not be an effective trap crop for the millet *Striga.*

Matteson:
Is seed quality and farmer acceptance an important issue in sorghum- and millet-breeding development for the Sahel?

Ramaiah:
Yes. Grain quality is very important. Promising cultivars of both sorghum and millet should undergo cooking-quality tests before they are recommended to the farmers.

Christensen:
Only a limited number of varieties have been tested over the whole African continent. How were they selected?

Ramaiah:
Preliminary evaluation of large numbers of lines is done at Kamboinse and promising ones are advanced to international testing.

Mercer-Quarshie:
How did cv Najjadh compare with N-13 and SRN-4841 in your experiments? We found it very resistant as measured by *Striga* counts.

Ramaiah:
Cv Najjadh compares well with N-13 and SRN-4841 and also yields more than N-13.

Breeding Sorghum with Resistance to *Striga asiatica* (L) Kuntze at ICRISAT Center

M. J. Vasudeva Rao, V. L. Chidley, K. V. Ramaiah, and L R. House*

Abstract

Breeding for Striga *resistance at ICRISAT Center, near Hyderabad, India, has the twin objectives of identifying sorghum source lines resistant to* Striga asiatica *and transfering the resistance to agronomically elite lines; 14 000 sorghum germplasm lines have been screened in the laboratory for their stimulant production and 640 low-stimulant lines have been identified. Studies on the genetics of stimulant production have indicated a preponderance of additive over nonadditive genetic variance. Selection for field resistance among the derivatives from Striga-resistant source lines x adapted crosses resulted in a higher proportion of field resistants in the low-stimulant than in the high-stimulant derivatives. In multilocation testing of the source lines, field reaction indicated that the best available low susceptible lines are N-13, 555, IS-4202, IS-7471, and IS-9985. The technique of growing test plants of the host in shallow seed pans in a soil medium has been found useful in differentiating resistant from susceptible host plants. An improved, three-stage system of screening for field resistance to* Striga *is described. Initial studies on* Striga *collected from five locations in India and four sorghum varieties indicated significant strain x variety interactions and SRN-4882B gave differential reaction. Intensive studies on host-parasite relationships, environmental interactions influencing* Striga, *screening methodology, guidelines to manage* Striga *sick fields, and surveys to understand species and race complexes have been projected as some of the priority areas of* Striga *research.*

Résumé

Sélection de génotypes de sorgho résistants au Striga asiatica *(L.) Kuntze, au Centre ICRISAT : Le travail de sélection pour la résistance au* Striga *chez le sorgho, fait au Centre ICRISAT près de Hyderabad en Inde, s'est fixé le double objectif d'identifier des lignées sources résistantes au* Striga asiatica *et de transférer cette résistance à un matériel à bonnes caractéristiques agronomiques. Quatorze milles lignées de ressources génétiques de sorgho ont été criblées en laboratoire pour leur production de stimulant et un ensemble de 640 lignées à faible stimulation ont été identifiées. Les études génétiques sur la production de stimulant ont montré qu'il y avait une variance génétique due plutôt aux facteurs additifs que non additifs. La sélection pour la résistance sur le terrain parmi les lignées issues des croisements lignées sources résistantes × lignées adaptées a révélé que le matériel dérivé des lignées à faible stimulation comportait plus de lignées résistantes que le matériel à forte stimulation. Une évaluation de la réaction sur le terrain des lignées sources a révélé que les meilleures sont : N-13, 555, IS-4202, IS-7471 et IS-9985. Une technique où les plantes-hôtes sous étude sont cultivées dans un plat de semence peu*

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profond rempli de terre permet de différencier les lignées résistantes et sensibles. Un système d'évaluation amélioré pour la résistance au Striga *sur le terrain étalé sur trois étapes de criblage est décrit. Les études initiales sur le* Striga *collecté sur cinq sites en Inde et quatre variétés de sorgho ont montré qu'il y a des interactions souche × variété significatives. SRN-4882B a eu une réaction différentielle. Les études intensives sur les relations hôte-parasite, les interactions du milieu influencant le* Striga, *la méthodologie de criblage, les lignes de conduite dans la gestion des champs infestés par le* Striga, *les enquêtes pour comprendre les espèces et complexes des races sont proposées comme domaines prioritaires de recherche sur le* Striga.

Striga, a root parasite of grasses, is recognized as a serious problem of the sorghum crop in several semi-arid tropical (SAT) countries. Losses due to *Striga hermonthica* Benth. have assumed economic proportions on sorghum and millets in many African countries. *Striga asiatica* (L.) Kuntze, which is more widespread than S. *hermonthica,* has been identified as an important problem in southern Africa, North and South Carolina in the United States, and India. Genetic resistance in sorghum to *Striga* is recognized as the most economic way to combat this problem. This paper describes the *Striga* resistance breeding activities at ICRISAT Center and explains the developments in screening methodology.

Screening Methodology for *Striga* Resistance Breeding

Research efforts to incorporate *Striga* resistance into an agronomically elite background in the past indicate that the absence of a reliable screening system has been a major constraint to significant progress. We therefore analyze the existing systems of screening and consider some improved screening methodologies.

Existing Screening Systems

The recognition and influence of the host roots on the parasite occur during three stages of parasite development: seed germination, haustorial establishment, and the final growth and establishment of *Striga.* Three mechanisms—low stimulant production, mechanical barriers to haustorial establishment (ICRISAT 1977), and antibiosis—that confer resistance on sorghum roots against the parasitization by *Striga* have been recorded (Doggett 1970). Field resistance to *Striga* is the combined expression of one or more of these mechanisms. Laboratory techniques screen for mechanisms either individually or in combination.

Laboratory Techniques

Several laboratory-screening techniques are available, such as the double-pot technique, the Pasteur pipette technique, the root-slope technique, sandwich techniques, antihaustorial factor screening, etc. Though laboratory techniques have several advantages, they are not often well correlated with field screening, mainly for two reasons: first, the field resistance to *Striga* cannot be explained by any single mechanism alone; second, field results are influenced by strong environmental interactions that are not allowed to act in laboratory techniques.

Pot-Screening Techniques

Generally, pot screening involves growing the host in pots artificially inoculated with *Striga* seeds; the reaction of the host is judged by counting the *Striga* seedlings that emerge above the ground. Although these techniques are not completely reliable, they could be useful, since the *Striga* infestation in pots is more definite than in artificially infested fields.

Field-Screening Techniques

Growing the sorghum lines in a field that is naturally or artificially infested with *Striga* and screening for field reaction is a commonly used technique; however, field screening is often not reliable because of various uncontrollable factors.

Efficiency Requirements of Screening Techniques

The efficiency requirements expected of the screening technique depend on the kind of material and the degree of accuracy required. The kinds of material that usually form part of a *Striga* resistance breeding program are: landraces from germplasm; segregating progenies, usually from crosses between resistant and adapted high-yielding but susceptible varieties; and advanced generation lines.

The landraces and advanced generation lines are almost homozygous and need maximum efficiency in screening, which should also be able to identify absolute resistance, if available. The testing must be adequately replicated. Among the segregating progenies, the F_2 generation has to be treated on an individual-plant basis, while from the F_3 onwards, they could be treated on a family basis, though single-plant screening would still be advisable.

The Seed-Pan Technique

At ICRISAT, a seed-pan technique of screening for *Striga* resistance is being developed. The test material is grown in a shallow seed pan approximately 35 cm in diameter at the top, 15 cm at the bottom, and 15 cm high, accommodating about 2.5 kg of a mixture of sand and clay soil. The shape and size of pan are important, because this pan concentrates the host roots and thus favors a higher frequency of *Striga* establishment. A 1:1 mixture of sand and clay soil provides optimum conditions for the growth of the parasite. *Striga* seeds, pretested in the laboratory for germination, are planted 10 to 15 days preceding the planting of the test material so as to condition them before they come in contact with the host roots. The recommended sowing rate is 100 mg (approximately 20 000 seeds) per pan. To obtain uniform infestation across pans, it is useful to mix the whole lot of *Striga* seeds with the soil required for the entire experiment and distribute it equally by weight in the pans. The pans are kept watered regularly.

Reaction of the test entry to *Striga* is monitored by uprooting the host plant at about 50 days after sowing and counting the subterranean *Striga* initials. Alternatively, the host may be allowed to grow longer and the *Striga* counted after emergence above the soil surface. The soil in the seed pan is insufficient for growing the plants more than 50 days but a wooden flat, 60 x 60 x 15 cm, is useful for such a purpose.

Two experiments conducted to verify the usefulness of the seed-pan technique are described.

Table 1. Mean subterranean *Striga* counts on susceptible and resistant sorghum cultivars in seed pans.

Season	Date of sowing	Cultivar[1]	Mean *Striga* counts at host age of				
			27	29	31	35	49 days
Rainy	8 July 1980	CSH-1	2.0	4.0	4.7	8.6	7.6
		Swarna	3.0	3.0	5.0	4.2	12.3
		N-13	0.5	0.3	0.0	0.2	0.0
			20	25	32	40	50 days
Postrainy	24 Oct 1980	CSH-1	0.0	0.3	1.2	0.7	1.2
		Swarna	0.0	0.5	1.4	2.5	4.3
		N-13	0.0	0.3	0.7	0.0	0.0
			22	28	32	42	52 days
Summer	23 Feb 1981	CSH-1	0.0	0.2	0.4	7.0	10.5
		Swarna	0.0	0.0	0.4	2.9	7.1
		N-13	0.0	0.2	0.0	0.5	0.3
			20	25	30	40	50 days
Rainy	17 Jun 1981	CSH-1	0.2	1.2	3.0	10.2	13.0
		Swarna	0.3	1.2	3.0	9.5	11.0
		N-13	0.0	0.0	0.0	0.2	0.5

1. CSH-1 and Swarna are susceptible; N-13 is resistant.

Comparison between resistant and susceptible cultivars. Two susceptible sorghums, CSH-1 (a hybrid) and Swarna (a variety), and a resistant variety, N-13, were compared, using the seed-pan technique. Comparisons were made over four normal sorghum-growing seasons at ICRISAT Center, Patancheru, with at least six replications for each observation. Subterranean *Striga* initials were counted, starting from 20 days after sowing to 50 days, in replicate samples to determine the optimum number of days for taking observations with this technique (Table 1 and Figure 1). The experiments were independently analyzed by the split-plot technique, with days to observations as main plot and varieties as subplots. Highly significant differences *(P* < 0.01) were observed between the varieties in all seasons (Table 2). Variation between blocks (pans) was nonsignificant in all seasons. As Table 1 and Figure 1 indicate, the rainy and summer seasons are the best for conducting seed-pan experiments to differentiate resistant from susceptible varieties. In the postrainy season the differen-

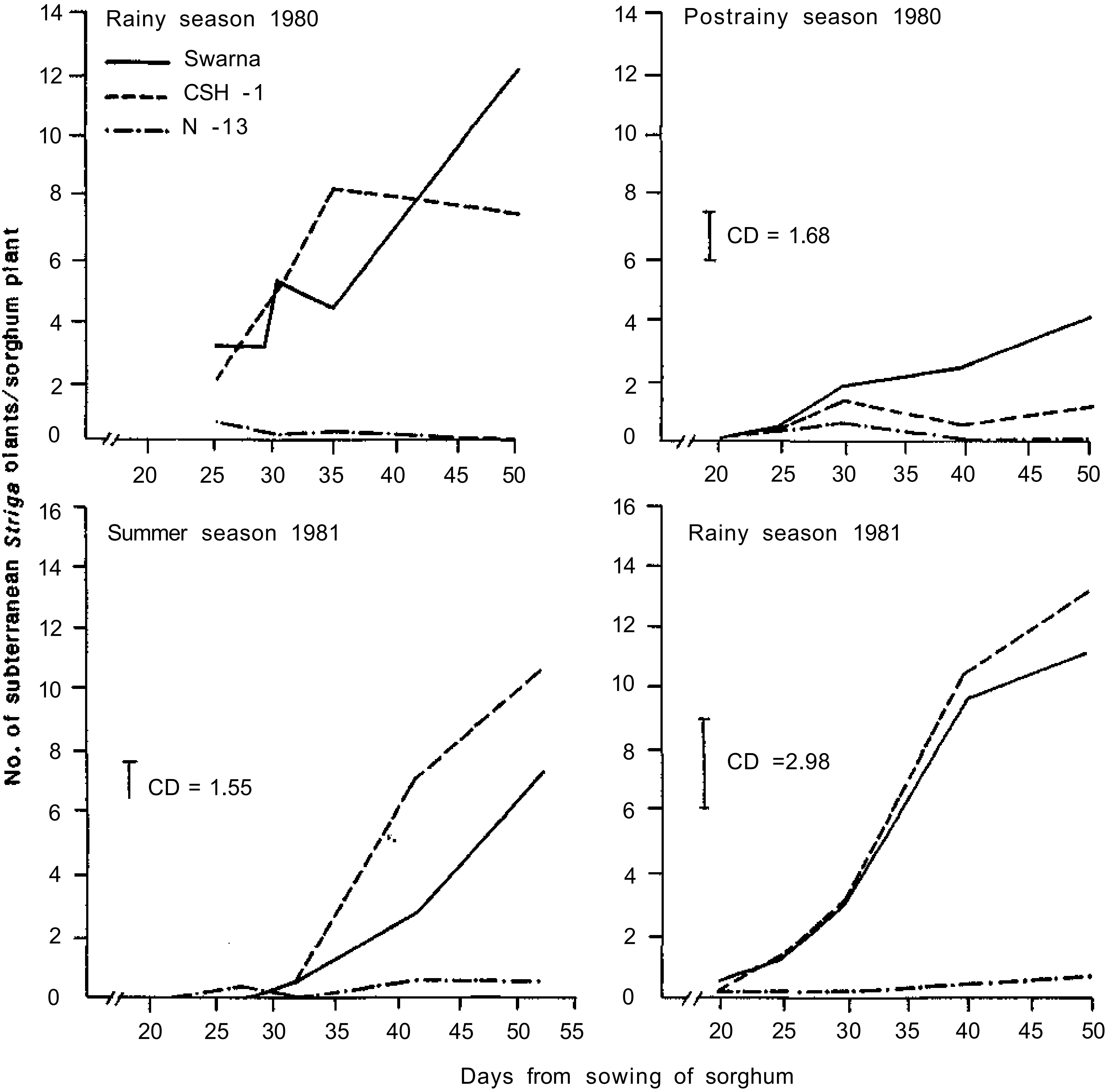

Figure 1. Subterranean* Striga *counts on the roots of resistant and susceptible cultivars of sorghum.

Table 2. **Analysis of variance for subterranean *Striga* counts in seed pans over three seasons.**

Source of variation	Postrainy season 1980		Summer 1981		Rainy season 1981	
	DF	MS	DF	MS	DF	MS
Blocks	5	1.55	7	7.24	5	3.29
Main plots (days)	4	8.93*	4	171.28**	4	218.18**
Error (A)	20	2.53	28	5.97	20	8.83
Subplots (cultivars)	2	16.53**	2	115.90**	2	243.38**
Main x subplots	8	6.20*	8	104.46**	8	50.43**
Error (B)	50	2.38	79	2.01	50	7.44
Total	89	2.78	120	17.74	89	3.68

' Significant at P <0.05; ** Significant at *P* <0.01.

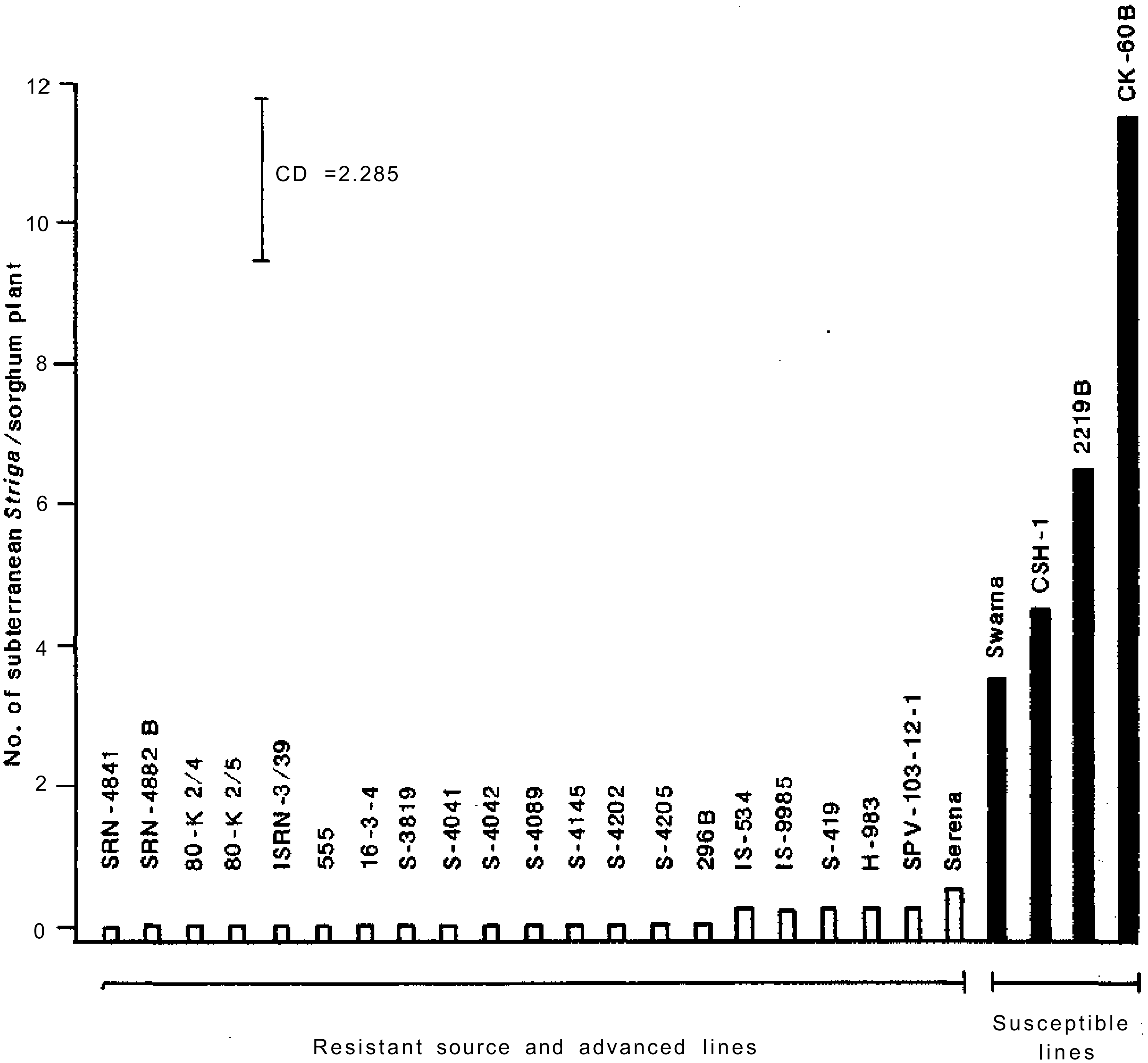

Figure 2. Subterranean Striga *counts of 25 sorghum lines in seed pans. (55-day counts) (D/S: 30.1.81).*

ces, though statistically significant, were not pronounced, probably because of low temperatures prevailing during *Striga* establishment.

Comparison of 25 sorghum lines. This experiment was conducted in summer 1981, using 21 resistant and 4 susceptible sorghum lines—in a randomized block design with four replications—to observe the differences in *Striga* reaction between lines. Significant differences were observed between test entries for the 55-day counts of the subterranean *Striga* (Figure 2). The resistant and susceptible groups differed significantly.

Improved Field-Screening Methodology

Field screening is often unreliable because of nonuniform *Striga* infestation. The common problems in field screening are:

- unreliable occurrence of *Striga* over years in the same field;
- difficulty of controlling levels of infestation;
- nonuniform *Striga* distribution in the field;
- significant environmental influence on *Striga* infestation; and
- high coefficients of variability in the experiments, reducing the chances of finding significant differences between treatments.

At ICRISAT, an improved system of testing for field resistance to *Striga* is being developed and tested. Basically, it involves testing at three stages: observation nursery, preliminary screening, and advanced screening.

Observation Nursery

This nursery consists of an unreplicated trial of a large number of test entries with a frequently replicated susceptible control. Test entries are grown in two-row plots and *Striga* is observed between rows. *Striga* reactions are standardized by expressing the counts in a test entry as a percentage of the average of the two nearest susceptible controls. Lines showing high *Striga* reactions are then rejected. In a segregating line, selection is made for agronomic expression and advanced in the nursery stage itself.

Preliminary Screening

The second stage of testing includes those entries that are agronomically good and in which *Striga* numbers are low or do not appear in the observation nursery. These entries are tested in three-row plots, replicated at least thrice, with a systematic check arranged in such a way that every test plot will have one check plot adjacent to it (Figure 3). In each replication, the *Striga* count of the test entry, expressed as a percentage of the adjacent systematic check (to adjust for nonuniformity in the field), is determined. A standard randomized block design analysis of these data usually gives a high coefficient of variation. Therefore, the interpretation of data from the existing system of preliminary screening conducted over locations has been modified to include further criteria to determine the resistance of an entry:

1. Check must show high *Striga* counts to make the comparison valid.
2. Test entry *Striga* reaction should be less than 10% of the adjacent check.
3. Test entry should be selected in all the replications at a location.
4. Test entry should be selected across several locations.
5. No averages should be used.

