CP 0118

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 x 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 x variété significatives. SRN-4882B a eu une réaction différentielle. Les études intensives sur les relations hôte-parasite, les interactions du milieu influençant 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 tropica! (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 jn 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 Fa 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 fiat, 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	8.5	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	fin
			22	28	32	42	52 days
Summer	23 Feb 1981	CSH-1.	0.0	*02*	0.4	7.0	10.5
		Swarna	0.0	0.0	0.4	2.9	7.1
		N-13	0.0	02	0.0	0.5	0.3
			20	25	:30	40	50 days
Rainy	17 Jun 1981	CSH-1	*02*	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	*02*	0.5

[1]. CSH-1 and Swama 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 (our 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-

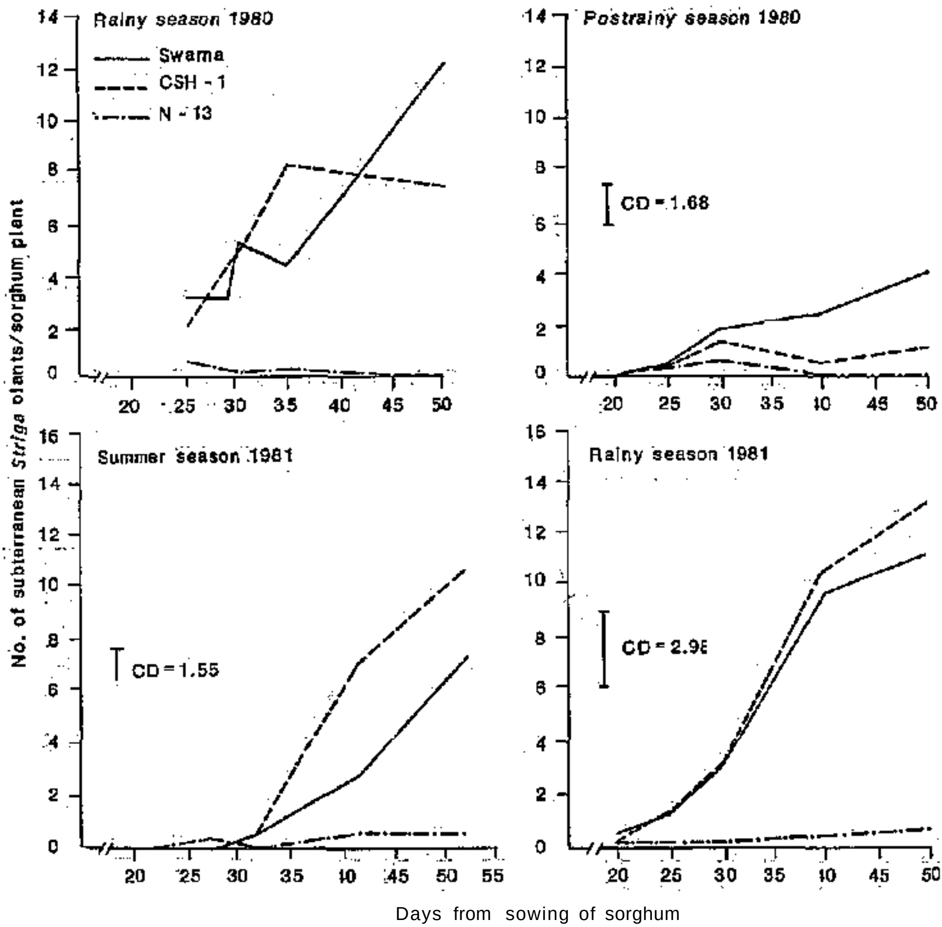

Figure 1, Subterranean Striga *counts on the roots of resistant and susceptible cultivars of sorghum.*

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

	Postrainy season 1980		Summer 1981		Rainy season 1981	
variation	DF	MS	DF	MS	DF	MS
Blocks	.5	1.55	7	*724*	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	2.3B	/9	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.