Based on these criteria, test entries can be classified into six classes of *Striga* reaction:

Confirmed resistant (R)
Confirmed susceptible (S)

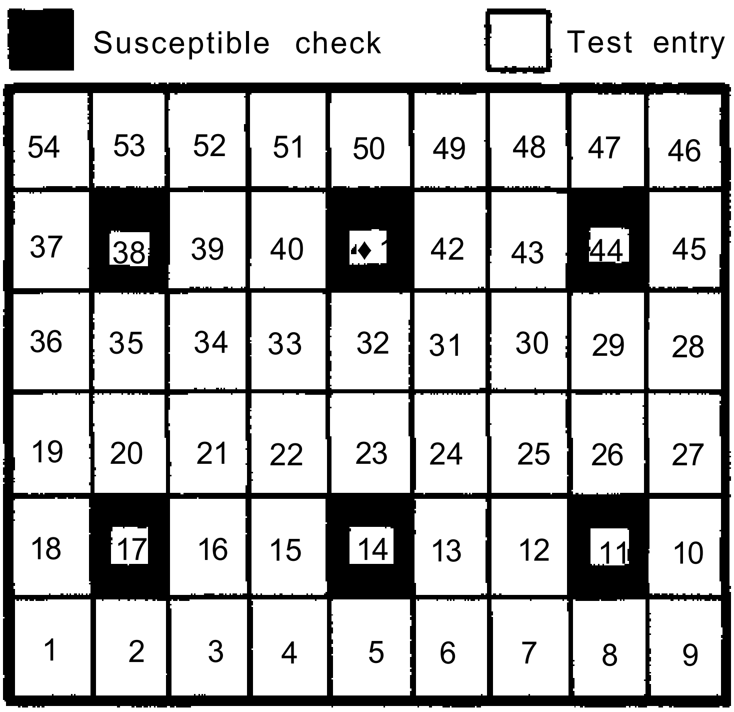

Figure 3. Field layout in the preliminary screening stage for* Striga *resistance.

Control low, therefore comparison not reliable (NR)
Resistant/susceptible (R/S)
Resistant/not reliable (R/NR)
Susceptible/not reliable (S/NR)

A confirmed resistant is an entry showing less than 10% of the *Striga* count of the adjacent control, which should show a high *Striga* count. Further, a confirmed resistant must show a valid resistance reaction across all replications and locations. A confirmed susceptible is one showing more than 10% of the *Striga* count of the control. This group also includes those that are infested irrespective of the infestation in the check. The third (NR) category comprises those entries where the comparison was not valid because the control had low *Striga* counts. The resistant/susceptible category includes entries that show various reactions across replications or locations, being resistant in some and susceptible in others. Resistant/susceptible reaction across locations may be an indication of *Striga* strain differences. The last two categories (R/NR and S/NR) are those showing different combinations of the first three reaction categories.These six classes give a set of valid criteria for evaluating

Table 3. Relative merits of selection criteria for *Striga* resistance reaction in sorghum (results from Preliminary *Striga* Trial-2, Akola, Maharashtra, India, rainy seasons 1979 and 1980).

Entry No.		1979		1980	
1979	1980	*Striga* count (% of CSH-1)	Single-unit comparison	*Striga* counts (% of CSH-1)	Single-unit comparison
1	1	7.87	R'	6.20	R
2	2	6.88	R	111.70	S
3	3	1.18	R	14.50	R
4	4	3.01	R	15.80	R
5	5	7.06	S'	4.10	R
8	6	2.43	R	38.90	S
9	7	0.14	R	4.00	R
10	8	1.67	R	21.80	S
11	9	9.54	S	34.10	S
15	10	1.63	R	122.80	S
17	11	3.54	R	4.50	R
19	12	23.38	S	98.50	S
20	13	9.38	S	11.20	R
21	14	0.93	R	3.20	R
22	15	1.94	R	0.90	R
23	16	5.61	R	11.30	S
24	17	5.27	R	15.30	S
25	18	1.84	R	10.90	R
27	19	9.66	S	61.10	S
28	20	16.91	S	9.70	R
29	21	3.84	R	13.00	R
30	22	18.05	S	15.80	S
35	23	9.63	S	25.60	S
38	24	95.80	S	68.10	S
39	25	3.21	R	12.20	S
43	26	8.34	S	20.80	R
53	27	0.59	R	24.60	R
56	29	3.21	R	4.90	R

1. R = Test entry *Striga* reaction < 10% of CSH-1, the susceptible check. S = test entry *Striga* reaction > 10% ot CSH-1. Compare Table 4.

Striga resistance, and this system of data interpretation has been designated *the single-unit* comparison (SUC).

Striga reaction data on a common set of 28 breeding lines—from the preliminary trial-2 conducted at Akola, *in* Maharashtra, India, in the 1979 and 1980 rainy seasons—were used to test the relative merits of the two types of selection criteria: (1) *Striga* counts expressed as a percentage of the adjacent systematic control averaged over replications and (2) the single-unit comparison (Table 3). Based on the averaged counts, of the 24 lines resistant in 1979, only seven remained resistant in 1980 and the number in the breakdown class (17) was very high (Table 4). Based on the single-unit comparison, out of 18 entries resistant in 1979,11 remained resistant in 1980, so nearly 60% of the entries were thus retained as resistant in both years. Therefore, the new selection criteria based on single-unit comparisons appear to be efficient in identifying field resistance to *Striga.*

Advanced Screening

This is the final stage of testing in which the confirmed resistant entries from preliminary screening are tested *in large* plots with a susceptible control plot all around the test entry. Figure 4 represents the checkerboard field layout for such a trial. Each plot is large enough (five or more rows) to allow yield and *Striga reaction to be measured fairly* accurately. The entire trial is surrounded on all four sides by a strip of the susceptible control plots. The layout could be useful in screening Striga-resistant sources and advanced generation lines that require greater precision in screening and reliable estimates of yield. It is possible to use statistical designs in this layout. The *Striga* reaction of the test entry could be adjusted by using the *Striga* reactions of four adjacent control plots as a covariate. Further, this layout is likely to reduce nonuniform *Striga* infestation resulting from differences in susceptibility among the previous season's genotypes in those plots.

Table 4. Relative merits of selections based on averaged *Striga* counts and on single-unit comparison.

A. Based on *Striga* counts[1] averaged over replications;

		1980 < 10%	1980 > 10%	Total
1979	<10%	7	17	24
	> 10%	1	3	4
Total		8	20	28

1. *Striga* counts expressed as a percentage of counts in susceptible control cv CSH-1. resistant = < 10% of control; susceptible = > 10% of control.

B. Based on single-unit comparisons[2]:

		1980 R	1980 S	Total
1979	R	11	7	18
	S	4	6	10
Total		15	13	28

2. For details of selection criteria used in single-unit comparisons, see text.

Screening for Low Stimulant Production

Breeding for *Striga* resistance at ICRISAT has the twin objectives of identifying Striga-resistant sour-

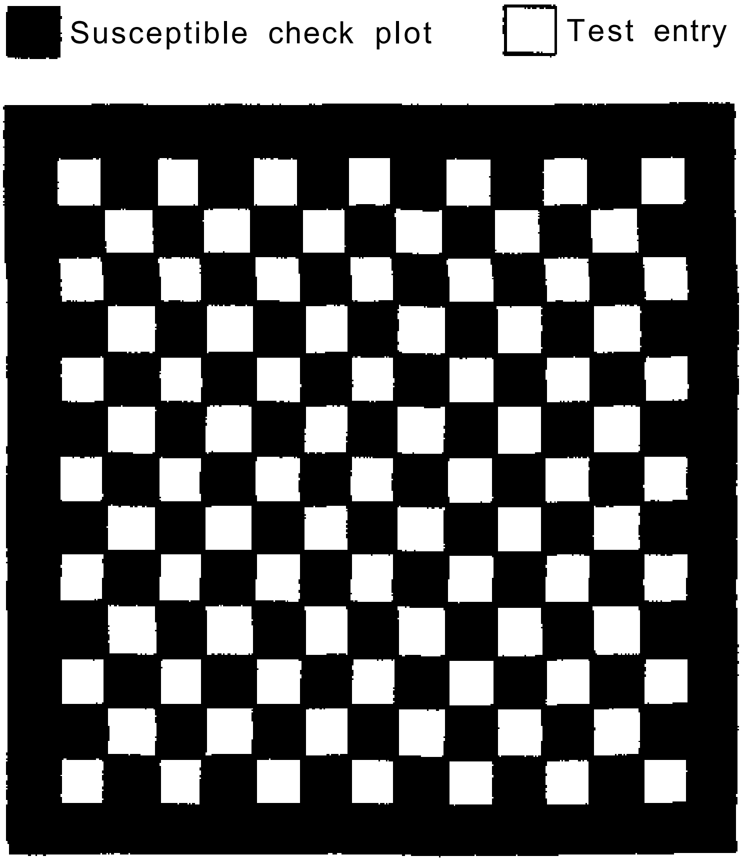

Figure 4. Checkerboard layout for advanced screening in* Striga *resistance breeding.

Table 5. Stimulant production and field reaction of the best advanced generation progenies (rainy season 1980).

Origin	Pedigree	Stimulant production of			Field reaction[1] to *Striga asiatica* at				
		Derivative[2]	Parent 1	Parent 2	Akola	Bhavanisagar	Hayatnagar	Phaltan	Patancheru
1/4	(555 x 168)-23-2-2-2	-[3]	-	+[3]	R	R	R	R	NT
1/6	(148 x 555)-19-2-1	-	+	-	S	R	R	R	NT
1/8	(555 x 168)-1-1	-	-	+	R	S	R	R	NT
1/9	(148 x 555)-bk	-	+	-	R	S	R	R	NT
1/15	(555 x 168)-23-1-5-2	+	-	+	R	S	R	R	NT
1/16	(KD-22-10 x 148)-bk	-	+	+	R	S	R	R	NT
1/21	(555 x 168)-23-1-bk	-	-	+	R	S	R	R	NT
1/37	(IS-2643 x 555)-2-1	-	-	-	R	R	R	R	NT
2/1	(555 x 168)-23-1-1	-	-	+	R	S	NT	R	R
2/3	(148 x 555)-1-2	+	+	-	R	R	NT	S	R
2/5	(148 x 555)-33-1-3	-	+	-	R	R	NT	R	R
2/7	(555 x 168)-16	-	-	+	R	R	NT	S	R
2/14	(Framida x 168)-9-2-3	-	-	+	R	R	NT	S	R
31/1	(SRN-4841 x SPV-104)-3	-	-	+	R	R	NT	R	NT
31/2	[SRN-4841 x (WABC x P-3)-2]-11-2	+	-	+	R	S	NT	R	NT
31/4	[SRN-4841 x (WABC x P-3)-3]-7-3	-	-	+	R	S	NT	R	NT
31/17	(555 x CS-3687)-8-1	-	-	+	R	R	NT	R	NT
31/19	(555 x EC-64734)-3	+	-	+	R	R	NT	R	NT
31/21	[555 x (PD x CS-3541)-29-3]-4-2-1	-	-	+	R	R	NT	R	NT
31/22	[555 x (PD x CS-3541)-29-3]-5-2-1	-	-	+	R	R	NT	R	NT
31/30	(IS-7227 x E35-1)-15-2	-	-	+	R	R	NT	R	NT
31/31	(IS-7227 x E35-1)-19-2	-	-	+	R	R	NT	R	NT
31/59	(IS-2203 x SPV-105)-3-2	+	+	+	R	R	NT	R	NT
		18- : 5+							

1. R = test entry resistant; S = test entry susceptible, based on single-unit comparison; NT = not tested.
2. Stimulant production tested against the Patancheru isolate of *S. asiatica*.
3. (-) = low stimulant production; (+) = high stimulant production.

ces and transfering the resistance to good agronomic backgrounds. During the initial years, we identified *Striga* resistance in sorghum as a function of three independent mechanisms: (1) low stimulant production by the host roots, (2) mechanical barriers to the establishment of *Striga,* and (3) antibiosis (ICRISAT 1977). Field resistance may stem from one or more of these mechanisms.

Germplasm Screening

About 14 000 sorghum germplasm lines obtained from the Genetic Resources Unit of ICRISAT have so far been screened against the Patancheru strain of S. *asiatica* in the laboratory, with the double-pot technique (Parker et al. 1977), and 640 lines have been identified as low stimulant producers.

Stimulant Production in Field Resistant Lines

During the 1980 rainy season, a set of 156 advanced-generation progenies derived from *Striga*-resistant sources x adapted-line crosses was studied for field reaction to S. *asiatica* in three trials at five locations. Twenty-three advanced generation progenies were field resistant at two to four locations (Table 5). When these lines were screened for stimulant production in the laboratory, 18 of the 23 resistant lines were low stimulant producers. Entries were reclassified based on the stimulant production, and the proportion of field resistants in each category was verified (Table 6). In all three trials at all five locations, the proportion of field resistants in the low-stimulant category was higher than the proportion of field resistants in the high-stimulant category, although all the derivatives were obtained from low- and high-stimulant crosses. These results suggested that screening for low stimulant production could be a valuable adjunct to a *Striga* resistance breeding program. If the material is screened for low stimulant production at least once during the process of selection, the chances of obtaining field resistance in the final selections appear to be better. However, these preliminary results need confirmation.

Genetics of Stimulant Production in Sorghum

A seven-parent diallel set involving two low-stimulant, field-resistant lines (SRN-4841 and IS-2221), three high-stimulant, field-resistant lines (N-13, NJ-1515, and IS-9985), and two high-stimulant susceptible lines (2219-B and CK-60-B)

Table 6. Proportions of low- and high-stimulant breeding lines of sorghum field resistant to *S. asiatica*.

			Proportion of lines resistant at											
			Akola		Bhavanisagar		Phaltan		Hayatnagar		Patancheru		Across locations	
Trial	Stimulant production	No. of lines tested	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1	Low	14	9	64.3	6	42.8	7	50.0	8	57.1			6	42.8
	High	34	10	29.4	1	2.9	7	20.6	4	11.8			1	2.9
	Total	48	19	39.6	7	14.6	14	29.2	12	25.0			7	14.6
2	Low	23	13	56.5	9	39.1	6	26.1			10	43.4	4	17.4
	High	8	3	37.5	3	37.5	0	0.0			2	25.0	0	0.0
	Total	31	16	51.6	12	38.7	6	19.4			12	38.7	4	12.9
3	Low	34	21	61.7	10	29.4	22	64.7					8	23.5
	High	43	16	37.2	7	16.3	17	39.5					2	4.6
	Total	77	37	48.0	17	22.1	39	50.6					10	12.9

was studied in the laboratory for the level of stimulant production needed to germinate the Patancheru strain of S. *asiatica.* There was a preponderance of additive over nonadditive genetic *variance* (Table 7), indicating the *usefulness of* straight selection for low stimulant production. IS-2221 was a low stimulant producer and also a good negative general combiner for low stimulant production (Table 8) and thus a good parent for use in breeding programs to incorporate this character.

Breeding Sorghums for Field Resistance to *Striga*

Identification of Sources of Resistance

Since 1977, 166 lines reported to be resistant to local strains of *Striga* were tested multilocationally to identify sources of resistance. Table 9 lists promising lines that have been tested and found reasonably stable. There is no absolute resistance to *S. asiatica* in sorghum and the best available sources are low susceptible. N-13, 555, IS-2203, IS-4202, IS-7471, and IS-9985 appear to be promising as source lines for use in breeding programs.

Table 7. Analysis of variance for combining ability for stimulant production in sorghum lines.

Source of variation	DF	Mean square
General combining ability	6	2038**
Specific combining ability	21	1580**
Error	54	111

** Significant at $P < 0.01$.

Table 8. General combining ability effects of the parents for stimulant production in a seven-parent diallel set of sorghum lines.

Parent	Stimulant production	GCA effect
SRN-4841	Low	13.57**
IS-2221	Low	-26.03**
N-13	High	4.91
NJ-1515	High	1.45
IS-9985	High	1.66
2219B	High	17.35**
CK60B	High	-12.92**

SE $(\hat{g})$ = 3.25
SE$(\hat{g}i-\hat{g}j)$ = 4.96
** Significant at $P < 0.01$.

Transfer of Resistance to Elite Backgrounds

Several hundred crosses have been made over the *past* few *years between different sources and agro*nomically elite and adapted stocks. Figure 5 indicates the flow of material for screening for field resistance to *Striga.* The absence of a reliable technique to screen segregating progenies for individual plants resistant to *Striga* in the field constitutes a major constraint to rapid progress in breeding for *Striga* resistance. The segregating material has been advanced in *Striga* sick fields and selected for low levels of susceptibility. Selection for other traits has generally been to correct undesirable traits in the original source lines while retaining *Striga* resistance, to provide good breeding stocks. In this process, many of the source lines have been eliminated, since they do not offer any good segregates. The resistant source line, 555, has been a common parent in a number of useful advanced lines.

Variability in *Striga asiatica*

Striga asiatica is widely distributed and exhibits variability in plant structure and flower color. The genus *Striga* also appears to possess intrinsic physiological differentiation leading to the existence of physiological strains. Though the existence of strains in *S. hermonthica* is indicated (King and Zummo 1977), this is yet to be established in S. *asiatica.* Preliminary observations indicate that there are morphological variants and different species that coexist as a *Striga* complex. Variation in *Striga* plants has been observed in the leaf form, branching habits, presence of roots, seed characters, and bract shape. *S. asiatica, S. densiflora, and S. angustifolia* coexist in regions of India where both rainy and postrainy sorghums are grown. In northwest India, *Striga* attacks millets and not sorghum, while in other regions it attacks sorghum, sugarcane, maize, and some minor millets but not pearl millet (Hosmani 1978). These observations thus indicate that the native *Striga* populations cannot be considered as a single *Striga* type; rather, they exist as a complex of different species, morphotypes, and probably physiological strains.

In the 1981 rainy season at Patancheru, we experimented with *S. asiatica* collected from five locations in India on one susceptible and three resistant cultivars, using the wooden-flat technique. The 75-day *Striga* counts on these lines were

Table 9. Reaction[1] of selected resistant sorghum source lines to *S. asiatica* in multilocation[2] testing, rainy seasons 1977-1980.[3]

		1977		1978				1979				1980			
S. No.	Pedigree	AKL	BSR	DWR	AKL	PNI	NAND	AKL	BSR	PNI	PTN	AKL	BSR	PTN	PCR
1	N-13	R	R	R	R	R	R	R	-	-	-	R	S	R	S
2	555	-	-	R	R	S	S	R	S	S	R	R	R	R	R
3	16-3-4	-	R	S	R	S	R	R	S	S	R	R	R	S	R
4	Serena	-	-	R	S	S	S	R	R	R	R	-	-	-	-
5	IS-2203	R	R	R	R	R	R	-	-	-	-	-	-	-	-
6	IS-4202	R	R	R	R	R	R	R	S	R	R	R	R	NR	NR
7	IS-7471	-	-	-	-	-	-	R	R	R	R	R	R	R	-
8	IS-9985	R	R	R	R	S	S	-	-	-	R	R	R	S	S
9	IS-2403C	-	-	-	-	-	-	R	S	R	R	-	-	-	-
10	IS-4242	R	R	S	R	R	S	R	S	R	S	S	S	S	NR
11	IS-5603	R	R	S	R	R	S	-	-	-	-	R	R	R	S
12	IS-6041	-	-	-	-	-	-	R	S	R	R	S	S	R	-
13	IS-6942	R	R	R	R	S	S	S	S	S	S	R	R	R	S
14	IS-7091	-	-	-	-	-	-	R	S	R	R	S	S	R	-
15	IS-7245	-	-	-	-	-	-	R	S	S	R	R	S	S	-
16	SRN-4841	R	R	S	R	S	S	R	S	S	R	R	R	S	S
17	NJ-1515	R	R	R	R	S	R	R	S	R	R	S	S	S	S
18	SRN-4882B	-	-	R	R	S	S	R	R	R	R	S	R	R	R

1. R = resistant; S = susceptible; NR = resistance not reliable.
2. AKL = Akola; BSR = Bhavanisagar; DWR = Dharwar; PNI = Parbhani; NAND = Nandyal; PTN = Phaltan; PCR = Patancheru.
3. 1977, 1978 results based on *Striga* counts expressed as percentage of control cv CSH-1, with $< 10\%$ = resistant, $> 10\%$ = susceptible; 1979 and 1980 results based on single-unit comparisons.

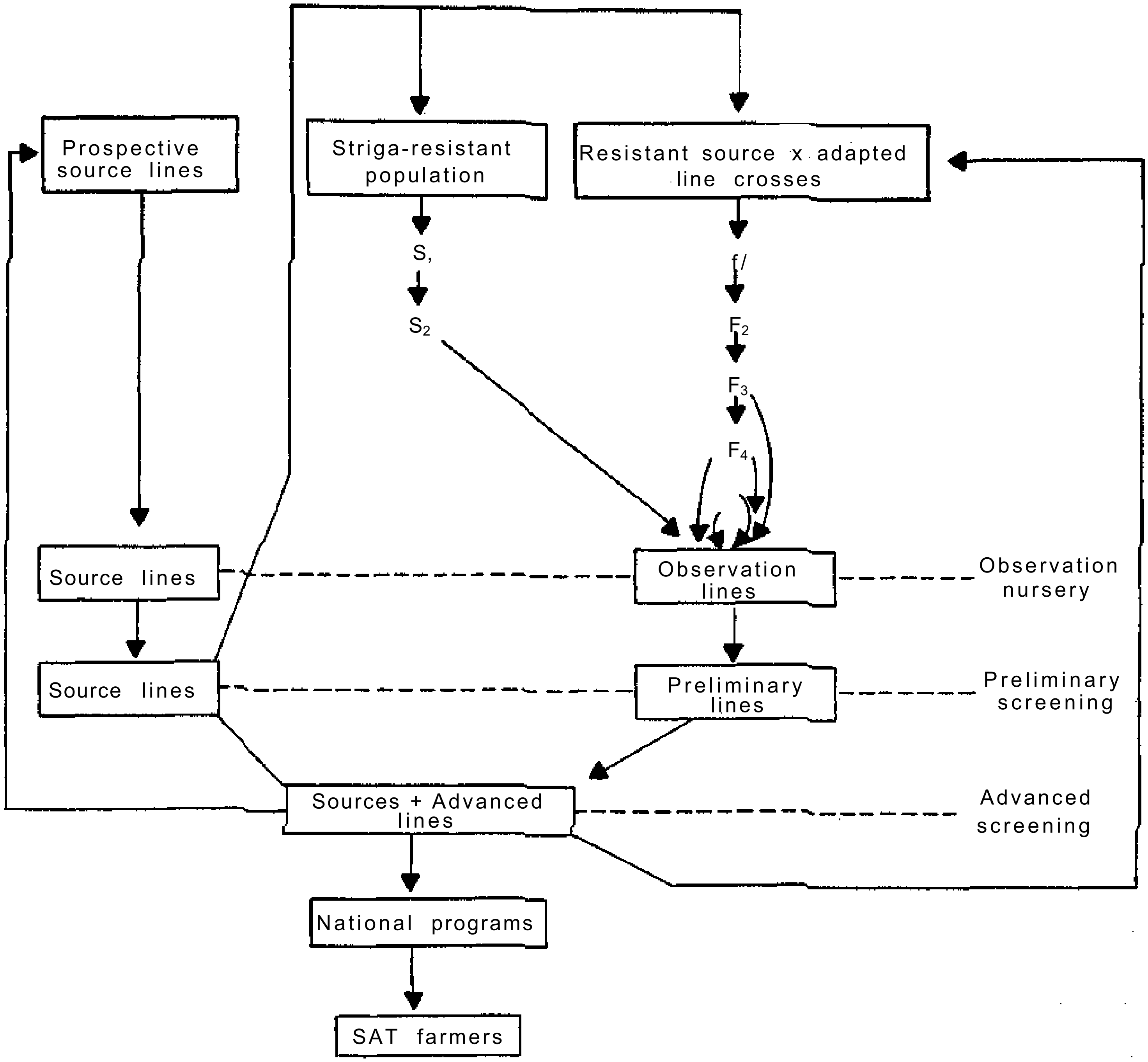

Figure 5. Flowchart of material for screening for field resistance to Striga.

expressed as a percentage of the susceptible control, Swarna. A split-plot design was used to analyze data, with strains of Striga as main plots and cultivars as subpiots. Analysis of variance (Table 10) showed significant strain x cultivar interactions, indicating the differential reaction of sorghum cultivars to Striga collected from different locations. Anova also indicated significant differences among cultivars. N-13 and IS-5106 were resistant against Striga from all locations, while SRN-4882B was resistant to Striga from three locations and susceptible to Striga from the other two (Table 11). Such resistance across Striga strains is a useful indication of stable resistance in a sorghum cultivar.

Priorities for Future Research on Striga

Host-Parasite Relationships

Significant progress has been made in understanding the nature, action, artificial synthesis, and use of stimulants. An array of lines with low stimulant production has been identified. However, very little is yet understood about the mechanical and chemical barriers that hinder parasite establishment. Identification of sorghum lines possessing these mechanisms and an understanding of their interactions

Table 10. Analysis of variance for *Striga* counts in experiment to determine differential reaction of sorghum cultivars to *Striga* strains.

Source of variation	DF	MS
Replications	2	2750
Strains	4	25330
Error (A)	8	9813
Cultivars	3	212183**
Strains x cultivars	12	20999*
Error (B)	30	7501

* Significant at $P < 0.05$ ** Significant at $P < 0.01$.

with other mechanisms would considerably assist breeding.

Environmental Interactions Influencing *Striga*

Quantified information on the influence of various environmental factors on *Striga* is insufficient. Such information would be useful for (1) increasing the *Striga* infestation by simulating these factors in *Striga* sick fields for screening purposes and (2) avoiding the occurrence of these factors while formulating cultural practices to reduce *Striga* attack.

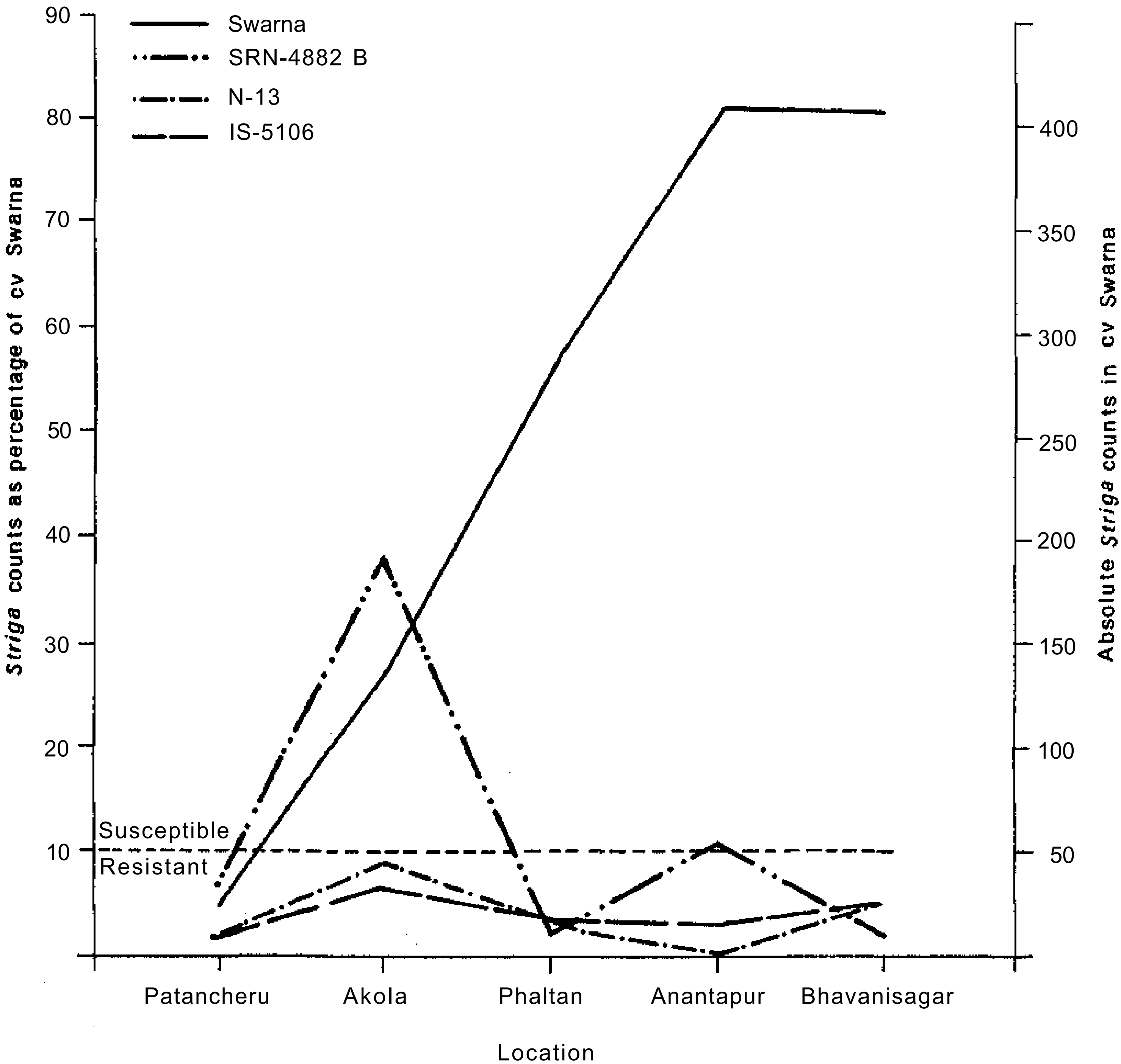

Figure 6.* Striga *reactions of tour cultivars of sorghum* Striga asiatica *collected from five locations.

Table 11. Effect of S. *asiatica* collected at five locations on three resistant sorghum cultivars (75-day counts expressed as percentages; wooden-flat; cv Swarna, the susceptible control, taken as 100%).

Cultivar	*Striga* collected from Patancheru	Akola	Phaltan	Anantapur	Bhavanisagar	Average
SRN-4882B (R)[1]	6.15	38.44	2.12	10.78	2.04	8.92
N-13(R)	1.53	8.75	2.35	0.82	4.40	3.21
IS-5106(R)	1.53	6.08	3.41	3.29	4.65	4.04
Swarna (S)[1]	100.00	100.00	100.00	100.00	100.00	100.00

1. R = resistant; S = susceptible.

Screening Methodology

Intensive research is required on developing new screening methods, especially to screen single plants for resistance to *Striga.* Efforts are also required to refine existing field-screening procedures to identify resistant material. Real progress can be made only when techniques are devised to produce consistently high levels of attack in the field.

Management of *Striga* Sick Fields

Agronomic practices to develop and manage *Striga* sick fields are not well developed, and more research is needed in this direction. In the initial choice of a field for *Striga* research, particular emphasis is required on the optimum soil type for *Striga* growth, and on fertilization practices—both dosage and timing—land preparation, intercultivation, and other management practices that will remove other weeds and allow only *Striga* to be established.

Species and Race Complexes

It is suspected that the distribution of *Striga* species follows specific environmental patterns. Morphological variants have also been noticed in the native *Striga* complexes. Studies are required to understand the pollination systems, natural crossing, and different morphological or physiological types of *Striga.*

Acknowledgment

The technical assistance of B. Raghavender is acknowledged.

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Discussion

Musselman:
I suspect that *Striga asiatica* and S. *densiflora* may be related. For example, there is no obvious difference between the seed-coat morphology of the two species. Could S. *densiflora* be one "phase" of variation in S. *asiatica?*

Vasudeva Rao:
I agree that there are strong possibilities that they are related. However, with reference to seed-coat ornamentation, we have found conspicuous differences between them. Proof for the exact relation is not available at present.

Musselman:
1. Has any work been done to determine the differ-

ence between the number of seedlings that don't emerge and those that do?
2. Are any roots present that do not end in haustoria?

Vasudeva Rao:
1. Very preliminary work on 25 varieties in two replications in wooden flats indicated that the correlation coefficient between the numbers of aerial and subterranean *Striga* at harvest was nonsignificant. It appeared to us that given a favorable soil environment, all the *Striga* that successfully establish on a host root can emerge above the ground. We have not worked on the differences in *Striga* emergence between resistant and susceptible varieties.
2. We have not carefully observed whether there are roots present that do not end in haustoria.

Lanting:
I have observed in fields a heavy attack of the spittle bug, but at the same time a lot of *Striga* attack. So I don't think that the spittle bug is of real value in controlling *Striga.* What are the results in India?

Vasudeva Rao:
We have noticed spittle bug on *Striga* plants as well as other associated grasses. We did not notice any damage to *Striga.*

Mercer-Quarshie:
How laborious is the advanced screening technique compared with the method used by Dr. Ramaiah and from which he has been able to identify good resistant varieties?

Vasudeva Rao:
The greater the number of entries, the more laborious the advanced screening will become. We feel advanced screening could be very useful when valid comparisons are required between resistant and susceptible lines. The checkerboard layout will be useful in farmer's field demonstrations. The number of entries should be limited to a few in order to limit labor requirements.

Christensen:
One of the drought-resistance tests used is to grow sorghum in sand pots, withdrawing the water for a long period during growth. Could this be combined with *Striga* pot tests?

Vasudeva Rao:
Yes. This is certainly a very useful possibility of the seed-pan technique.

Ba, Khalidou:
What progress has ICRISAT made with biological control of *Striga?*

Vasudeva Rao:
ICRISAT *Striga* activities do not include biological control; however, some casual observations indicate that some insects (especially gall insects) and some fungi occur on S. *asiatica* in India.

Sharma:
Have you tried a honeycomb arrangement with the susceptible entry in the center for screening at early as well at the later stages of the breeding program? This system is likely to have two advantages: (1) give better control of CV and (2) accommodate more test entries than the checkerboard layout.

Vasudeva Rao:
The honeycomb layout is probably useful for single-plant screening for *Striga* resistance. The layout we use in the preliminary screening stage is an extension of the honeycomb layout, with similar advantages.

Criblage des cultivars de petit mil pour la résistance au *Striga hermonthica*

Z. G. Roger et K. V. Ramaiah*

Résumé

Criblage de cultivars de petit mil pour la résistance au Striga hermonthica : *Le présent rapport comporte les résultats de deux années d'évaluation de cultivars de petit mil, effectuée en Haute-Volta en champs paysans fortement infestés de* Striga hermonthica *et au Niger à la Station de recherche de Tarna, à Maradi. Ces résultats montrent qu'il existe un espoir dans l'exploitation de la résistance de la plante-hôte. Un certain nombre de variétés locales et des descendances de sélection ont été identifiées comme étant moins sensibles, parmi lesquelles Serere 2A-9, 80S-224, P-2671 et P-2950. Il est envisagé d'établir des parcelles à bonne infestation et de développer de meilleures techniques de criblage.*

Deux espèces principales de *Striga* parasitent le petit mil, le *S. asiatica* en Inde et le *S. hermonthica* en Afrique. Peu de recherches ont été menées antérieurement sur la résistance de cultivars de mil au *Striga* en Inde (Uttaman 1950; Krishnaiah et Rao 1968; Mathur et Bhargava 1971) et en Afrique (Singh 1978; Ogborn 1978; Lawrence 1977). Le programme sur le *Striga* de l'ICRISAT a démarré, en 1979, en Haute-Volta pour les recherches sur le *Striga* du sorgho et au Niger pour le *Striga* du petit mil. Le programme du Niger, à Maradi, n'a pas reçu l'attention nécessaire à cause de l'absence d'une assistance technique. La plupart des travaux sur le petit mil sont menés au nord de la Haute-Volta en champs paysans naturellement infestés de *Striga* et à la Station de recherches de Tarna, à Maradi, utilisée comme point d'appui. Les objectifs de ce programme sont les suivants :

1. Développement de techniques de criblage;
2. Identification de cultivars de mil résistants au *Striga*;
3. Renforcement de la résistance obtenue par l'inter-croisement entre les différentes sources;
4. Incorporation des gènes de résistance dans les composites de mil ayant un haut rendement;
5. Etude des races physiologiques de *Striga* et leur signification dans le développement des cultivars et des composites de mil à résistance stable et à spectre large.

*ICRISAT, Ouagadougou, Haute-Volta.

Matériel et méthode

Matériel

Pendant la campagne 1979, deux essais ont été conduits. L'Essai international pour l'observation du *Striga* chez le petit mil (IPSOT) comprenait de 27 à 32 entrées que Lawrence (1977) à Ouahigouya (Haute-Volta) et Singh (1978) à Maradi (Niger) ont rapporté comme étant moins sensibles au *Striga*. Cet essai a été conduit à Ouahigouya et Thiou en Haute-Volta et à Maradi au Niger. Le deuxième est l'Essai international d'adaptation du petit mil (IPMAT) qui comprenait 21 entrées. En 1980, deux essais ont été mis en place, un essai de 90 entrées comportant des variétés locales ouest africaines et quelques sélections avancées par autofécondation provenant des essais de 1979. Le deuxième essai comprenait 63 lignées inbreds et des descen-

International Crops Research Institute for the Semi-Arid Tropics. 1983. Proceedings of the Second International Workshop on *Striga*, 5-8 October 1981, IDRC/ICRISAT, Ouagadougou, Upper Volta. Patancheru, A.P., India: ICRISAT.

dances F_3 obtenues du Centre ICRISAT à Patancheru en Inde.

Méthode

Au cours des deux années, les essais ont été conduits en champs naturellement infestés de *Striga* à Ouahigouya (1979) et Aourèma (1980) en Haute-Volta. Aucune inoculation artificielle n'a été effectuée à cause des risques importants de rendre désormais les champs des paysans impropres à la culture du mil. A la Station de recherche de Kamboinsé des parcelles à infestation artificielle n'ont pas été mises en place comme pour le sorgho parce que le petit mil dans cette région est pratiquement peu attaqué par le *Striga*.

Le dispositif expérimental utilisé est le bloc

Tableau 1. Resultats de l'Essai international pour l'observation du *Striga* chez le petit mil (IPSOT) contre le *Striga hermonthica*.

		Echelle moyenne du *Striga*			Poids des epis (kg/ha)
Numero	Origine/Pedigree	Ouahigouya	Maradi	Moyenne	Maradi
1	Serere 2A-9 (ICI-266)	2,0	1,8	1,9	3500
2	A836 x J1798-32-2-1 -4	1,7	2,0	1,9	4250
3	J104	-	2,0	2,0	590
4	111B	1,3	2,5	2,0	3330
5	BJ-104	2,0	2,0	2,0	4210
6	A836 x J1798-32-2-4-3	2,0	2,0	2,0	2250
7	MBH-110	2,0	2,3	2,1	3790
8	SD2 x Ex B (D-1088)-2-1	2,7	2,0	2,3	3960
9	Terrain local	3,0	2,5	2,6	8460
10	SSC-K77	1,7	3,3	2,6	3500
11	J1623 x 700490-2-6-2	3,0	2,3	2,6	3380
12	G73-K77	3,0	2,5	2,7	4710
13	3/4 Souna	2,0	3,3	2,7	4130
14	B282	1,7	3,5	2,7	2420
15	Syn. 7703 (T)	-	2,8	2,8	4670
16	MC-P76	-	2,8	2,8	3500
17	DC-3	3,0	2,8	2,9	3670
18	SDN-347-1	3,3	2,5	2,9	3460
19	J1188 x 700780-15-4	2,3	2,3	2,9	4800
20	A836 x 700651-3-1	2,7	3,0	2,9	2880
21	WC-C75	-	3,0	3,0	4250
22	IVS-A75	2,7	7,3	3,0	4710
23	T-166-2 x 700523-3-4-6	4,0	2,3	3,0	4130
24	MC-C75	-	3,0	3,0	3300
25	NEC Bulk	2,7	3,3	3,0	2250
26	ICMS-7708 (Sy 1)	3,7	3,0	3,3	4380
27	IVS-P77	3,7	3,3	3,5	5750
28	3/4 HK	4,7	2,8	3,6	6670
29	WC-K77	3,3	3,8	3,6	3920
30	Ex-Bomu	4,0	3,3	3,6	5090
31	SSC-H76	3,7	3,8	3,7	4000
32	NCS x 75	4,0	4,0	4,0	4170
	Moyenne d'essai	2,8 ± 1,35	2,8 ± 1,08		3844 ± 1480

complètement randomisé. Les critères d'évaluation prennent en compte : le niveau d'infestation de *Striga* dans les parcelles, noté de l'échelle 1 à 5 (1 = sans *Striga*, 5 = forte densité de *Striga*) et l'expression agronomique notée aussi de l'échelle 1 à 5 (1 = excellent, sans dommage apparent de *Striga*, 5 = mauvais, ayant été tué complètement par le *Striga*).

Résultats

Résultats de 1979

L'Essai international pour l'observation du* Striga *chez le petit mil (IPSOT). Les moyennes des échelles des niveaux d'infestation des essais d'Ouahigouya et de Maradi sont présentées au Tableau 1. Les moyennes de 2,8 aux deux essais indiquent un niveau d'infestation satisfaisant. Aucune des entrées testées dans les deux localités n'a été totalement indemne de *Striga*. Les entrées les moins sensibles au *Striga* ont été Serere 2A-9, A836 × J1798-32-2-1-4, J-104, 111B, A836 × J1798-32-2-4-3, BJ-104 et MBH-110. Plusieurs sélections des plantes individuelles ont été avancées pour des criblages ultérieurs. Les rendements obtenus à Maradi montrent qu'aucune entrée n'est meilleure que le témoin local.