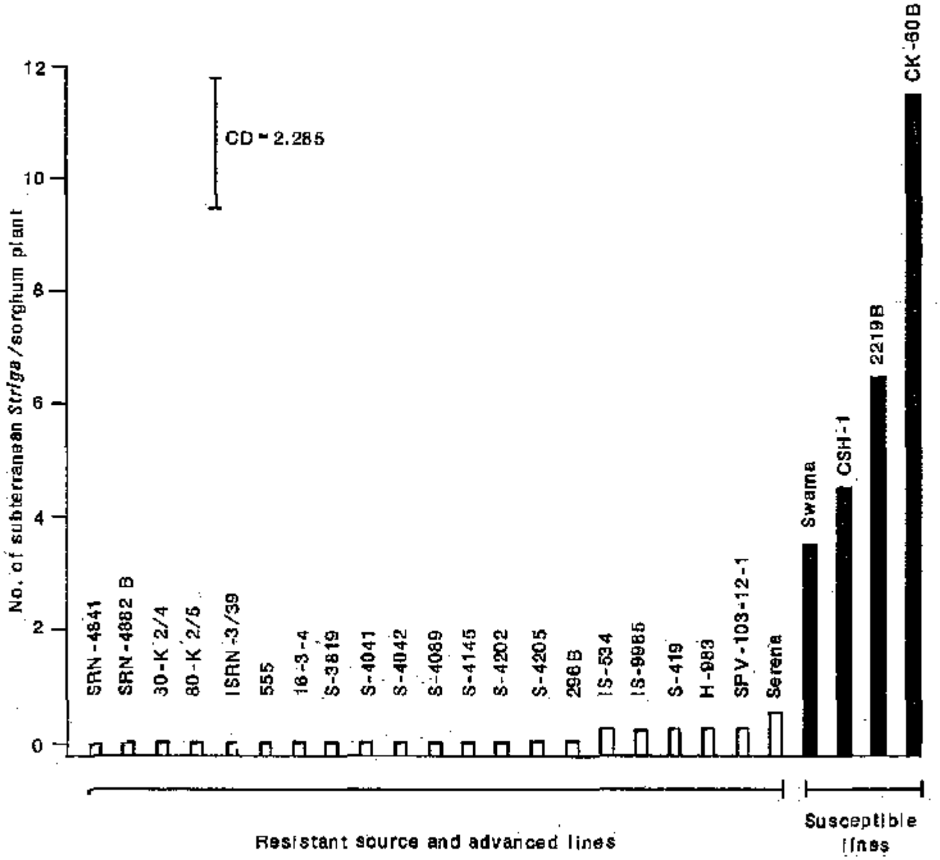

Figure 2. Subterranean Striga *counts of 25 sorghum lines in seed pans. (55-day counts) (D/S : 30.1.81).*

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~aver-" age 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 nurseiy. 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 replica tions 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)

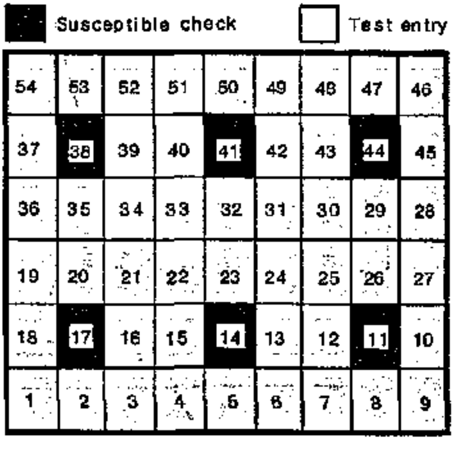

Figure 3. Field layout in the preliminary screening stage for Striga *resistance.*

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 ail 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 replicalions 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[1]	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[1]	4.10	R
8	6	2.43	R	38.90	S
9	7	0.14	R	4.00	R
10	a	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% of 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 lest 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 targe 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 susceptibie 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		Total
		< 10%	> 10%	
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		Total
		R	S	
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-

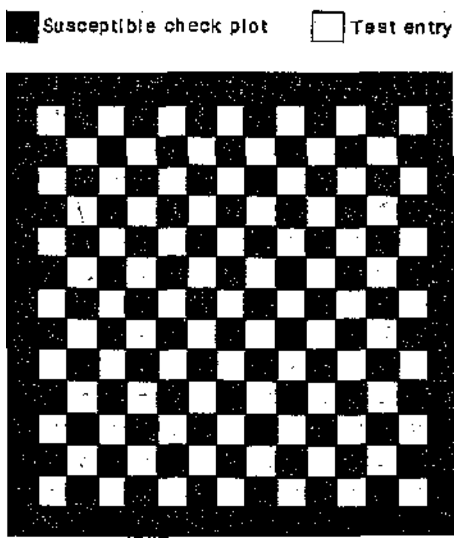

Figure 4. Checkerboard layout for advanced screening in Striga *resistance breeding*

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]	-	+	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.*

Trial	Stimulant production	No. of lines tested	Proportion of lines resistant at: Akola No.	%	Bhavanisagar No.	%	Phaltan No.	%	Hayatnagar No.	%	Patancheru No.	%	Across locations 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"
CK608	High	12.92"

SE $(\hat{g}_i)$ = 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 agronomically 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.