L'essai à Thiou a été semé tard à cause de l'installation tardive des pluies et les entrées ont souffert de la sécheresse en fin de cycle. Aucune donnée significative n'a pu être obtenue. Un certain nombre de sélections ayant survécu à la sécheresse ont été avancées pour être évaluées en 1980.

L'Essai international d'adaptation du petit mil (IPMAT). Les moyennes des échelles des niveaux d'infestation de l'essai conduit à Ouahigouya sont présentées au Tableau 2. La moyenne de 3,4 indique un essai ayant un niveau d'infestation satisfaisant. Aucune entrée n'a été indemne de *Striga*. PHB-14, NHB-3 et MBH-110 ont été moins sensibles.

Tableau 2. Résultats de l'Essai international d'adaptation du petit mil (IPMAT) contre le *Striga hermonthica* à Ouahigouya, Haute-Volta.

Numéro	Origine/Pedigree	Echelle moyenne de *Striga*[a]
1	NHB-3	1,5
2	PHB-14	1,5
3	MBH-110	2,5
4	MBH-124	2,5
5	ICH-220	2,5
6	MC-K77	2,5
7	SSC-H76	3,0
8	ICH-165	3,0
9	ICMS-7818	3,0
10	ICMS-7817	3,0
11	ICMS-7803	3,5
12	NEC-H77	3,5
13	Témoin local	3,5
14	UCH 4	4,0
15	IVS 5454	4,0
16	WC-C75	4,0
17	ICH-241	4,0
18	IVS-P77	4,5
19	WC-B77	4,5
20	ICMS-7703	5,0
21	ICMS-7819	5,0
	Moyenne d'essai	3,4 ± 1,15

a. Les entrées ont été notées sur une échelle de 1 à 5 : 1 = peu de *Striga*; 5 = plusieurs *Striga*.

Résultats de 1980

Le Tableau 3 présente les résultats de l'essai des variétés locales ouest africaines et les sélections issues des essais de 1979. L'essai a souffert de la sécheresse en fin de saison au nord de la Haute-Volta et dans d'autres parties du pays. L'infestation de *Striga* était satisfaisante avec une moyenne d'essai de 3,6. La moyenne pour l'expression agronomique de 3,6 indique que les entrées en général sont en-dessous de la performance moyenne dans le champ de *Striga*. Considéré dans ce cadre, le Tableau 3 montre quelques sélections prometteuses contre le *Striga*. Serere 2A-9 continue d'être moins sensible, mais son expression agronomique est plutôt pauvre. D'une façon encourageante, deux sélections 80S-224 et 80S-228, de l'essai IPSOT réalisé à Thiou en 1979 ont été indemnes de *Striga* dans les trois répétitions. Deux autres entrées, SDN-347-1 et 80S-239 (une variété locale de Tenkodogo, Haute-Volta), ont été aussi libres de *Striga* dans les trois répétitions. Les entrées P-2671, P-2950, P-1524, 80S-210 étaient moins

Tableau 3. Comportement des cultivars de petit mil selectionnes a Aourema, Haute-Volta.

			Moyenne[a]	
Numero	Origine	Pedigree	Echelle de *Striga*	Echelle agronomique
1	80S-224	Selection de Thiou-2	1,0	2,7
2	80S-228	Selection de Thiou-6	1,0	3,0
3	SDN-347-1	—	1,0	3,0
4	80S-239	Tenkodogo Local-1	1,0	5,0
5	80S-226	Selection de Thiou-4	1,3	3,0
6	80S-210	Bitou Local	1,3	5,0
7	P-2671	—	1,7	2,0
8	Serere 2A-9	—	1,7	4,0
9	P-2950	—	2,0	2,5
10	P-1524	—	2,0	3,0
11	80S-238	Zandkom Local	2,0	5,0
	Moyenne d'essai		3,6	3,6

a Les entrees ont ete notees sur une echelle de 1 a 5. Echelle de *Striga:* 1 = peu de *Striga;* 5 = plusieurs *Striga.* Echelle agronomique: 1 = excellent, sans dommage apparent; 5 = mauvais, dommage grave cause par le *Striga.*

sensibles. Les entrées 80S-224, P-2671 et P-2950 étaient agronomiquement satisfaisantes.

L'essai de 63 lignées inbreds et de descendances F_3 du Centre ICRISAT s'est montré inférieur aux autres. Deux lignées inbreds, 5258 et 5237, ont été retenues pour être évaluées en 1981.

Discussion

L'un des principaux facteurs qui diminuent le rendement du petit mil dans les pays du Sahel de l'Afrique de l'Ouest est le *Striga hermonthica*. Les sécheresses répétées, un sol pauvre et le choix limité de cultures rendent le problème du *Striga* encore plus aigu. Dans le passé, il n'y a pas eu d'efforts sérieux pour lutter contre ce parasite dans la région. Ainsi, l'ICRISAT a été handicapé au début de son travail par le manque de matériel de base.

Les résultats présentés dans ce rapport suscitent un certain espoir dans l'exploitation de la résistance chez le petit mil. L'absence de sources de forte résistance dans le matériel évalué jusqu'à maintenant montre que des efforts intensifs de sélection doivent être faits pour atteindre le niveau de résistance souhaitée en partant des génotypes moins sensibles. Deux voies peuvent être utilisées : la méthode classique de sélection pedigree et les procédures appropriées d'amélioration des populations.

Un certain nombre de variétés locales de Haute-Volta ayant présenté une attaque nulle de *Striga* en champs paysans infestés, collectées en 1979, se sont montrées moins sensibles au *Striga*. Ces variétés venant du sud (autour de la latitude 11°N) ne fleurissent pas au nord (audessus de la latitude 13°N) qui a une saison des pluies relativement plus courte. L'introduction des variétés locales d'une région à l'autre est ainsi limitée. Ces variétés doivent passer par un processus de sélection avant d'être introduites dans une autre région. Pour tester les mils photosensibles à cycle long, une localité à forte pluviométrie dans le sud est recherchée. Farako-Bâ a été identifié pour ces tests. En intercroisant les variétés photosensibles et non photosensibles et en soumettant les générations en ségrégation aux deux environnements extrêmes on pourrait briser l'adaptation spécifique très étroite des régions.

Les résultats de ces deux années de test demandent à être confirmés par des techniques de criblage appropriées. Il existe aussi un besoin urgent de développer des parcelles infestées, d'élaborer des techniques de criblage et des critères de sélection, etc.

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Screening of Pearl Millet Cultivars for Resistance to *Striga hermonthica*

Z.G. Roger and K.V. Ramaiah*

Abstract

This paper presents the results of 2 years' testing of pearl millet varieties in fields heavily infested with Striga hermonthica *in Upper Volta and at the Tama Research Station at Maradi, Niger. The results show promise for exploiting host plant resistance. A few local varieties and breeding progenies have been identified as less susceptible, especially Serere 2A-9, 80S-224, P-2671, and P-2950. It is proposed to develop a good sick plot and appropriate screening techniques.*

Pearl millet is attacked mainly by two *Striga* species, S. *asiatica* in India and S. *hermonthica* in Africa. Hitherto very little research has been done on *Striga* resistance of millet cultivars in India (Uttaman 1950; Krishnaiah and Rao 1968; Mathur and Bhargava 1971) or in Africa (Singh 1978; Ogborn 1978; Lawrence 1977). The ICRISAT *Striga* program started in 1979 in Upper Volta for sorghum and in Niger for pearl millet. The Niger program in Maradi has not received much attention due to lack of technical support. The bulk of the work on pearl millet is carried out in northern Upper Volta in farmers' fields naturally infested by *Striga* and at the Tarna Research Station in Maradi. The objectives of the program are:

1. Developing screening techniques.
2. Identifying Striga-resistant millet cultivars.
3. Increasing resistance levels through intercrossing of different sources of resistance.
4. Incorporating resistance genes in high-yielding millet composites.
5. Studying physiological races of *Striga* and their roles in development of millet cultivars and composites with broad-spectrum and stable resistance.

*ICRISAT, Ouagadougou, Upper Volta.

Materials and Methods

Materials

Two trials were carried out in the 1979 cropping season. The International Pearl Millet *Striga* Observation Trial (IPSOT) comprised 27 to 32 entries reported to be less susceptible to *Striga* by Lawrence (1977) at Ouahigouya, Upper Volta, and by Singh (1978) at Maradi, Niger. This trial was conducted at Ouahigouya and Thiou in Upper Volta and at Maradi in Niger. The International Pearl Millet Adaptation Trial (IPMAT) included 21 entries. Two trials were carried out in 1980; one comprised 90 entries including local landraces of West African origin and a few elite selections from the 1979 trials. The second trial consisted of 63 inbred lines and F_3 progenies from ICRISAT Center, Patancheru, India.

Methods

The trials were conducted in fields naturally infested with *Striga* at Ouahigouya (1979) and at Aourema, Upper Volta (1980). There was no artificial infestation as it would render these fields unsuitable for millet cultivation. At the Kamboinse Research Station artificially infested plots were not developed because in this region pearl millet is almost *Striga-iree.*

International Crops Research Institute for the Semi-Arid Tropics. 1983. Proceedings of the Second International Workshop on *Striga,* 5-8 October 1981, IDRC/ICRISAT, Ouagadougou, Upper Volta. Patancheru, A.P., India: ICRISAT.

The experimental design used here is the complete randomized block.The parameters evaluated on a 5-point scale include: *Striga* emergence level in plots (1 = no *Striga* and 5 = high density of *Striga*) and agronomic expression (1 = excellent, without apparent *Striga* damage, and 5 = completely destroyed by *Striga*).

Results

Results of 1979 Trials

The International Pearl Millet Striga *Observation Trial* (*IPSOT*). The mean *Striga* emergence levels in the trials conducted in Ouahigouya and Maradi are presented in Table 1. The trial mean of

Table 1. Results of the International Pearl Millet *Striga* Observation Trial (IPSOT) against *Striga hermonthica* in Upper Volta and Niger.

	Mean *Striga* emergence			
Origin/Pedigree	Ouahigouya, Upper Volta	Maradi, Niger	Mean	Head wt (kg/ha) Maradi
Serere 2A-9 (ICI-266)	2.0	1.8	1.9	3500
A-836 x J1798-32-2-1 -4	1.7	2.0	1.9	4250
J-104	-	2.0	2.0	590
111-B	1.3	2.5	2.0	3330
BJ-104	2.0	2.0	2.0	4210
A836 x J1798-32-2-4-3	2.0	2.0	2.0	2250
MBH-110	2.0	2.3	2.1	3790
SD-2 x ExB(D-1088)-2-1	2.7	2.0	2.3	3960
Temoin local	3.0	2.5	2.6	8460
SSC-K77	1.7	3.3	2.6	3500
J1623 x 700490-2-6-2	3.0	2.3	2.6	3380
G73-K77	3.0	2.5	2.7	4710
3/4 Souna	2.0	3.3	2.7	4130
B-282	1.7	3.5	2.7	2420
Syn. 7703 (T)	-	2.8	2.8	4670
MC-P76	-	2.8	2.8	3500
DC-3	3.0	2.8	2.9	3670
SDN347-1	3.3	2.5	2.9	3460
J1188 x 700780-15-4	2.3	3.3	2.9	4800
A836 x 700651 -3-1	2.7	3.0	2.9	2880
WC-C75	-	3.0	3.0	4250
IVS-A75	2.7	3.3	3.0	4710
T-166-2 x 700523-3-4-6	4.0	2.3	3.0	4130
MC-C75	-	3.0	3.0	3300
NEC Bulk	2.7	3.3	3.0	2250
ICMS-7708 (Sy 1)	3.7	3.0	3.3	4380
IVS-P77	3.7	3.3	3.5	5750
3/4 HK	4.7	2.8	3.6	6670
WC-K77	3.3	3.8	3.6	3920
Ex-Bornu	4.0	3.3	3.6	5090
SSC-H76	3.7	3.8	3.7	4000
NCS x 75	4.0	4.0	4.0	4170
Trial mean	2.8 ± 1.35	2.8 ± 1.08		3844 ± 1480

2.8 in each location indicates a satisfactory infestation level. None of the entries tested at both locations was totally *Striga*-free. The less susceptible lines were Serere 2A-9, A836 x J1798-32-2-1-4, J-104, 111B, A836 x J1798-32-2-4-3, BJ-104, and MBH-110. Several individual plant selections were advanced for further screening. At Maradi no entry performed better than the local control.

The trial at Thiou was sown late because rains arrived late. The entries were affected by drought at the end of the cycle so no significant data could be obtained. Still some selections that withstood the drought were advanced for testing in 1980.

The International Pearl Millet Adaptation Trial (IPMAT). The mean *Striga* emergence levels in the trial carried out at Ouahigouya are presented in Table 2. The mean of 3.4 indicates a satisfactory emergence level. No entry was free of *Striga,* but PHB-14, NHB-3, and MBH-110 were less susceptible.

Results of 1980 Trials

Table 3 presents the trial results of local landraces of West African origin and the elite selections from the 1979 trials. The drought in northern Upper Volta and other parts of the country at the end of the cycle affected the trial. *Striga* infestation was satisfactory with a trial mean of 3.6. The mean agronomic expression of 3.6 indicates that in general the performance is below average in a *Striga*-infested field. Table 3 shows some promising *Striga*-resistant

Table 2. Results of the International Pearl Millet Adaptation Trial (IPMAT) against *Striga hermonthica* at Ouahigouya, Upper Volta.

Origin/Pedigree	Mean *Striga*[1] emergence
NHB-3	1.5
PHB-14	1.5
MBH-110	2.5
MBH-124	2.5
ICH-220	2.5
MC-K77	2.5
SSC-H76	3.0
ICH-165	3.0
ICMS-7818	3.0
ICMS-7817	3.0
ICMS-7803	3.5
NEC-H77	3.5
Temoin local	3.5
UCH-4	4.0
IVS-5454	4.0
WC-C75	4.0
ICH-241	4.0
IVS-P77	4.5
WC-B77	4.5
ICMS-7703	5.0
ICMS-7819	5.0
Trial mean	3.4 ±1.15

1. Entries were scored on a scale of 1 to 5: 1 = low *Striga* counts; 5 = high *Striga* counts.

Table 3. Performance[1] of pearl millet cultivars selected at Aourema, Upper Volta.

Entry	Origin	Pedigree	Mean *Striga* emergence	Mean Agronomic expression
1	80S-224	Selection from Thiou-2	1.0	2.7
2	80S-228	Selection from Thiou-6	1.0	3.0
3	SDN-347-1	-	1.0	3.0
4	80S-239	Tenkodogo local-1	1.0	5.0
5	80S-226	Selection from Thiou-4	1.3	3.0
6	80S-210	Bitou local	1.3	5.0
7	P-2671	-	1.7	2.0
8	Serere 2A-9	-	1.7	4.0
9	P-2950	-	2.0	2.5
10	P-1524	-	2.0	3.0
11	80S-238	Zandkom local	2.0	5.0
	Trial mean		3.6	3.6

1. Entries were scored on a scale of 1 to 5. *Striga* emergence: 1 = low; 5 = high counts.
Agronomic expression: 1 = excellent; no apparent damage; 5 = poor, severe *Striga* damage.

selections. Serere 2A-9 continues to be less susceptible though its agronomic expression is poor. Two selections, 80S224 and 80S228, from the 1979 IPSOT trial in Thiou were *Striga*-free in three replicates. Two other entries, SDN 347-1 and 80S-239 (a local variety from Tenkodogo, Upper Volta) also were *Striga-free* in three replicates. Entries P-2671, P-2950, P-1524, 80S-226, and 80S-210 were less susceptible. Entries 80S-224, P-2671, and P-2950 were agronomically satisfactory.

The trial with 63 inbred lines and F_3 progenies from ICRISAT Center was inferior to the others, but two inbred lines (5258 and 5237) were retained for further testing in 1981.

Discussion

Striga hermonthica is one of the main yield-reducing factors in pearl millet in the West African Sahelian countries. Continuous droughts, infertile soil, and the limited number of crop options have aggravated the *Striga* problem. Until now, no serious effort has been made to eradicate this parasitic weed in this region and initially, ICRISAT was handicapped in its research work by the lack of basic information.

However, the results given here show that resistance of pearl millet is a possible solution. The absence of sources of high resistance in the test material stresses the need for an intensive breeding program starting with less susceptible genotypes to obtain the desired resistance level. There are two possible approaches for this effort: the classical method of pedigree selection and population improvement.

A few local Voltaic varieties found to be *Striga*-free in infested fields and collected in 1979 are less susceptible to *Striga.* As these varieties are from the south (about 11 ° N latitude) they do not flower in the north (above 13° N latitude), which has a relatively short rainy season. This is an obstacle to introducing local varieties from one region to another as they must pass through a selection process before being introduced in another region. Long-duration photosensitive varieties needed to be tested at a high-rainfall location in the south; Farako-Ba was identified for these trials. This specificity of adaptation could be overcome by crossing photosensitive with photoinsensitive varieties and by subjecting the segregating generations to two extremely different environments.

The trial results over these 2 years need to be confirmed by appropriate screening techniques. There is also an urgent need to develop sick plots and screening techniques, and to define selection criteria.

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See page 81.

Striga Studies and Control in Nigeria

A. Tunde Obilana*

Abstract

Sorghum, gero *millet (photoinsensitive pearl millet),* maiwa *millet (photosensitive pearl millet),* dauro *millet (transplanted pearl millet), maize, and cowpeas are confirmed hosts of* Striga *in the Nigerian savannas. The distribution and host range of the species, particularly* S. hermonthica *and* S. gesnerioides, *in the four different savanna zones are indicated.*

Research methodology and evaluation methods for Striga *studies related to host resistance and integrated control measures are discussed. The breeding procedures used in developing resistant cultivars and the genetic studies described are for sorghum. Very little work has been done on millets, maize, or cowpeas. Developing resistant cultivars in these crops, especially millets, maize, sorghum, and cowpeas, requires an urgent research input.*

Résumé

Etudes et lutte contre le Striga *au Nigeria : Le sorgho, le mil* gero *(petit mil non photosensible), le mil* maiwa *(petit mil photosensible), le mil* dauro *(petit mil repiqué), le maïs et le niébé sont des hôtes confirmés du* Striga *dans les savanes du Nigeria. La distribution et les différents hôtes des espèces de* Striga, *en particulier le* S. hermonthica *et le* S. gesnerioides, *dans les quatre zones de savanes sont présentés dans cette communication.*

La méthodologie de recherche, ainsi que les méthodes d'évaluation pour les études sur le Striga *concernant la résistance des hôtes et les mesures de lutte intégrée sont décrites. Le processus de sélection des cultivars résistants et les études génétiques sont décrits pour le sorgho. En ce qui concerne le mil, le maïs et le niébé, peu de recherches ont été effectuées. Il est urgent de développer des cultivars résistants pour toutes ces espèces, surtout le petit mil.*

Striga spp are the most important parasitic weeds of crop plants in the Nigerian savanna. Their damaging effects on host plants are well known to both farmers and researchers. Under severe *Striga* infestation total crop losses have been observed in some farmers' fields and research plots when susceptible hosts are planted. No host crop variety has been found to be immune to attack. It is pertinent, therefore, to search for ways of controlling this pest.

Research work has been directed towards control, employing field resistance as part of an integrated control package. Two main species are being emphasized: (1) *Striga hermonthica* Benth., a parasite of the cereals sorghum, millets, and maize and (2) *Striga gesnerioides,* a parasite of cowpea. Efforts towards *Striga* control started as early as 1971, with screening studies, and later expanded to include evaluating the occurrence and distribution of these parasitic weeds. Actual breeding for resistance and the development of an integrated control package were initiated in 1976.

This paper reviews research activities to control *Striga,* including resistance and related studies, screening, and chemical and cultural control methods. Basic problems encountered in these stu-

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dies, including evaluation techniques, experimental designs, and selection criteria, are discussed. Future research needs for possible solution to *Striga* problems in relation to the host-parasite-environment interactions are indicated.

Ecology and Host Range

The commonest species of *Striga* in the Nigerian savannas is S. *hermonthica.* It devastatingly parasitizes all cereals grown under rainfed conditions, including sorghum, millet, and maize. S. *hermonthica* occurs in ecological zones extending from latitude 7° N to 14° N (Figure 1) and exhibits differential parasitism on different host crops across these zones.

The host range of S. *hermonthica* (Table 1) includes sorghum, maize, *gero* (early-sown, early-maturing) millet, *dauro* (transplanted, late) millet, and *maiwa* (late-sown, late-maturing) millet. These hosts are ecologically specific. Sorghum is cultivated over the savanna region (although with cultivars of different maturities) and is also a host in all the regions. Gero millet, while grown from the northern Guinea savanna (NGS) to the northern Sudan savanna (NSS), is only a host in the NSS, where it is cultivated more than is sorghum. In the southern Sudan savanna (SSS) and NGS it becomes a non-host, although it is grown extensively in mixtures with sorghum. Maiwa millet, on the other hand, is mainly cultivated in the NGS and SGS, where it becomes a host. The third type of millet, dauro millet, is restricted to a small area of the SGS around the Jos Plateau and its foothills, where it also becomes a moderately susceptible host.