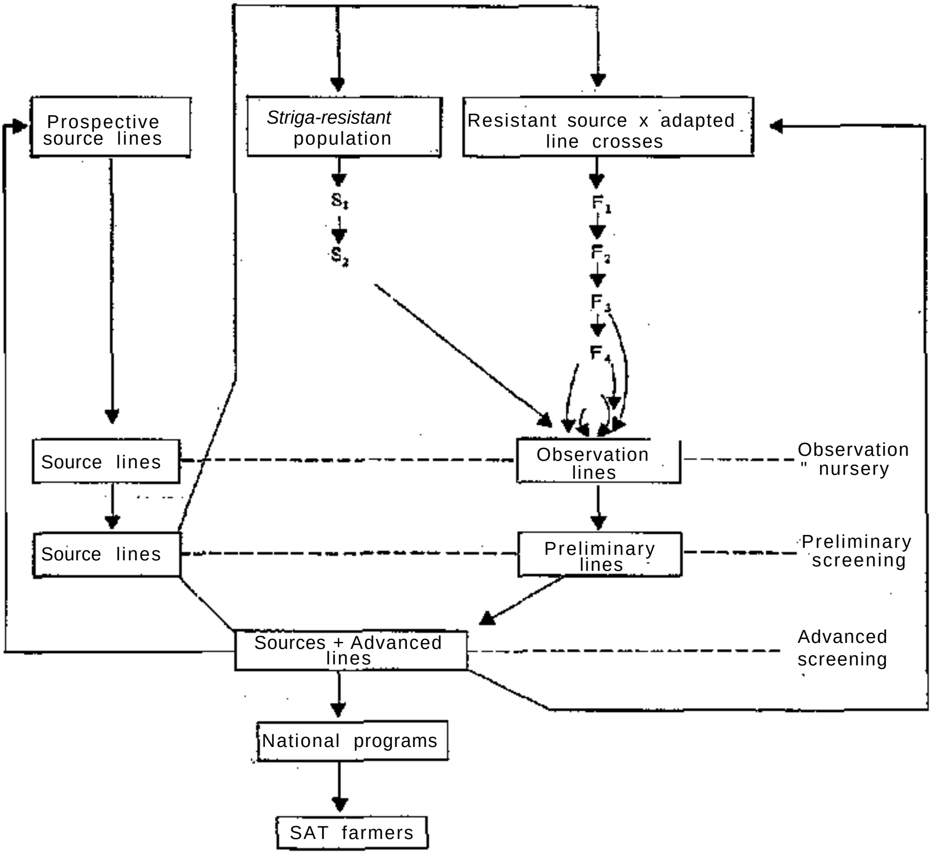

Figure 5. Flowchart of material for screening for field resistance to Striga

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 subplots. 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* <0.0t.

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.

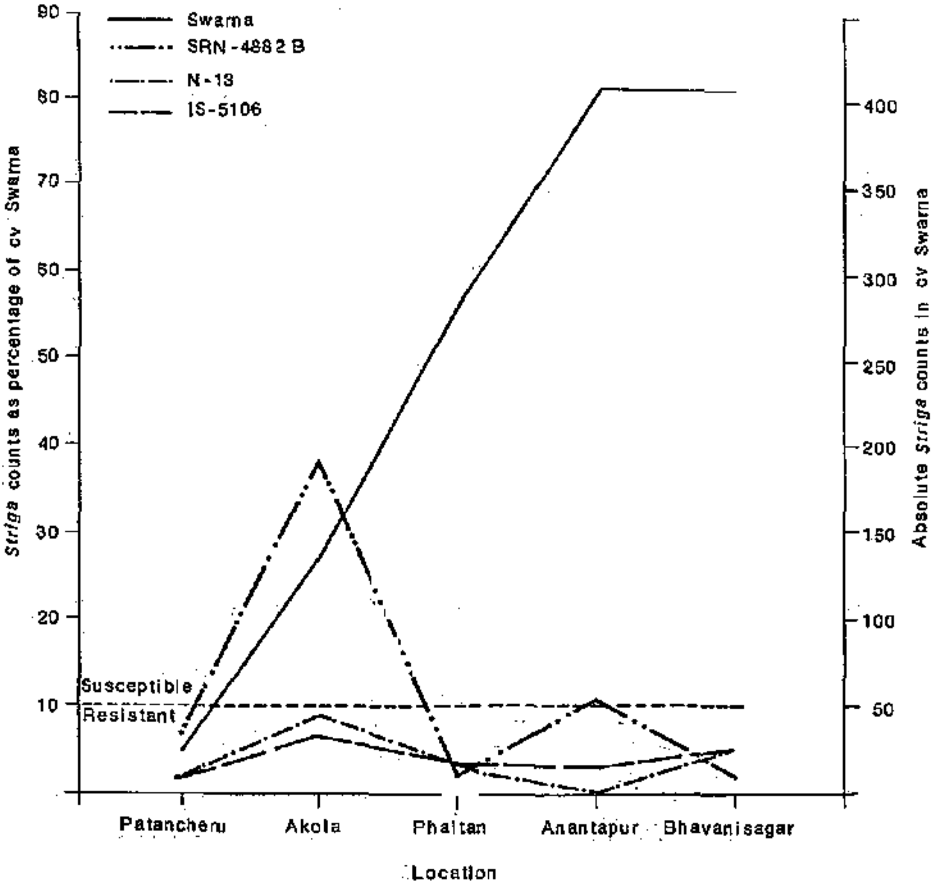

Figure 6. Striga *reactions of four cultivars of sorghum* Striga asiatica *collected from live locations.*

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					Average
	Patancheru	Akola	Phallan	Anantapur	Bhavanisagar	
SRN-4882B (R)[1]	6.15	33.44	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

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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 thai 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..