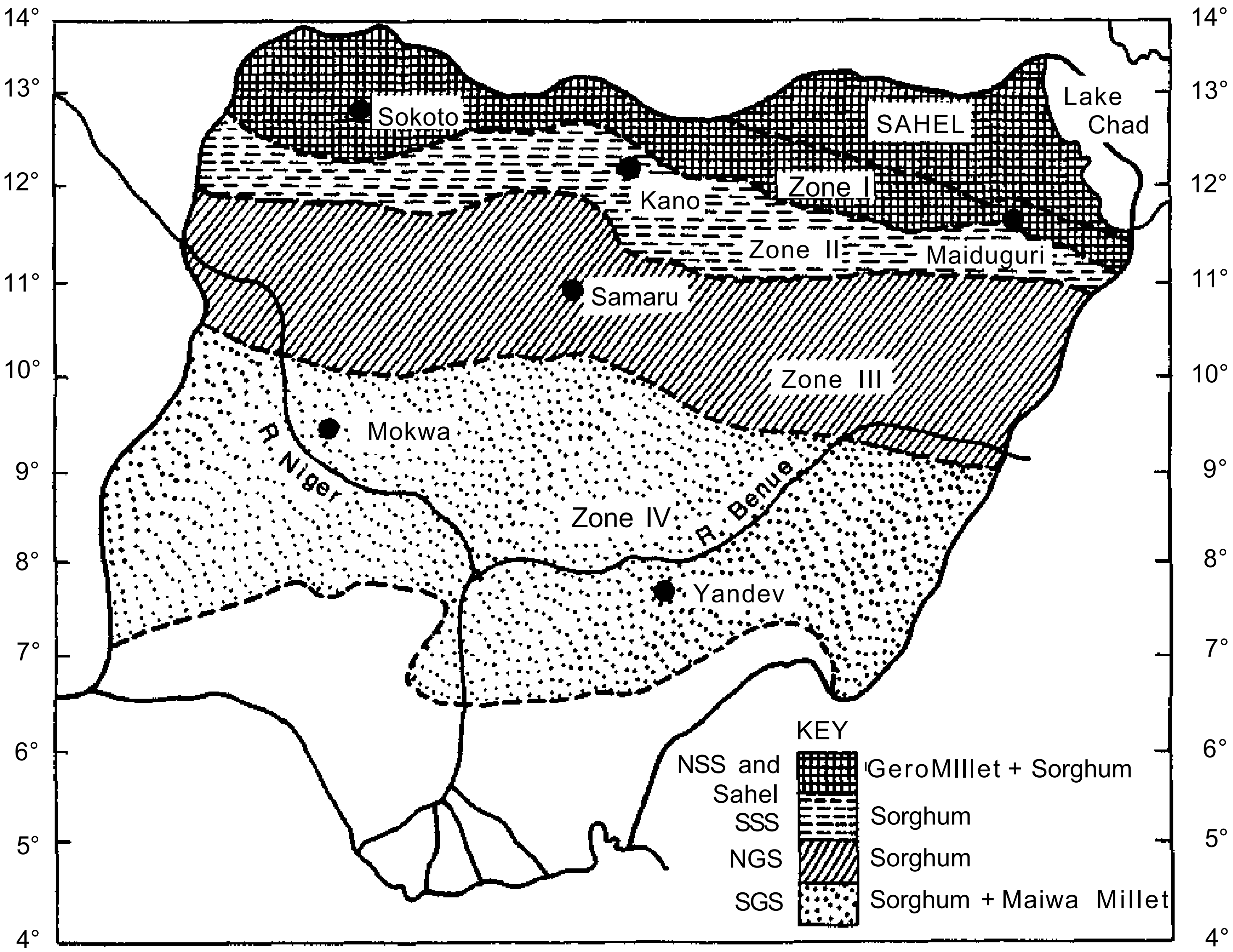

Figure 1. Ecological zones of the savanna area in Nigeria and distribution of host-specific* S. hermonthica *strains. NSS = Northern Sudan Savanna; SSS = Southern Sudan Savanna; SGS = Southern Guinea Savanna; NGS = Northern Guinea Savanna.

Table 1. Savanna ecological zones in Nigeria and host range of *Striga hermonthica.*

Ecological zone	Latitude	Annual rainfall (mm)	*Striga* infestation on cereal crops				
			Gero millet	Dauro millet	Maiwa millet	Maize	Sorghum
Northern Sudan savanna (NSS) and Sahel	11°-14°N	600	Host	-	-	-	Host
Southern Sudan savanna (SSS)	10°50'-13°N	750	Nonhost[2]	-	-	Host	Host
Northern Guinea savanna (NGS)	9°-12°N	1000	Nonhost	-	Host	Host	Host
Southern Guinea savanna (SGS)	6°30'-10°30'N	1100	-	Host	Host	Host	Host

1. (-) = not grown in this zone.
2. Although gero millet is a nonhost in this zone, it is susceptible.

An interesting pattern of parasitism of *S. hermonthica* was observed and described by Ogborn (1979b). In the drier NSS and Sahel (Zone I Figure 1), where gero millet predominates, with a little sorghum, only the gero millet was parasitized. In the wetter SSS and NGS (Zones II and III), where both millet and sorghum (more of sorghum) are extensively grown, only the sorghum crop is attacked. In the very wet and very long-season SGS (Zone IV), both sorghum and maiwa millet are attacked, while dauro millet is only lightly attacked.

These phenomena indicate host specificity in *S. hermonthica,* which was confirmed experimentally by King and Zummo (1977) and corroborated by Parker and Reid (1979). They attributed such host specificity to physiologic specialization in the parasitic weed. Their experiments identified distinct crop strains referred to as the "millet strain" and "sorghum strain." In interzone areas where more than one crop may be attacked, Zone I-Zone II (sorghum-gero millet), Zone II-Zone III-Zone IV (sorghum-maize), and Zone IV (sorghum-maiwa millet-dauro millet), it is uncertain whether the different crops are attacked by the respective specific strains or whether there are additional strains. This uncertainty was also indicated by Parker and Reid (1979). The fact that maize becomes susceptible in three zones—II, III, IV—and maiwa millet in two—III, IV—both crops being grown with sorghum, could indicate that there may be two more strains, a "maize strain" and a "maiwa strain." Their presence should not be ruled out without further investigation.

Because of the distinct differences in the four ecologic zones (Figure 1) and the occurrence of host-specific strains, the existence of ecologically specific strains could be suggested. Although there is no evidence for it yet, suspicion needs to be experimentally confirmed. Already, samples of *Striga* seeds from the four ecologic zones have been collected from different crop fields. Field and laboratory studies are expected to be carried out on the differential emergence and virulence of these "ecologic strains" of S. *hermonthica* in the four different ecologic environments.

The possible existence of both crop strains and ecologic strains in *Striga* is an aspect for future research.

Cowpea (*Vigna unguiculata*) is the only known host of *Striga gesnerioides,* occurring in the two Sudan savannas (Zone I and II). It is spreading southward fast and is of potential danger to cowpea fields in the NGS (Zone II).

Striga Studies in Millet and Maize

Most of the cultivated pearl millets (gero, dauro, and maiwa) have been found to be susceptible only in the zones where they predominate, and resistant (nonhost) in the zones where they are grown in mixtures with sorghum or maize. Where they are susceptible, yield loss due to *Striga* attack was not observed to be of economic significance in either the local or the few improved cultivars. Consequently, little *Striga* work is being done on millets except for observations on damage to gero millet, which has been quoted to be 19.7% in the predominantly gero millet zone (NSS) (Ogborn 1979a).

Although the extent of maize cultivation is vast (maize is grown in three zones—SGS, NGS, and SSS) and the crop has been severely damaged by *Striga* in all three zones, very little work has been done on the host-parasite relationship. It is only very recently, in 1980, that screening of maize germplasm for resistance to *Striga* started in the Yandev substation of the Institute for Agricultural Research. The use of *Striga* seed germinators in the field also has started at this site, but reliable results have not yet been obtained.

Striga Studies in Cowpeas

The threat posed by *S. gesnerioides* to cowpea is very serious in the Sudan savanna zones (Zones I and II) and this species is also a potential danger to cowpea farther south in the Guinea savanna, mainly because seeds are wind-borne. In fact, a small cowpea test field was completely destroyed at Samaru (Zone III) in 1980. All the work on cowpea *Striga* has so far been in the field and involves mainly assessment of crop losses and screening for sources of resistance.

Assessment of Crop Loss

In an experiment to assess the loss caused by *S. gesnerioides,* Emechebe (1981) reported that the losses in yield associated with *Striga* damage can be as high as 100%, which, according to his report, depends primarily on the number of *Striga* plants attacking the crop and on the level of resistance in the cowpea variety.

Screening for Host Resistance

Field screening for resistance or tolerance to *S. gesnerioides* in cowpeas was carried out for 3 years in 1977, 1978, and 1979 at Kano. In these trials *Striga* attack was severe and nearly all cowpea lines were susceptible, with only about 5% showing some signs of tolerance or resistance. None has been found really resistant.

Striga Studies in Sorghum

The major research activities on *Striga* in Nigeria are on grain sorghum and include three main aspects: host resistance, crop husbandry, and synthetic germinators. The research methodology and evaluation techniques for each of these aspects are discussed below.

Host Resistance

Identification of Resistance

Some progress has been made in identifying sources of resistance to *Striga* in sorghum in Nigeria. Previous work on this aspect and evidence for resistance to *S. hermonthica* included a screening program at Samaru, in which Zummo (1974) identified some lines that possess enough *Striga* tolerance to allow them to be grown in areas where the weed is a problem. King (1975), while screening 8000 lines from the world sorghum collection at Samaru, observed a high level of field resistance in approximately 1% of the entries. None of these lines screened so far has completely suppressed *Striga* attack.

In a series of screening trials between 1975 and 1979, 34 selected lines were used in advanced tests for reaction to *Striga.* Table 2 shows the reaction of the seven best lines selected for breeding, based on the relatively low number of emerged *Striga* plants per sorghum plant. They are therefore considered resistant. The best of these lines are SRN-4841A, SRN-6788A, and SRN-6838A, all of which have brown seed,

Varietal resistance is the most feasible and economic means of control. Progress has also been made in identifying and developing elite pure lines with resistance to *Striga* and that are usable per se by farmers (Obilana 1979). Thirty-five long-season and medium-maturing elite sorghum varieties were studied in a naturally infested plot; of these, four lines were resistant and three tolerant. L-187 (a long-season Zone III cultivar), RZ1 and YG-5760 (medium-season Zone II cultivars),and BES(short-season Zone I cultivar) were resistant; FFBL (long-season Zone III cultivar) and HP-3 and HP-8 (short-season Zone I cultivars) were tolerant.

Breeding Procedures

Breeding sorghum for resistance to *Striga* was initiated by Dr. M.M. El-Rouby in 1975 and has been continued by me since 1978. The breeding activities involve hybridization and selection, population improvement by recurrent selection, and screening of elite varieties in *Striga* sick fields.

Table 2. Reaction of selected breeding lines to *Striga* in field-screening tests at Samaru, Nigeria.[1]

Line	Average no. *Striga* plants/sorghum plant				
	1975	1977	1978	1979	Mean
SRN-1352A	1.6	2.8	0.7	0.9	1.5
SRN-4310A	2.1	1.7	1.9	0.5	1.6
SRN-4841A	0.1	0.1	1.0	0.0	0.3
SRN-4882A	1.8	2.1	0.5	0.6	1.3
SRN-6496A	0.5	2.1	1.3	0.6	1.1
SRN-6788A	1.2	0.4	0.2	0.0	0.5
SRN-6838A	0.2	1.4	1.0	0.6	0.8
Mean[2]	1.1	1.4	0.9	0.5	1.0
Mean[3]	1.8	2.1	1.8	1.5	1.8
Mean of check variety[4]	1.9	3.0	5.8	11.1	5.5

1 Data computed from pathology notes of the Cereals Improvement Program Cropping Scheme Meetings 1976 to 1980. IAR. Zaria. Nigeria.
2 Mean of selected breeding lines.
3 Mean of all 34 selected lines used in advanced tests.
4 Susceptible check variety used is L-2123.

Hybridization, followed by selection, started by crossing the seven selected tolerant or resistant lines (Table 2) to several elite lines. The F_1s are being advanced by the modified bulk-breeding procedure up to the F_5 or F_6. Then the pedigree system of selection is used in the form of individual head rows to produce elite pure lines. All the segregating populations will be planted in a *Striga*-infested field, with selection for large heads with many bold grains in the presence of *Striga* attack, in each generation. It is expected from these experiments that elite pure lines will be identified that are resistant or tolerant to *Striga* and are ready to be used as improved cultivars.

Population improvement by recurrent selection involved the creation of a random-mating population with the selected resistant or tolerant lines listed in Table 2 and a male-sterile gene (ms7) followed by four cycles of random mating. This resulted in a Strga-resistant composite that turned out to be too tall, and selection within it proved futile. Consequently, steps were taken to reduce its height. It was crossed to an elite semidwarf variety L-187 and further synthesized in isolation for two seasons to form the modified Striga-resistant composite (MSRC). This population is being improved by recurrent mass selection in a *Striga* sick field. Only one cycle of selection has been completed in this population.

All the lines developed and selected from advanced segregating generations that have not been previously tested for *Striga* reaction are included in *Striga* trials. Their reaction to *Striga* is known by the time they reach the promising-line trial stage. The outstanding resistant or tolerant lines are finally entered into yield evaluation trials.

Genetic Variation

Experiments were carried out in 1979 in the naturally Strga-infested field at Samaru to determine the relative amount of genetic and environmental variation involved in resistance to *Striga* in sorghum. Observations taken in these experiments included *Striga* counts (flowering, non-flowering, and total) after sorghum heading, harvest stand counts, number and weight of sorghum heads, and dry stalk weight. Sixteen elite varieties were included in this trial.

Preliminary results showed that environmental variance (S^2e) was substantial—twice as large as the genotypic variance (S^2g) and phenotypic variance (S^2p) for all traits observed and used as criteria for resistance. Extremely large environmental variation was obtained for dry stalk weight, indicating its inappropriateness as a measure of resistance. Among the *Striga* counts, the total number of emerged *Striga* was the most useful, being the only trait negatively correlated with head weight (r = -0.2). High positive correlation coefficients were obtained between number of flowering *Striga* plants, number of nonflowering *Striga* plants, stand establishment counts, harvest stand, and number of heads, showing that with the increase in the number of sorghum plants, there is a relative increase in the incidence of *Striga* (Table 3).

Yield Loss Due to *Striga*

The damaging effect of *Striga* in sorghum has been estimated to range from 30% yield loss in the more resistant lines to 80% in the susceptible lines (IAR 1975). Another estimate places the yield loss between 39% and 53% of potential yield (Ogborn 1979a).

A study involving advanced inbred lines and F_1 hybrids was made to assess the yield loss in sorghum. Twenty-eight sorghum F_1 hybrids were tested in 1978 and 1979, both in naturally *Striga*-sick and in normal uninfested plots, using the hill-plot technique and single-row plots 6 m long, respectively, with ten replications. The plots were in two fields about 4 km apart at Samaru. There were no notable environmental differences between the two plots, except the *Striga* infestation. The reaction of the materials to *Striga* was based on the total emerged *Striga* plants per hill plot. On the other hand, the criterion for yield loss was the difference in yield of the same test hybrid between normal and sick plots. Resistant hybrids were defined as those with low *Striga* counts and high yields in the sick plot; susceptible ones were those with high *Striga* counts and low yields; tolerant types, those with high counts and high yields. Of the 28 hybrids tested, 6 were resistant, 5 highly tolerant, 7 tolerant, and 10 susceptible, based on the evaluation criteria listed in Table 4. Yield losses ranged from as low as 5% in the resistant group to as high as 95% in the susceptible group (Table 5).

During the same year, 1978, 300 F_5 lines were tested in a randomized complete block design (RCBD) in six groups (Obilana 1979). The advanced inbred lines were not previously tested for *Striga* reaction, nor were they derived from resistant x susceptible crosses. Head weights plotted against total *Striga* counts (Figure 2) were used as criteria for selection. The six groups were composited and the range of total *Striga* counts and relative head weights per hill of three sorghum plants in each group are shown in Table 6.

Definite trends are shown by the graphs in which

Table 3. Correlation coefficients (r_p) between *Striga* counts and indicated traits.

Trait	Number of FS[1]	Number of NFS[1]	Harvest stand	Head weight	Dry stalk weight	Total *Striga*	Number of heads
Number of NFS	0.44**						
Harvest stand	0.31**	0.27**					
Head weight	0.17*	0.04	0.29**				
Dry stalk weight	0.14*	0.06	0.51**	0.63**			
Total *Striga* (TS)	0.23**	0.31**	0.09	-0.16*	-0.14*		
Number of heads	0.39**	0.51**	0.67**	0.19*	0.16*	0.44**	
Initial stand	0.39**	0.28**	0.65**	0.37**	0.55*	0.18*	0.39**

*, ** Significant at $P = 0.05$ and $P = 0.01$, respectively.

1. FS = Flowering *Striga*; NFS = Nonflowering *Striga*.

Table 4. Mean *Striga* counts and head weight in four reaction categories of sorghum crosses.

Reaction category	No. of flowering *Striga*	No. of nonflowering *Striga*	Total no. of *Striga*	Head weight (t/ha)
Resistant	4.3	4.1	8.4	2.11
Highly tolerant	15.2	15.3	30.5	1.84
Tolerant	9.6	6.3	15.9	1.45
Susceptible	8.7	7.1	15.8	0.61

Table 5. Comparative performance of four groups of sorghum hybrids in *Striga-sick* and *Striga-free* plots at Samaru, Nigeria.

	Head weight (t/ha)				Yield loss (%)		Reaction to *Striga*[2]
	Normal plot		Sick plot				
	Mean	Range	Mean	Range	Mean	Range	
Group A (6)[1]	3.4	2.8-4.2	2.3	1.6-3.4	32.7	5-56	Resistant
Group B (5)	3.9	3.2-4.5	1.7	1.4-2.0	55.4	45-63	Highly tolerant
Group C (7)	3.7	3.1-4.6	1.5	1.1-1.9	61.1	57-64	Tolerant
Group D (10)	3.6	3.0-4.4	0.6	0.2-0.8	82.8	75-95	Susceptible

1. Figures in parentheses represent number of hybrids.
2. Description is based on total number of *Striga* plants per hill and net yield loss due to *Striga* attack.

the top and bottom 10% of the entries, classified by head weight per hill; were used in each group. Two distinct categories emerged. The top 10% in every group supported very low numbers of *Striga* plants per hill, while the bottom 10% supported relatively very high *Striga* counts. Interestingly, in group V (Fig. 2V) the bottom 10% gave higher yields than the top 10%. However, *Striga* counts were low in this group, so that the comparison was not reliable. A few lines that had high *Striga* counts per hill but with very high yields also were identified (Figure 2 II, shaded portion).

Experimental Techniques and Selection Criteria

The reliability, repeatability, and validity of screening procedures depend strongly on the experimental procedures and evaluation criteria used. To achieve better success, the following techniques need be standardized: (1) field-plot techniques, (2) infestation techniques and (3) indices of resistance.

Field Plot Technique

There are two main considerations for choosing a particular field-plot technique for studying *Striga* resistance: the experimental design and the field layout. Several alternatives are available for both. In Nigeria, at the initial stage of *Striga* work, hill plots of 90 x 90 cm were used for evaluating and selecting resistant varieties, while row plots were used for pedigree selections. Hill plots were most useful where infested fields are small and large numbers of genotypes are to be evaluated, and the RCBD is the easiest to use with hill plots.

Infestation Technique

Natural *Striga* infestation is the most easily available and cheapest to use in African countries; how-

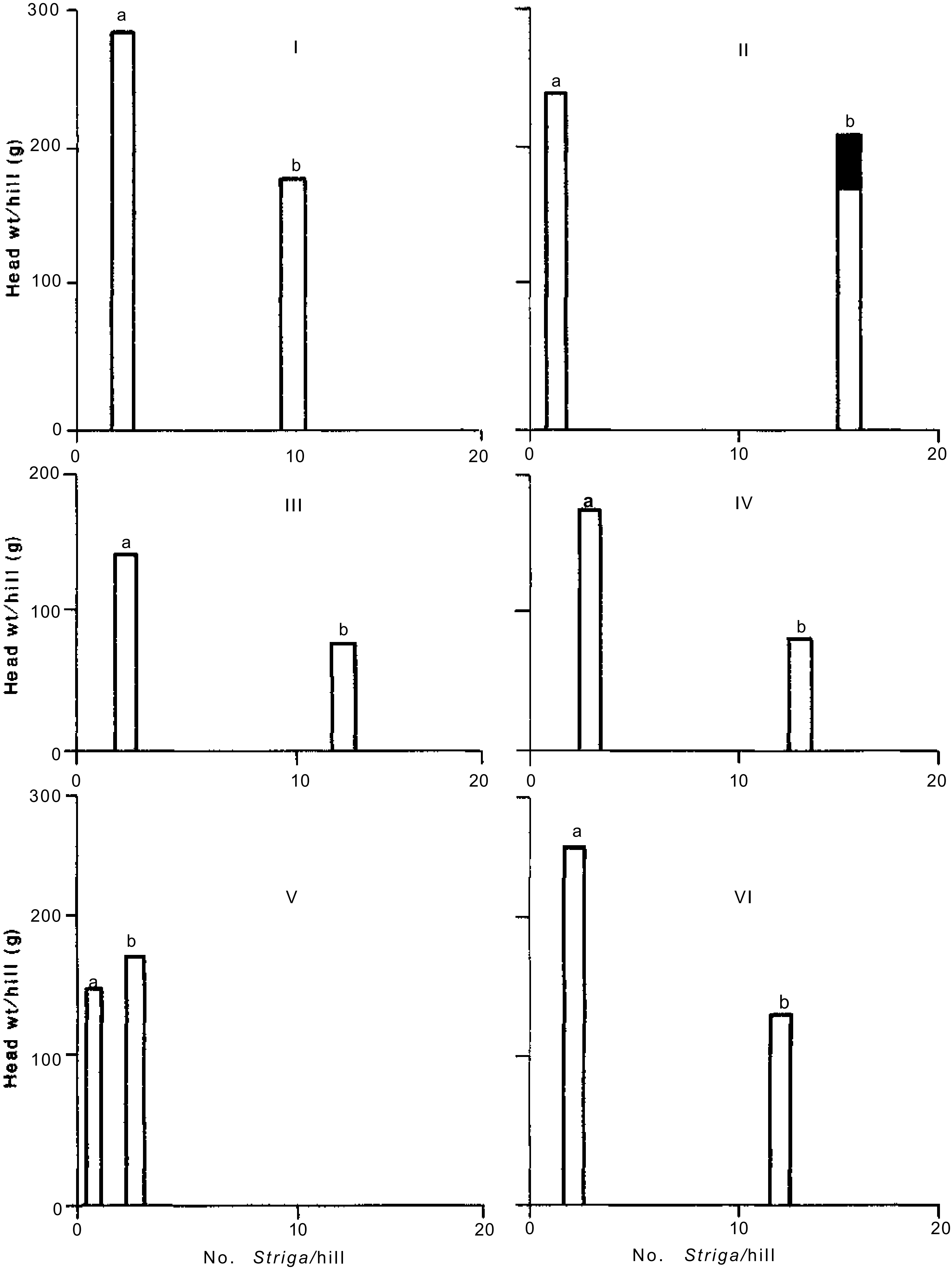

Figure 2. **Striga** ***reactions of six groups (I-VI) of 300*** F_5 ***lines, a = top 10%. b = bottom 10%.***

Table 6. *Striga* reaction and head weight of 300 F_5 lines of sorghum.

Group	Number of entries	Range: Total no. *Striga* plants/hill	Range: Head weight/hill (g)
1	100	a. 1.2 - 2.5	222.0 -344.7
		b. 8.2-12.0	136.7 -225.4
		c. 5.1	223.9
2	100	a. 0.5 -1.7	60.0 -144.0; 197.77-287.7
		b. 10.4-19.3	82.9 -174.5; 179.9 -244.4
		c. 4.9	167.4
3	25	a. 1.3-2.8	132.8 -154.6
		b. 10.6-14.7	53.5 -104.6
		c. 6.4	111.6
4	25	a. 1.6-5.1	131.7 -213.4
		b. 11.4-14.4	67.3 -89.4
		c. 7.7	129.4
5	25	a. 0.0-0.3	141.7 -173.1
		b. 2.7-3.3	163.2 -189.9
		c. 1.3	179.2
6	25	a. 0.8-2.4	258.3 -262.5
		b. 8.7-16.0	125.0 -150.0
		c. 5.5	188.6

a. = top 10% and b. = bottom 10%, based on head weight per hill; C. = grand mean of all entries.

ever, such infestation is not uniform. Unevenly infested fields can be improved by spreading seeds of *Striga* uniformly all over the sick plot at the end of the growing season. This method has been used to develop a fairly good and relatively large (about 3 ha) *Striga* sick plot on the University Farm at Samaru.

Artificial infestation, however, would give the most valid results if a method can be developed, especially for genetic studies and screening work. The use of a known quantity of *Striga* seeds, in Eplee bags or some other holding medium, worked into the soil in predetermined evaluation plots before the season, would be ideal. However, the economics should be considered when testing such techniques.

Indices of Resistance

Uniform criteria for evaluating and selecting resistance need to be developed. At present, several criteria are being used by different workers. In Nigeria, we have been using vegetative and yield component traits of sorghum plants and *Striga* counts as selection criteria. As indicated earlier in this paper, these traits and counts include: establishment and harvest stand counts, dry stalk weight, number of heads, head weight, and number of *Striga* plants per plot or per plant. Resistance is defined as a low *Striga* count; conversely, susceptibility is a high *Striga* count. However, the ranking of lines or varieties by this definition differs from that obtained from a combination of low *Striga* count with high yield.

The indices of resistance should include: (1) precise symptoms at seedling stage, before and after heading, and maturity; (2) intensity and extent of damage, and (3) rating scale. Even now, the relationship between the number of *Striga* plants and a particular level of damage has not been worked out. Also, the rating scales are not yet standardized. In fact, the pertinent question is: what should be used for the rating scale as an index of resistance—*Striga* counts or yield loss, or both?

Crop Husbandry and Chemical Control

The challenge of finding a control for *Striga* that the Nigerian farmer can quickly adopt might possibly be met through integrated control measures (Ogborn 1979a). Ogborn recommended the use of (l) cultural practices such as stubble cleaning in sorghum and millet fields after harvest; (2) crop rotation with nonhosts and with catch crops such as early-maturing sorghum with grain-mold resistance in long-season zones; (3) mixed cropping without host crops (Ogborn 1972); (4) fertilizer application with very high doses of nitrogen as topdressing; (5) chemicals, including synthetic *Striga* germinators such as ethylene (ethephon) or strigol analogues (GR7and GR45) in the absence of cereal host crops (Ogborn 1979b); soil-active herbicide sprays, e.g. Oleo-linuron (for small farms) and bromoxynil (for large-scale farms) with very low-volume sprays (VLV) and intermittent directed foliar application (IDFOLA) in millet and sorghum; and (6) use of resistant or tolerant varieties.

However, many of these suggested control measures are impracticable or expensive—for example, use of synthetic *Striga* germinators and soil-active herbicides using VLV and IDFOLA—or they are socioeconomically unacceptable—for instance, the use of mixed cropping without host crops by peasant farmers, in areas where host crops such as sorghum are the staple food.

Although application of extra nitrogen as fertilizer seems very plausible (IAR 1981), the economic considerations are enormous. It could be inferred from such studies that the amount of fertilization required for a substantial reduction of *Striga* infestation is 75 kg P_2O_5/ha and 100 to 200 kg N/ha. This is a high dosage, significantly higher than the earlier recommended dose of 33 kg N/ha and 23 kg P_2O_5/ha.

Future Research Needs

Future research considerations toward solving the *Striga* problem should be cooperative, with basic research findings used to solve field problems. More work is required in genetic studies and in the interaction of *Striga* with its growth medium, including Sfnga-environment and *Striga*-host crop interactions. Results from such research would help us understand *Striga* strains and the implications for developing sick fields and for interzonal and interregional exchange of research materials and information.

There is an urgent need to search for sources of resistance and to intensify the development of resistant varieties in gero millet, maize, and maiwa millet in the wetter savannas, and resistant varieties of cowpeas.

It is my view that only the use of resistant crop varieties with appropriate production practices will effectively control the *Striga* menace.

Acknowledgment

The author herewith acknowledges the basic work of the cereal pathologists, the early work of Dr. M.M. El-Rouby, and the substantial crop husbandry and chemical control studies of Mr. J.E.A. Ogborn, all at the Institute for Agricultural Research, Zaria, Nigeria.

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Discussion

Vasudeva Rao:
I suggest that we use the name SRN-4841 and not IS-8686 because IS-8686 in the germplasm has a different seed color from SRN-4841.

Obilana:
I agree.

Ramaiah:
In view of the significant micro- and macro-variations one finds in the West African soils, how valid are your conclusions based on *Striga-sick* and *Striga-free* plots separated by 4 km?

Obilana:
This is the nearest I could go at the time of the experiment, as there was no way to obtain *Striga*-free plots in the naturally *Striga-sick* field where the experiment was carried out. I agree that the validity of the conclusions may be debatable.

Ramaiah:
Did you ever compare SRN-4841 with local red sorghums in northern Nigeria?

Obilana:
No. But parameters of acceptability for beer-making suggest that it is not usable at present by farmers.

Ramaiah:
What was the coefficient of variation in the data you used for correlation studies?

Obilana:
In all the experiments the coefficients of variation were very high.

Ramaiah:
What is the field-plot technique you used for screening F_2 individual plants in inheritance studies?

Obilana:
I used hill plots of three sorghum plants per hill. I do appreciate the invalidity of this technique for F2 evaluations.

Ramaiah:
Are the "crop-specific strains" and "ecologically specific strains" of *Striga* different?

Obilana:
Yes. Since the different varieties of sorghum are ecologically specific and the ecologic zones differ from each other, the "crop strains" will have to be different from my newly suggested "ecologically specific strains," which need to be looked into and confirmed.

Ramaiah:
Why does *Striga* not cause economic damage to millet in your region?

Obilana:
I don't know. This is our observation even in Zones I and II, where a millet strain exists.

Ouedraogo:
What is the optimal dimension of a plot? Which is the optimal density of *Striga?*

Obilana:
Optimum *Striga* level desirable would be a good sick plot with uniformly high *Striga* emergence. The plot size will vary depending upon the precision required.

Mercer-Quarshie:
Given the problem of nonuniform emergence of *Striga* in the field, how can you adequately study the genetics of resistance using emergence as a criterion?

Obilana:
The problem of field resistance was indicated in my presentation. However, there is a need to have some preliminary information on these aspects with the available tool (in this case naturally *Striga-slck* fields), which is being improved for *Striga* emergence uniformity and frequency.

Matteson:
Does *Striga* occur in the coastal areas of Nigeria?

Obilana:
It has not been found and recorded yet, even on maize or rice.

Parker:
Is it not wrong to dismiss the idea of "mixed cropping without host"? Ogborn does not propose that

farmers should stop growing sorghum but that it should be grown as a sole crop every 5 years (on one-fifth of the farm) rather than as a one-fifth component of the cropping every year on every field.

Obilana:
The suggestion is not dismissed, but its limitation is the difficulty of its acceptance by farmers practicing mixed cropping. This is especially so since some of the mixed cropping is in the form of relay cropping and some in the form of double cropping.

Vasudeva Rao:
What is the significance of flowering and nonflowering *Striga* observations?

Obilana:
These factors are observed separately to see which is more correlated with head weight and thus a better factor to use in resistance and yield-loss studies. I observed that total *Striga* count—the sum of both flowering and nonflowering *Striga*—*is* the best factor to evaluate.

Progress in Control of *Striga asiatica* in the United States

Robert E. Eplee*

Abstract

Striga asiatica (*witchweed*) *was discovered in eastern North Carolina, United States of America, in 1956. Subsequently a survey program was initiated to locate and map all infested lands. Some 150 000 ha have been found infested in South and North Carolina. A regulatory program was simultaneously implemented to diminish the rate and extent of spread of the parasite. Through this effort the pest has been confined to the general area of infestation at the time of discovery. The United States Department of Agriculture established a research facility within the infested area to develop methods of detection, containment, control, and Ultimately eradication. One phase of the research, concerned with ways to stop* Striga *growth and reproduction, has resulted in a variety of herbicide-application techniques and cultural-control practices. The second phase of the research effort aims to rid the soil of the persistent viable seeds. This research has resulted in the identification of the natural stimulant, strigol, and in the development of technology for the practical use of ethylene gas to induce "suicidal" germination* of Striga *seeds. Progress is also being made on the use of synthetic analogues of strigol. Technology has developed to the point where it now appears biologically possible to eradicate this parasitic weed from the USA.*

Résumé

Progrès faits dans la lutte contre le Striga asiatica *aux Etats-Unis* : *Le* Striga asiatica *fut découvert dans l'est de la Caroline du Nord aux Etats-Unis en 1956. Une enquête a alors été lancée, en vue de localiser et d'établir la carte des terres infestées. Quelque 150 000 ha infestés furent alors répertoriés dans les Carolines du Nord et du Sud. Une réglementation phytosanitaire fut immédiatement mise en vigueur afin de diminuer le taux et l'expansion de ce parasite. Grâce à cette mesure, la phanérogame parasite est restée dans les limites de la région originellement infestée. Le Ministère de l'Agriculture des Etats-Unis a établi des installations de recherche dans la région infestée, en vue de développer des méthodes permettant de détecter cette mauvaise herbe, de freiner sa propagation, de lutter contre elle et enfin de l'éliminer. L'une des phases de la recherche, concernant le développement de moyens visant à arrêter la croissance et la reproduction du* Striga, *a permis de développer des techniques d'application des herbicides et des pratiques culturales de lutte. La deuxième phase de ce plan de recherche vise à débarrasser le sol des graines viables qui y persistent. Cette recherche a abouti à l'identification d'un stimulant naturel, le strigol et à l'élaboration des techniques pour utiliser le gaz éthylène qui provoque une "germination suicidaire" des graines de* Striga. *Les recherches s'orientent également vers l'utilisation des analogues de synthèse du strigol. La technologie s'est développée à un point tel qu'il apparaît aujourd'hui biologiquement possible d'éliminer cette mauvaise herbe des Etats-Unis.*

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International Crops Research Institute for the Semi-Arid Tropics. 1983. Proceedings of the Second International Workshop on *Striga,* 5-8 October 1981, IDRC/ICRISAT, Ouagadougou, Upper Volta. Patancheru, A.P., India: ICRISAT.

Striga asiatica (L.) Kuntze (witchweed) is one of the several parasitic plants belonging to Scrophulariaceae that for years have plagued man in his production of field crops. *S. asiatica* and its sister species, *S. hermonthica, S. gesnerioides,* and *S. aspera,* have long been known throughout the Old World tropics, Africa, India, and much of the tropical and subtropical climatic zones. Witchweed has been reported to cause more crop damage than any other pest on the African continent; since it is a root parasite, it may be characterized as the silent reaper, undramatically robbing the crops of nutrients and moisture. The damage from witchweed far exceeds what might be expected based on the biomass of the parasite. The interference with movement of nutrients and moisture through the root system—and some metabolic toxicant, which is strongly indicated—causes devastating effects on the host crop, often leading to severe to total yield losses.

In 1956 *S. asiatica* was identified in an area in eastern North Carolina. The infestation has been found on some 153 960 ha in southeastern North Carolina and northeastern South Carolina. In view of the potential devastating effects of witchweed on corn, sorghum, rice, and other graminaceous crops, a decision was made in the USA to impose a federal quarantine on the infested area. Since, at that time, weeds were not legally recognized as pests, the quarantine was imposed under the Plant Quarantine Act, which considered witchweed a "parasitic disease" of corn. Both North and South Carolina imposed state quarantines to regulate intrastate movement. This represented the first quarantine action taken against a weed. However, it was not until some 17 years later, in 1974, with the passage of the Noxious Weed Act, that the U.S. Congress established a procedure for protecting the USA from devastating weeds of foreign origin, such as *Striga,*

The imposition of the federal and state quarantines (USDA 1976) provided a mechanism to prevent the spread of witchweed outside the infested area. It required that all equipment, commodities, and material be free of seed and soil before leaving the infested area. This is accomplished through fumigation, washing, or other means of cleaning. This most successful regulatory program has been accomplished by a dedicated staff of federal and state regulatory officials and by constant input through extension, vocational, agricultural, and news media personnel. Credit must also go to the farmers and agribusiness people of the area, who have done their part.

Although witchweed has been found on more than 150 000 ha in 38 counties in the eastern Carolinas, this area is basically the same as that originally found infested. To date, witchweed has been eradicated over some 8700 ha in eight counties, and this area has been released from quarantine.

Soon after witchweed was found in 1956 and its adverse effect on American agriculture determined, a research facility was established at Whiteville, North Carolina—within the infested area so as to minimize the possibility of inadvertent spread of the pest and to allow work within the quarantined area. A research farm was also established near Dillon, South Carolina. These research facilities were established to develop the methodology to contain and eventually to eradicate witchweed from the USA.

Early work at these facilities focused on developing control methodology, with some attention given to basic research on the host-parasite relationship. From this early research it was demonstrated that witchweed could produce up to a half million microscopic seeds per plant. Saunders' work (1933) indicated that these seeds could maintain viability in the soil for up to two decades, germinating only if chemically stimulated by a constituent in the root exudate of host plants.

In addition to the regulatory activities to prevent the spread of witchweed, its eradication from the USA involves two other general areas of activity: (1) controlling growth, development,and reproduction of the plant, and (2) effectively devitalizing seeds in the soil.

The primary mechanism for controlling the growth and development of witchweed has been the development of a versatile and diversified herbicide program, which is administered and funded by the United States Department of Agriculture, Animal and Plant Health Inspection Services, Plant Protection and Quarantine. Cooperative activities are conducted by the states. Much of the weed control activity conducted by the farmer is of direct benefit to the eradication effort.

Early in the witchweed control program 2,4-dichlorophenoxyacetic acid (2,4-D) was the chemical of choice for control in corn (Shaw et al. 1962). Because the infested area produces large acreages of crops susceptible to 2,4-D, i.e., cotton, soybeans, and tobacco, the research station designed special high-clearance sprayers equipped with low-pressure whirlchamber nozzles. With this equipment herbicide damage seldom occurs outside the target area. Other herbicide treatments have been and are still being developed for the program. Paraquat (Eplee and Langston 1970) is used extensively, with application directed to the base of corn plants. The dinitroaniline herbicides, such as trifluralin, besides controlling grass, also provide direct control of witchweed. Oxyfluorfen (GOAL®) (Langston et al. 1976) is a herbicide that gives both contact kill and residual preemergence control. We now have effective herbicides that will give direct control of witchweed or eliminate all host grasses in most conceivable situations. In addition, farm practices, such as the use of early-maturing corn varieties with field tillage immediately after early harvest, have drastically shortened the control season, significantly reducing the cost of the program. By control of grass in infested lands planted to nonhost *crops,* the farmer is depriving the witchweed of an alternate host, thereby contributing to the control effort.

It has now become possible to prevent the growth of witchweed in the USA; however, to achieve this level of control costs money. Present funding for witchweed control does not permit this level of control activity on all infested areas.

The elimination of witchweed seeds by devitalizing them in the soil is crucial to a successful eradication program. The development of an artificial seed stimulant was an objective of early research, and the natural stimulant was isolated, identified, and named "strigol" (Cook et al. 1972).

The identification of the natural stimulant has led to a great deal of synthesis research to produce biologically active analogues. Strigol was chemically synthesized by Heather et al. (1974), but strigol is not considered practical as a soil treatment. Other scientists—for instance, Johnson et al. (1976)—have synthesized analogues of strigol, but all of these are still in various stages of development. Further development of these synthetic stimulants is warranted, especially for their potential benefit to Africa and other infested areas.

Coincidental with the identification of strigol, Egley and Dale (1970) demonstrated that ethylene gas (C_2H_4)was highly effective in inducing the germination of preconditioned witchweed seeds. Preconditioning as used here refers to a physiological condition in which mandatory temperature and moisture regimes have been met so the seed germinates in response to a chemostimulant.

With this discovery, major effort was devoted to determining the potential for practical use of ethylene (Eplee 1975), and to developing the methodology for field application. It was established that when ethylene was injected 15 to 20 cm deep into the soil at 1.6 kg/ha during the period May to July, it would diffuse out more than 1 m from the point of injection, initiating the "suicidal" germination of all preconditioned seeds in this zone. Special equipment for field application of ethylene was designed and constructed similar to that used for the application of anhydrous ammonia. A single ethylene application, properly applied, can reduce the witchweed seed population of a site by more than 90%. Three applications in consecutive years, along with an escape-plant control program, are adequate to eradicate witchweed from a site. The cost of an ethylene treatment is less than U.S. $25/ha. However, even with this available methodology, less than 3% of the total area is treated annually because of limitation of funds.

At present we have a quarantine and regulatory program for witchweed that has succeeded in restricting this pest to its original area, even though we know it will grow anywhere in the USA where corn is commercially grown. We have herbicide treatments and agronomic practices that can prevent growth, development, and seed production. We have ethylene and fumigation treatments that can deplete viable seeds in soil. We have specialized equipment with which to apply these treatments safely and effectively. We have an ongoing research program to enhance efficiency and to ensure that technology stays ahead of the treatment program. The small area in the eastern Carolinas is the only place in the Americas that this Old World menace to agriculture is known to occur. The crops threatened by this parasite are valued at more than $20 billion annually, with crop loss potential in the hundreds of millions. It appears that the time is right for some serious attention to completing the task of eradicating *Striga* from the USA.

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Discussion

Reneaud:
If ethylene is injected during the vegetative period of maize, is it dangerous, producing massive germination of the parasite at the root zone?

Eplee:
Ethylene causes disoriented germination of *Striga* seeds, so that they do not attack the host roots.

Andrews:
Does ethephon germinate *Striga* seed as well as ethylene?

Eplee:
Not on acid soils.

Reneaud:
Which is the optimal period for ethylene application? What are the criteria for application?

Eplee:
Apply ethylene or the stimulants when the soil has had a minimum of 2 weeks of soil moisture—perhaps 3 weeks after the start of the rainy season; however, treatment, I believe, may be applied any time over a 6-week period.

Sandwidi:
What is the duration of residual activity of the *Striga* germination stimulant, natural or synthetic?

Eplee:
Ethylene has a flash effect when it comes in contact with *Striga* seed: it induces germination within a few hours and then diffuses. Root exudates are produced as long as the root grows, after roots stop growing or die, no exudates are produced.

Occurrence of *Striga* and Its Possible Control in Cropping Systems in Northern Ghana

W. A. Stoop, H. Lanting, and K. V. Ramaiah*

Abstract

Striga *is a parasite of sorghum, pearl millet and maize, the staple food crops grown in the West African SAT, including northern Ghana. The incidence* of Striga *at a particular location is a function of complex interactions between* Striga, *host crop, and other environmental factors, such as soil and rainfall. A careful observation of cropping systems, soil types, and incidence of* Striga *in northern Ghana has revealed that (1)* Striga *damage is most devastating on cereal crops grown outside their most favored position in the toposequence and on patches of poor soil within specific land types and (2)* Striga *damage is least on early-maturing millet and maize. The* Striga *problem is bound to grow with increasing population pressure on land and consequent cultivation of crops on unsuitable lands. Although host-plant resistance offers excellent scope for control, complementary agronomic practices are required to reduce* Striga *damage. Areas to be emphasized in future agronomic research are outlined.*

Résumé

Le Striga *et la lutte menée au niveau des systèmes de culture au nord du Ghana :* Le Striga *est une plante parasite des cultures de base que sont le sorgho, le petit mil et le maïs dans les pays des zones tropicales semi-arides d'Afrique de l'Ouest, y compris le Nord du Ghana. L'incidence de* Striga *à un endroit particulier résulte des interactions complexes entre le* Striga, *la culture-hôte et d'autres facteurs environnementaux tels que le sol et la pluviométrie. Une observation attentive des systèmes de culture, des types de sol et de l'incidence du* Striga *au nord du Ghana a révélé : (1) le* Striga *provoque le plus de dégâts dans les cultures céréalières cultivées hors de l'emplacement qui leur est le plus favorable sur la toposéquence et plus généralement sur des parcelles de sols pauvres appartenant à certains types de terrains; (2) les cultures précoces de petit mil et de maïs sont les moins attaquées par le* Striga. *Il est à craindre que le problème du* Striga *se pose avec davantage d'acuité dans le futur suite à la croissance démographique et à la pression sur les sols qui obligeront à cultiver sur des sols qui ne conviennent pas particulièrement aux cultures. Bien que la résistance de la plante-hôte offre d'excellentes possibilités de lutte, des pratiques agronomiques complémentaires sont nécessaires pour minimiser les dégâts causés par le* Striga. *Les recherches agronomiques à entreprendre sont définies.*

During our frequent travels through the West African semi-arid tropics, we have observed *Striga* (*Striga* hermonthica Benth.), a parasitic weed that grows on several cereal crops in this region. In some areas *Striga* has become so severe that virtually no cereal crop can be grown. Since *Striga,* seeds remain viable in the soil for many years and will germinate when an appropriate host is introduced, it is extremely difficult to control this pest.

In this paper we describe the conditions, the host crops, and the crop growth stage in which we have seen *Striga.* On the basis of these observations,

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suggestions are made for control, or at least minimizing *Striga* damage.

Cropping Patterns in Relation to Land Types

As described in earlier publications (Stoop et al. 1981), a huge diversity of cropping systems occurs in the West African semi-arid tropics, in response to rainfall (total amount and distribution), soil types, and socioeconomic factors.

Besides a large random microvariability in soil properties (even from square meter to square meter), one will generally find a more systematic variation in soils along toposequences, mainly resulting from different soil-moisture regimes and runoff effects (Fig.1), leading to four major land types:

1. Uplands and upper slopes: dry, well-drained, often coarse-textured, shallow soils, low in organic matter.
2. Lower slopes: humid, well-drained, deep soils.
3. Lowlands: temporary wet, fine-textured, deep soils (colluvial), high in organic matter.
4. Swamps; soils inundated for short spells, high in organic matter.

The moisture infiltration rates of the upland soils as well as the presence of dense soil layers within 1 m of the surface (laterite or clay pans) are considered to be of critical importance for the soil-moisture situation elsewhere along the toposequence, particularly on the midslope, due to a lateral water flow through the soil. This process is particularly relevant to the coarse-textured upland soils of northern Ghana, but is of less significance for the more silty (crusting) soils in the central parts of Upper Volta.

Over the years farmers have matched suitable major crops to each of the land types, e.g., rice on swamps, sorghums on lowlands, maize on lower slopes, millet and groundnut on uplands. Work at the Kamboinse station in Upper Volta has demonstrated that by correctly matching crops to specific soil conditions, the yields of the respective crops can be more than doubled (Stoop and Pattanayak 1979). But since rainfall varies from year to year, causing variations in optimum soil moisture at each location, certain crop mixtures are also planted; e.g., rice and red sorghum; maize and sorghum; sorghum and millet; maize and millet.

On lowlands early millet, a 3-month crop, is planted with sorghum in early May; sorghum takes over as major crop in August when conditions become wet. On uplands, early and late millets are combined, as in northern Ghana and northern Nigeria, or late millet is added to maize in southern Mali on the well-drained soils of the slopes, thus stretching the season from May to early December, when the millet is finally harvested (maize is harvested by the end of September).

Occurrence of *Striga*

Over the years *Striga* has been observed throughout the West African SAT on all soils, both dry and wet, and on all cereal crops, mainly during September and October. Particularly in the Upper Region of Ghana, the *Striga* infestation is widespread and severe, offering a good opportunity to study variations in attack as related to crops and soils.

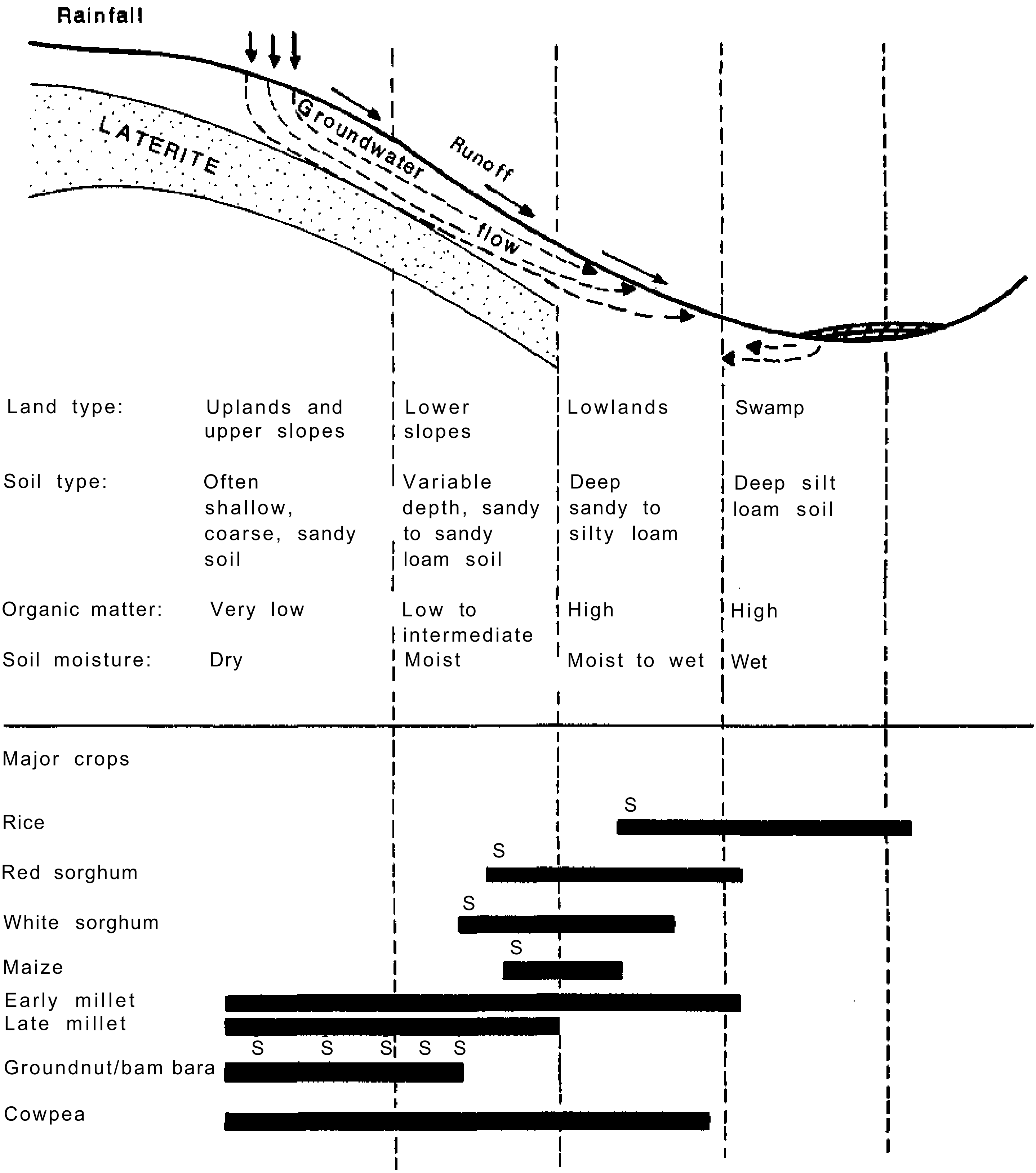
Striga Attack in Response to Crops and Crop Varieties

In northern Ghana *Striga* occurs extensively and by mid-September both late millet and red sorghum fields were seriously affected in many locations in the east. In western Ghana maize grown as an intercrop in sorghum was parasitized to some extent, as were early millet plants that had not been removed (early millet is harvested by the end of July and maize in September). Thus, though all cereals—maize, sorghums, and millets—appear equally susceptible, the actual *Striga* damage appears least on early-maturing millet and maize.

This probably is associated with "wet dormancy" of *Striga* seed during the prolonged wet period at the beginning of the rainy season (Vallance 1950). The *Striga* populations specific to those two crops are also kept under control by different natural enemies such as insect pests and diseases, which are favored by more humid conditions. However, a prolonged drought at the beginning of the season may break the wet dormancy of *Striga* seed, then these crops probably would suffer *Striga* damage.

Striga Attack in Response to Differences in Soils

In various farms in northern Ghana, the severity of the *Striga* attack varied considerably even within a single field of one crop. Sometimes, this variation could be attributed to differences in management by the farmers such as localized use of farmyard manure or ammonium sulfate. In other cases distinct differences in soil were responsible. In fields that, according to the toposequence concept, were typically millet or sorghum lands, Striga-affected areas were always associated with less fertile soil,



S = positions where *Striga* attack appears most likely.

Figure 1. Schematic presentation of relationship between land types along common toposequences in West Africa and corresponding crops. Areas where crops overlap offer possibilities for intercropping.

as reflected by low organic matter contents and/or a coarse texture. These soils are more prone to moisture stress than the high organic matter and/or clay soils; as a result, the wet dormancy of *Striga* seeds will be broken more readily and earlier in the cropping season, further weakening the cereal plants, which are already suffering from the effects of poor soil fertility.

In summary, the *Striga* damage appears most devastating in cereal crops that are grown outside their most favored position in the toposequence (e.g., for red sorghum the transition to millet lands) and more generally on patches of poor soil within specific land types,

Agronomic Research and Possibilities for *Striga* Control

From the preceding sections it is obvious that the *Striga* problem is likely to become even more serious in the future. Growing populations and increased pressures on suitable land will most probably cause further soil degradation, thus favoring *Striga.* Moreover, the cropping of marginal lands or the growing of crops on lands not optimally suited to them will probably increase. Therefore, various options to control *Striga* should be studied systematically.

Others have discussed the various possibilities of host-plant tolerance or even resistance. Though the outlook for success in this area is promising, the huge range in sorghum and millet varieties required to meet the various ecological environments will be a serious obstacle. Thus, in addition to the breeding work, agronomic investigations aimed at minimizing *Striga* damage are important. In this respect there appear to be various options:

1. To study the effects of various soil amendments, such as farmyard manure, urea, and ammonium sulfate on *Striga.* Urea and ammonium sulfate were shown to affect *Striga* germination under laboratory conditions (Pesch et al., these Proceedings) and ammonium sulfate applications have been used successfully by Ghanaian farmers.
2. To study the interaction effects between date of planting and length of the cereal cropping cycle on the extent of *Striga* damage in following years. It could be investigated whether plants of the early millet and early maize varieties could enhance *Striga* germination without providing a viable host to support subsequent *Striga* growth and seed formation, since these crops will be harvested around August or early September.
3. To study the use of trap crops (e.g., cotton, groundnut, cowpea), that encourage *Striga* germination but are not parasitized themselves. In this respect various crop-rotation schemes and intercropping systems, adapted to various land types in the toposequence, should be tested. Among possible cropping systems for northern Ghana, one may consider early millet with groundnut (3-month cycle) and red sorghum with late cowpea.

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Discussion

Andrews:
On the land where millet is intercropped with late millet and sorghum, do you think there are two *Striga* strains existing, one for millet and one for sorghum?

Lanting:
We are not sure, but *Striga* flowers at different times

on the millet and sorghum, which might indicate different strains.

Musselman:
What are the natural enemies on early-maturing crops in northern Ghana?

Ramaiah:
(1) Pathogens like *Fusarium* attack some *Striga* plants and kill them because of heavy rains in July and August. (2) Some larvae (not yet identified) feed on the leaves and defoliate *Striga* plants. (3) Lack of insect vectors limits cross-pollination and seed set. (4) Wet dormancy permits few *Striga* seeds to germinate. One or all of these factors limit buildup of *Striga;* thus *Striga* has not become serious on early-maturing crops. However, if there is early drought, *Striga* can appear on these crops at damaging levels.

Ba Khalidou:
How have you estimated 80% yield loss? How is ammonium sulfate distributed to farmers and what dose is used?

Lanting:
The estimate of 80% yield loss is an approximate visual observation, subjective statement. Ammonium sulfate is available for sale to farmers through extension service centers; the exact dosage used is not known but it must be heavy in order to affect *Striga.*

The Need for Consideration of Biocontrol in *Striga*

Lytton J. Musselman*

Abstract

There is a lack of data on the kinds of organisms that could be considered in a potential biological control program for Striga. *The larvae of the Nymphalid butterfly* Precis coenia (= Junonia coenia) *have been observed to be voracious feeders on* Striga asiatica *in the USA, where seed production was markedly reduced during the 1981 season.*

Résumé

Intérêt de la lutte biologique contre le Striga *: Actuellement, on manque d'informations sur les organismes susceptibles d'intervenir dans un programme de lutte biologique potentiel contre le* Striga. *Aux Etats-Unis, on a observé que les larves de* Precis coenia (= Junonia coenia) *se nourrissalent voracement de* S. asiatica *et qu'elles ont permis de faire baisser considérablement la production de graines de* Striga *à la campagne 1981.*

A recent review (Girling et al. 1979) has drawn attention to the potential for biological control of *Striga* species. The purpose of this note is to emphasize the need for additional surveys for biocontrol agents, especially fungi, and to report damage to S. *asiatica* by *Precis coenia* in the United States.

Discussion

Precis coenia is a common nymphalid butterfly of the southeastern United States that is essentially restricted in its food plants to members of the subfamily Rhinanthoideae of the Scrophulariaceae. Preferred plant parts include buds, developing capsules, and leaves. I have not observed the caterpillars eating the mature seeds, but this deserves attention also.

In the region of the USA where S. *asiatica* is present, *Precis coenia* completes its life cycle in about 1 month. During the growing season the butterfly can complete several generations and therefore build up a very heavy infestation on *Striga* plants. During the summer of 1981 a record infestation was observed in the U.S. Department of Agriculture *Striga* fields in the vicinity of Whiteville, North Carolina. Few *Striga* plants were free of *Precis* larvae, and seed production was drastically reduced. At this stage the attacked *Striga* plants were only skeletons with all leaves, buds, flowers, and capsules eaten.

At present, there is little interest in developing a *Striga* biocontrol program in the USA because of the existing effective control and eradication program. However, we are attempting to develop a pilot program to determine the feasibility of a biocontrol program.

Precis (as *Junonia)* has been reported from East Africa but as yet is unknown in West Africa. Tests are needed to determine the palatability of S. *hermonthica* from West Africa to the *Precis* from East Africa. It would also seem desirable to assess the palatability of S. *hermonthica* to the American *Precis.* My preliminary observations reveal that the American strain of S. *gesnerioides* (more or less host-specific for *Indigofera;* Fabaceae) is not eaten. One factor that may influence palatability is the biochemicals transfered from the host into the *Striga.*

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I would encourage the collection of fungi growing on *Striga* species. To my knowledge no rust fungi have ever been collected from any *Striga.* In addition to *Striga,* related West African genera such as *Buchnera, Alectra, Cycnium,* and *Rhamphicarpa* should be surveyed not only for fungi but also for insect parasites.

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Discussion

Andrews:

How do you know that a transfered control insect will still prefer *Striga,* and not some other, possibly economically important, crop?

Matteson:

Feeding tests are routinely performed to ensure that phytophagous insects introduced into new areas do not attack valued and economically useful plants.

Studies on the Root Parasite *Striga asiatica* (L.) Kuntze

Bharathalakshmi*

S. *asiatica* (L.) Kuntze, a root parasite, causes damage to many crops such as sorghum, maize, pearl millet, sugarcane, finger millet, *Paspalum,* and others.

The germination of *Striga* seed in nature requires a stimulant produced by the host root. For the seed to respond to this stimulant, exposure to temperatures between 30° and 35°C in moist conditions for several days is a prerequisite. Subsequent to germination the radicle penetrates the host root.

The weed poses a serious problem in many parts of the world, and in India it is reported to cause heavy reduction in yields of sorghum, pearl millet, and sugarcane. Sorghum is the principal crop cultivated in many parts of Karnataka, Andhra Pradesh, Tamil Nadu, and Maharashtra, and is the staple food of a large proportion of the people. Similarly, pearl millet is the important crop in some parts of northern and western India. Both these crops, especially in dry areas, suffer heavily from *Striga* attack. In Karnataka, the *Striga* menace has become very severe, especially after the introduction of hybrid sorghum in Bellary, Dharwar, and Belgaum districts; as a result, many farmers in these areas have abandoned sorghum cultivation.

Many cultural, chemical, and biological methods have been tried to control this weed but the problem remains unsolved. A thorough understanding of the host-parasite relationship is essential to explore ways and means to combat the menace; hence, detailed studies were undertaken on various aspects of this parasite.

S. *asiatica* has a very wide ecological range and attacks a wide range of hosts. Field survey revealed preferential association of this *Striga* species with certain hosts and morphological differences among the *Striga* plants parasitizing different hosts. The flowers in this species are of three colors: white, yellow, and red. Of these, white and yellow flowers are found in India. Only white-flowered plants were found in cultivated fields; yellow-flowered ones were found parasitizing grasses. This research examined whether the success of the species over a wide range of conditions could be attributed to the presence of physiological races.

It was evident from the field survey that sorghum was the most common host of *Striga* in Bellary and Mandya districts. In the stretch between Bellary and Harapanahalli, crop yields suffered 50 to 100% loss due to *Striga.* Pearl millet was also attacked, but to a lesser degree; however, other crops like maize, foxtail millet, finger millet, and cotton were unaffected. In Mandya district, around Kikkeri, sorghum and *Paspalum* fields showed heavy infestation, while finger millet, except in 1977, was free from *Striga.*

Striga plants attacking different hosts varied in vigor, as expressed in height of the plant, number of branches, number and size of leaves and capsules, and weight of capsules and seeds. The sorghum *Striga* was the most vigorous of all.

The different seed collections varied in levels of metabolites such as. reducing sugars, free amino acids, proteins, and total phenolics. The electrophoretic pattern of seed proteins varied qualitatively but not the thin-layer chromatographic pattern of phenolics. Two of the phenolic spots inhibited germination of different *Striga* samples.

The seed samples of *Striga* collected from different host fields could be induced to germinate, after the required temperature pretreatment, by their respective host-root exudates. Cross induction was effective only with certain hosts.

Among the growth regulators only cytokinins and ethrel could induce germination of pretreated seeds of *Striga,* but the germination percentage differed with each sample. The response of the collections

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This paper is a synopsis of the author's Ph.D. thesis submitted to the Bangalore University, Bangalore, India. It was presented by C. Parker on the author's behalf.

International Crops Research Institute for the Semi-Arid Tropics. 1983. Proceedings of the Second International Workshop on *Striga,* 5-8 October 1981, IDRC/ICRISAT, Ouagadougou, Upper Volta. Patancheru, A.P., India: ICRISAT.

differed at different concentrations (10, 25, 50, 75 and 100 ppm) of kinetin, benzyladenine, and zeatin. Even the different pretreatment periods (0,5, and 10 days) given to the seeds had varied effects on germination of the samples. Ethrel could induce germination only of sorghum *Striga* but not of the other samples. The response of these collections to a synthetic germination stimulant, GR7 (1,10, and 100 ppm) also varied significantly. Cyclic AMP (10 ppm) and cytozyme (0.1 to 0.0001 ppm) could also induce germination of *Striga* seeds.

The collections from the Bellary area required longer pretreatment at higher temperature for maximum germination than those from the Mandya area; they also required a higher temperature for any germination.

After pretreatment, the levels of free amino acids and RNA increased, whereas those of proteins and phenolics decreased, but the extent varied with samples. The electrophoretic pattern of seed proteins showed two new bands, some bands reduced in intensity and others disappeared during treatment; in this respect also, *Striga* samples differed.

To study the penetration stage, the germinated seeds of *Striga* of different collections were inoculated onto the roots of 10-day-old seedlings of sorghum, pearl millet, finger millet, and *Paspalum.* The penetration percentage was higher with the respective host of the collection. In cross-induction tests the response was very small.

The medium (GR7,1 ppm) in which the seeds of *Striga* were germinated and grown for 5 days was assayed for cellulase and protease activity, which varied with the samples.

Seed collections of sorghum *Striga* from the Mandya and Bellary regions and *Paspalum Striga* from the Mandya region were grown in pots, with various hosts such as sorghum, *Paspalum,* finger millet, and pearl millet. In general, emergence was highest on the host from which it was collected. Sorghum *Striga* emerged earlier than *Paspalum Striga,* and emergence in the Mandya sorghum *Striga* was greater than that in the Bellary collection.

On hosts other than their own, sorghum and *Paspalum Striga* showed various responses. Sorghum *Striga* emerged to a very low degree on *Paspalum* and finger millet but not at all on pearl millet. *Paspalum Striga* emerged to a low degree on finger millet but not at all on sorghum or pearl millet. Trials on host specificity in *Striga*—laid out in Ittigi, a village in Bellary district—confirmed the results of the pot trials.

In pot trials conducted under identical conditions, both mature *Striga* plants that emerged with their respective hosts and the seeds produced by these retained the characteristic differences that were evident in the field collections.

The benzene fraction of the root exudate of sorghum, pearl millet, and *Paspalum* was subjected to TLC, and the stimulant spots were tested for germination of all the samples. In this case, too, germination due to cross induction was very low.

The cell wall material of the roots in these hosts showed different amounts of cellulose and lignin.

Sorghum grains were subjected to presowing hardening with caffeic acid, ferulic acid, and vanillic acid each at 1,5,15, and 25 ppm and distilled water, and the treatment consisted of four cycles each of 4 h soaking of the grains in the solutions, followed by drying to their original weight.

In the seedlings raised from the hardened grains, the ability of the root exudate to induce parasite seed germination was reduced by 71 to 96%. The three sorghum *Striga* samples collected from different areas showed different responses to hardening.

The hardening treatment also effectively reduced the number of *Striga* seedlings attached to 20- and 40-day-old host plants. Emergence of the parasite in association with 40-day-old host plants was also significantly low in the treatment.

Sorghum plants from hardened and unhardened grains were raised to maturity in pots holding soil mixed with *Striga* seeds. The average emergence of parasite per pot in the treatment decreased by 30 to 70%. The results have been confirmed in field trials.

The hardening caused no adverse effect on the host; instead, it increased dry-matter production and grain yield by 8 to 24%.

Analysis of the root exudate of the seedlings from the hardened seed showed either an increase in the total phenolics or decrease in the stimulant, or both, depending on the hardening agent. But there was no qualitative change attributable to the treatment. Lignin and cellulose contents in the roots of the treated plants were higher than in the control.

One and two sprays of phenolic acids to sorghum plants were also useful in lowering the germination-inducing ability of the host-root exudate by 16 to 38%. Foliar spray coupled with hardening was more effective.

The above findings indicate the occurrence of physiological races in S. *asiatica* and account for the adaptability of the parasite to a wide range of hosts cultivated under various conditions. This would also partly explain why the control measures devised so far have not been fully successful, as the response of the different races to these treatments varies. The presowing hardening treatment with phenolic acids is very simple, relatively cheap, and achieves a twofold purpose of reducing *Striga* incidence while improving crop yield.

Session 5

Summaries of Discussions

Discussion Leaders: C. Parker, A.T. Obilana, K.V. Ramaiah, and R.E. Eplee

Laboratory and Pot-Screening Procedures

1. The double-pot technique (Parker et al. 1977) used at ICRISAT Center to identify low-stimulant sorghum varieties in the germplasm has shown a low correlation when tested under field conditions. This may be because (a) the procedure did not "result in maximum sensitivity to local *S. asiatica"* and/or (b) the low-stimulant mechanism may not confer total field resistance on its own under varying environmental conditions. This calls for refinement of screening techniques and reinforcement of field resistance with a combination of several resistance mechanisms.

A screening procedure with higher preconditioning temperature and perhaps other modifications might be a more stringent selection method for low stimulant production. The 640 lines so far selected should be retested with a modified technique to see if a better correlation can be obtained. The importance of constant conditions for this technique is emphasized by the different results obtained at WRO from one test to another.

More work is needed to determine the exactinfluence of host age, *Striga* seed preconditioning, and light and temperature conditions. The possible role of microorganisms in modifying the activity of root exudates also needs more study. A procedure for diluting root exudates and obtaining quantitative estimation of relative activity of root exudates from different *Striga* strains was described and is recommended for more precise work.

2. Other techniques involving plants grown in soil should be explored further as alternatives to the double-pot technique. One involving "sandwiches" of preconditioned seeds placed onto the root had not given consistent correlation with the double-pot technique, but could perhaps correlate with field resistance, provided a way could be found to reduce the sensitivity of the technique and so obtain better differential between test varieties. The Eplee-bag technique should be tested in pots as a possible further alternative. The seed-pan technique should be tested with other species and strains of *Striga.*

3. There is urgent need to understand other resistance mechanisms so that suitable laboratory-screening techniques can be devised. The WRO project is exploring this but does not yet have answers.

4. Meanwhile pot tests to estimate field resistance could perhaps be developed, but experience so far is that useful resistant varieties such as N-13 do not always demonstrate resistance to S. *hermonthica* in well-watered small pots of soil, low in nitrogen. But large pots of the same soil allow resistance to be demonstrated. Further work already in progress suggests that the N-13 type of resistance may be more reliably shown with high fertility (preferably in small pots).

5. It is important to regulate the number of *Striga* seeds per pot so that there is a linear relationship between *Striga* infestation and parasite emergence above ground.

Reference

PARKER, C, HITCHCOCK, A.M., and RAMAIAH, K.V. 1977. The germination of *Striga* species by crop root exudates: Techniques for selecting resistant cultivars. Pages 67-74 *in* Proceedings, Sixth Asian-Pacific Weed Science Society Conference, 11-17 July 1977, Jakarta, Indonesia.

Field-Screening Techniques

1. There is an urgent need to standardize (a) *Striga* infestation techniques of test material, (b) field-plot techniques, and (c) indices of resistance.

2. *Striga* sick plots should be developed on fairly uniform soils to avoid *Striga* and soil-type interactions. Uniform infestations could be achieved by artificial inoculation, either by (a) broadcasting and incorporating the *Striga* seed into the soil by shallow plowing with a tractor and/or (b) drilling a mixture of *Striga* seed and sand into the test rows a couple of weeks before planting the test material.

3. Statistical designs such as the randomized complete block design (RCBD) and lattice designs can be used together with row plots where the number of lines to be field-tested is small. For a larger number of pure-line varieties or F_2 individual plants, the hill-plot technique is better. The three-stage screening methodology developed at ICRISAT looks promising and may be used in programs intending to breed Striga-resistant varieties. However, this methodology needs testing against S. *hermonthica.*

4. Indices of resistance need to be standardized, A combination of low *Striga* count with high grain yield in a *Striga* sick plot is a useful index of resistance.

Breeding Programs

1. Two aspects are recognized as important in a breeding program: gene pyramiding, or strengthening of resistance per se, and gene utilization, or use of resistance genes to breed high-yielding, stable, resistant cultivars.
2. Gene pyramiding. Two types of crosses are recognized which can reinforce resistance: (a) crosses between varieties with different resistance mechanisms apparently controlled by different resistance genes and (b) crosses between varieties with the same resistance mechanism but with different resistance genes. There is an urgent need to understand the various resistance mechanisms and to identify different resistance genes by appropriate laboratory and biometrical analyses.
3. Gene utilization. (a) Understanding the inheritance of resistance is best achieved by making diallei sets of crosses or by studying the F_2S and backcrosses. (b) Transfer of resistance to high-yielding varieties by pedigree and backcross methods is encouraging and should therefore be continued. (c) Population improvement with male-sterile genes is ideal for *Striga* resistance. Recurrent selection with a full-sib system is well suited to identifying *Striga*-free fertile and sterile plants in a sick plot. In pearl millet, however, it is suggested that less susceptible lines be intercrossed by selection of selfed plants in segregating generations grown in a *Striga* sick plot.

Agronomic Practices

1. Integrated management systems should be developed for the control of *Striga;* these should include: (a) stopping reproduction of emerged *Striga* plants and (b) devitalizing populations of *Striga* seeds in the soil. In such management systems the elements that require particular attention are: tillage, use of trap crops, effects of shading, the role of nitrogen, removal of *Striga* plants to avoid reinfestation, use of germination stimulants to rid the soil of viable seed, and techniques for hardening of host-crop seed. It is particularly important that work on all these aspects be accompanied by thorough monitoring of *Striga* seed and seedling behavior in the soil.

From these basic investigations effective management schemes may be developed to alleviate the effect of *Striga* as a crop pest. These would be based on the agroecosystems involved and on social acceptability at the farmer's level.
2. To place the effects of *Striga* in proper perspective, an assessment needs to be made not only of the direct economic yield losses caused by the pest but also of the resulting indirect sociological impact on the lives of the farmers. It is essential that *Striga* workers make direct measurements of yield loss due to *Striga,* either by artificially inoculating clean sites or by cleaning plots in infested areas with fumigant or ethylene.

Sommaire des discussions

Procédures de criblage en laboratoire et en vase

1. La technique "double-pot" (Parker et al. 1977) a été utilisée au Centre ICRISAT pour identifier parmi les ressources génétiques de sorgho les variétés à faible stimulation. L'évaluation sur le terrain de cette technique a révélé une faible corrélation. Ce phénomène peut s'expliquer par le fait que (a) la procédure n'a pas permis d'avoir une sensibilité maximum au *S. asiatica* indigène et/ou (b) le mécanisme de la faible stimulation seul n'assure pas une résistance totale sous les conditions changeantes retrouvées dans l'environnement. Il faudrait donc améliorer les techniques de criblage et augmenter la résistance au champ grâce à une combinaison de plusieurs mécanismes de résistance.

Une procédure de criblage qui utilise une plus haute température de pré-conditionnement et éventuellement d'autres modifications pourrait assurer une sélection plus rigoureuse pour une faible stimulation. Une réévaluation des 640 lignées sélectionnées jusqu'à maintenant s'impose avec une modification de la technique afin de voir si cela donne une meilleure corrélation. L'importance des conditions constantes dans cette technique est mise en évidence par les résultats variables obtenus dans les essais effectués à la Weed Research Organisation d'Oxford au Royaume-Uni.

Il faudra mieux connaître l'influence exacte de l'âge de l'hôte, le pré-conditionnement de la semence du *Striga* et les conditions de luminosité et de température, sans négliger le rôle éventuel des micro-organismes dans la modification de l'activité des exsudats des racines. Une procédure pour diluer les exsudats des racines et obtenir une évaluation quantitative de l'activité des exsudats des racines en utilisant différentes souches de *Striga* a été recommandée.

2. En outre, il faudrait étudier les techniques alternatives, où les plants sont cultivés dans le sol. Les résultats de la technique "sandwich", où la semence pré-conditionnée est placée sur les racines ne correspondent pas à ceux de la technique "double-pot". Mais, elle pourrait être en corrélation avec la résistance au champ si l'on trouvait une façon de réduire la sensibilité de cette technique et ainsi avoir une meilleure différentielle entre les variétés de l'essai. La technique "Eplee-bag" devrait être évaluée en pots comme une alternative. La technique "seed pan" devrait être évaluée en utilisant d'autres espèces et souches de *Striga*.

3. Il est pressant de comprendre les autres mécanismes de la résistance pour développer de meilleures techniques de criblage en laboratoire. Le projet WRO étudie cette possibilité.

4. On peut envisager la mise en place d'essais en vases de végétation pour évaluer la résistance au champ, mais l'expérience montre que les variétés résistantes et utiles, telles que N-13, ne manifestent pas toujours une résistance au *S. hermonthica* dans de petits vases de sol bien humide et pauvre en azote. Cependant cette résistance est mise en évidence dans ce même sol si l'on utilise des vases plus grands. Le travail actuellement en cours indique que le type de résistance de N-13 ressort mieux avec une plus forte fertilité (préférablement dans de petits vases).

5. Il est important de fixer le nombre de graines de *Striga* par vase afin d'obtenir une relation linéaire entre l'infestation par le *Striga* et l'émergence du parasite.

Référence

PARKER, C., HITCHCOCK, A. M., et RAMAIAH, K. V. 1977. The germination of *Striga* species by crop root exudates: Techniques for selecting resistant cultivars. Pages 67–74 *in* Proceedings, Sixth Asian Pacific Weed Science Society Conference, 11–17 juillet 1977, Jakarta, Indonésie.

Techniques de criblage au champ

1. Il faut d'urgence normaliser (a) les techniques d'infestation du matériel expérimental par le *Striga*, (b) les techniques d'expérimentation au champ et (c) les indices de résistance.

2. Les parcelles infestées par le *Striga* seront placées sur des sols assez homogènes, afin d'éviter des interactions *Striga* et type de sol. L'inoculation artificielle qui donne une infestation uniforme est effectuée par (a) un semis à la volée, suivi par l'incorporation de la semence du *Striga* dans le sol par un labour mécanisé peu profond et/ou (b) en enfoncant le mélange sable-semence dans les rangées à ensemencer avec le matériel expérimental quelques semaines avant le semis.

3. Des méthodes statistiques telles que le dispositif des blocs de Fisher et le dispositif du carré latin pourront être utilisées pour les parcelles en rangées où le nombre de lignées à évaluer est restreint. Pour un plus grand nombre de lignées pures ou de plants individuels F_2 les parcelles avec poquets sont préférables. La méthodologie à trois stades définie à l'ICRISAT semble prometteuse et peut servir dans des programmes visant à sélectionner des variétés résistantes au *Striga*. Cette méthodologie devrait être encore évaluée contre *S. hermonthica*.

4. Il faut normaliser les indices de résistance. Il est bon d'utiliser une combinaison d'un faible nombre de *Striga* avec un rendement en grain supérieur dans une parcelle infestée.

Programmes d'amelioration

1. Deux aspects sont consideres importants dans un programme de selection: le regroupement "pyramidation" des genes (gene pyramiding) ou renforcement de la resistance per se, et utilisation de genes resistants pour selectionner des cultivars resistants a haut rendement et plus stables.

2. Regroupement des genes. Deux types de croisements permettent d'augmenter la résistance : (a) croisements entre variétés ayant différents mécanismes de résistance apparemment régularisés par différents gènes de résistance et (b) croisements entre différentes variétés ayant le même mécanisme de résistance, mais ayant différents gènes de résistance. Il convient de mieux comprendre les différents mécanismes de résistance et d'identifier les différents gènes de résistance par des analyses de laboratoire et biométriques appropriées.

3. Utilisation des gènes. (a) L'héritabilité de la résistance est mieux comprise par des croisements diallèles ou l'étude des F_2 et des rétrocroisements. (b) Transférer la résistance aux variétés à haut rendement par des méthodes pedigree et de rétrocroisement donne des résultats encourageants; ce travail devrait se poursuivre. (c) Pour la résistance au *Striga*, une amélioration des populations en utilisant les gènes de la stérilité mâle est idéale. La sélection récurrente, avec le système full-sib, est bien adaptée et permettrait d'identifier des plants stériles ou féconds mais exempts de *Striga* dans une parcelle infestée. Cependant, chez le petit mil, il est recommandé d'intercroiser les lignées moins sensibles par la sélection de plants autofécondés des générations en ségrégation produits sur des parcelles infestées par le *Striga*.

Pratiques agronomiques

1. Il est nécessaire de développer un système intégré de gestion pour lutter contre le *Striga*. Il s'agit de : (a) arrêter la reproduction des plants de *Striga* émergés, et (b) dévitaliser les semences de *Striga* se trouvant dans le sol. Les composantes importantes d'un tel système sont : le travail du sol, les cultures pièges, l'ombrage, l'azote, le sarclage des plants de *Striga*, afin d'éviter une réinfestation par les graines, l'utilisation des stimulants de la germination pour débarrasser le sol des semences viables et les techniques d'endurcissement des semences des cultures hôtes. Il sera important que ce travail soit associé à une surveillance des graines du *Striga* dans le sol, la germination et l'émergence.

Ces recherches de base permettront de définir des programmes de gestion efficaces pour alléger l'effet néfaste de *Striga*. Celles-ci seront fondées sur les agro-écosystèmes existants et acceptables aux paysans.

2. Une évaluation des pertes de rendement et de l'impact sociologique est essentielle, car cela permettra d'avoir une appréciation utile du *Striga* comme parasite des cultures. Les études sur le *Striga* devraient porter sur les pertes de rendement causées par le *Striga*, soit par l'inoculation artificielle des parcelles exemptes de ce parasite ou le nettoyage des parties infestées à l'aide de fumigants ou de l'éthylène.

Session 6

Plenary Session and Recommendations

Chairman: K.V. Ramaiah **Rapporteur: M.J. Vasudeva Rao**

Recommendations of the Second International Workshop on *Striga*

1. Reinforcement of *Striga* research and control programs with more scientists is very strongly recommended.
2. In the light of ICRISAT's existing breeding program in Africa, it is recommended that ICRISAT establish a complementary research unit to utilize a farming-systems approach to investigate agronomic methods of *Striga* control.
3. The FAO/CILSS Project on Integrated Pest Management is urged to devote efforts to:
   a. assess crop losses due to *Striga* and
   b. investigate interactions of *Striga* with insects and the potential for biological control.
4. The USAID/CILSS Regional Food Crop Protection Program should undertake the task of raising awareness of the *Striga* problem and training technicians from CILSS countries in *Striga* control.
5. The International Institute of Tropical Agriculture (IITA) should be asked to initiate *Striga* control programs in maize and cowpea in view of the increasing *Striga* buildup on these crops, particularly in West Africa.
6. The USAID/SAFGRAD proposed project on *Striga* control in Africa urgently needs to be started.

Recommandations du Deuxième atelier international sur le *Striga*

1. Renforcer les programmes de recherche et de lutte contre le *Striga* grâce à un plus grand nombre de chercheurs.

2. Compte tenu de l'actuel programme de sélection de l'ICRISAT en Afrique, établir une unité de recherche supplémentaire utilisant une approche fondée sur les systèmes de production, afin d'étudier les moyens agronomiques de lutte contre le *Striga*.

3. Le projet sur la lutte intégrée contre les parasites organisé par la FAO/CILSS devrait :
   a) Evaluer les pertes culturales dues au *Striga*.
   b) Etudier les interactions du *Striga* avec les insectes et le potentiel d'une lutte biologique.

4. Le programme régional de protection de cultures vivrières USAID/CILSS devrait relever le défi de la sensibilisation au problème du *Striga* et de la formation de techniciens dans les pays du CILSS pour lutter contre cette mauvaise herbe.

5. L'Institut international d'agriculture tropicale (IITA) devrait débuter un programme de lutte contre le *Striga* chez les cultures de maïs et de niébé, suite à leur infestation croissante par le *Striga*, en particulier en Afrique de l'Ouest.

6. Le projet de l'USAID/SAFGRAD sur la lutte contre le *Striga* en Afrique devrait débuter sans délai.

Appendix 1

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