

# Breeding for Pest Resistance in Sorghum

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In view of potential economic and environmental constraints of insecticide use, breeding of crop varieties with resistance to harmful insects is a promising method of insect control. Such sorghum varieties offer the most effective way of controlling pests, particularly in areas where technological knowhow and resources are limited.

buted in the U.S., Canada, Mexico, and Latin America and attack sorghum during all stages of growth (Rao et al. 1977).

These major insect pests will be used in this paper to illustrate concepts of breeding for resistance. It is recognized that these priorities might change with time.

## Major Insect Pests of Sorghum

Although nearly 100 insect species have been recorded as pests of sorghum in the semi-arid tropics, stem borer, midge, shoot fly and earhead bugs are the most widespread and devastating (Table 1). Sorghum shoot fly (*Atherigona varia soccata*) is prevalent in South and South East Asia, the Middle East, Mediterranean Europe and Africa. Among the stem borers, *Chilo partellus* and *Sesamia inferans* are distributed in the Indian Subcontinent, South East Asia, and East and West Africa; *Sesamia critica* in East, North East and Mediterranean Europe except France and the Iberian Peninsula; *Busseola fusca*, *Eldana saccharina*, *Acigna ignefusalis* and *S. calamistis* in the African continent and *Diatraea saccharalis* and *D. grandeosella* in the Americas (Seshu Reddy, personal communication). Sorghum midge (*Contarinia sorghicola* Coq.) is almost a universally distributed pest. Among earhead bugs, *Calocoris angustatus* is a serious pest in South India and *Agnoscalis* species in the Sudan; several other species of bugs and earhead caterpillars have been reported from various parts of India and Africa. The nymphs and adults of the sucking chinch bug (*Blissus leucopterus*) are widely distri-

Table 1. Distribution of different insect species.

Shoot Fly	
<i>Atherigona varia soccata</i>	South and South-East Asia, Middle East, Mediterranean Europe, and Africa
Stem Borers	
<i>Chilo partellus</i> , and <i>Sesamia inferans</i>	Indian Subcontinent; S E Asia, East and West Africa
<i>S. critica</i>	East, North-East and Mediterranean Europe, except France and Iberian Peninsula
<i>Busseola fusca</i> , <i>Eldana saccharina</i> , <i>Acigna ignefusalis</i> and <i>S. calamistis</i>	African Continent
<i>Diatraea saccharalis</i> and <i>D. grandeosella</i>	Americas
Midge	
<i>Contarinia sorghicola</i>	Almost universal
Earhead Bugs	
<i>Calocoris angustatus</i>	S. India
<i>Agnoscalis</i> species	Sudan
Chinch Bug	
<i>(Blissus leucopterus)</i>	USA, Canada, Mexico, and Latin America.

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## Breeding for Insect Resistance

Breeding is a process of changing a characteristic of a population over a number of generations by applying selection pressure on the population. The rate of success in a resistance breeding program is associated with several factors.

1. The availability of a broad germplasm base from which good, stable and diverse sources of resistance can be selected.
2. The availability of effective, efficient and reliable screening techniques. For this it is essential to have a good knowledge of the biology of the insect, the insect-host plant relationship and the insect-environment relationship.
3. If possible, knowledge of the mechanism of resistance; whether it is tolerance, preference or antibiosis.
4. Knowledge of the mode of inheritance.
5. Selection of the right breeding procedures.

In order to accomplish these goals efficiently a good interdisciplinary team approach between breeder and entomologist is essential.

## Shoot Fly

The shoot fly can be a severe pest attacking sorghum in the seedling stage. Eggs are laid singly on the lower surface of leaves. The emerging maggot migrates to the growing point, kills it (causing a deadheart), and feeds on the decaying tissue. Once plants are 30 to 40 cm tall they become resistant to this pest.

### Source Material

A systematic search for over 20 years for sources of resistance, primarily by field screening of the world sorghum germplasm collection, was undertaken by the All India Coordinated Sorghum Improvement Project (AICSIP) and recently by ICRISAT. Over 10 000 germplasm lines have been screened for this pest, and 213 lines have been selected as low susceptibles. Among selected lines IS-923, IS-2195 and IS-2312 have performed well in AICSIP trials. These selected low susceptible lines belong to different taxonomic and geographic regions. Earlier, most of the shoot fly resistant sources identified were from the South India winter sorghums belonging to either Durra or Dagadi groups. Now several new sources have been identified that represent several other re-

gions and taxonomic groups. Absolute resistance to this pest has not been found. The degree of tolerance/resistance of the source varieties varies with season, year and particularly with fly pressure. Most shoot fly resistant sources have the *glossy* expression during the seedling stage. Some of the sources have gone through multilocation testing in countries where shoot fly is a problem and some have been found to be stable. Singh et al. (1978) conducted a stability study on 15 lines in six environments and noticed that most of them were consistent in their fly reaction; IS-1054, IS-5469 and IS-5490 were found to be the most stable.

The main culms of plants attacked by the fly are killed and tillers that develop subsequently may also be killed. However, some varieties produce synchronous fast-growing agronomically productive tillers that produce good yields. Such "recovery resistant" types are quite often detected in the field and are useful in overcoming field loss.

de Wet et al. (1976) indicated the possibility of transferring shoot fly resistance through introgression from *Saccharum* to *Sorghum*. Initial efforts have not been rewarding.

### Screening Technique

In sorghum, though the Starks' interlards and fish meal technique was very effective in creating uniform and desired levels of shoot fly infestation, very little progress was made over the last two decades. One important reason could be that selection was made at the time of harvest when there was no effective way to identify plants with real resistance. At maturity, a large proportion of the shoot fly damaged plants recovered and looked similar to undamaged plants. At ICRISAT this practice was followed until the 1977 postrainy season and resulted in hardly any progress.

It was found necessary to score all seedlings soon after the stage of damage is over and to maintain identity until maturity. There was concern about escapes, i.e., plants that were missed by the egg-laying adult. The proportion of such plants varies with the level of infestation (Table 2). It could be assumed that the plants having no eggs are escapes, but this would eliminate oviposition nonpreference reported by Maiti and Bidinger in 1979. They found that trichomes on the abaxial surface of the leaf contribute to less egg laying. This information assisted in categorizing different mechanisms of resistance that could

**Table 2. Some criteria for selecting mechanisms of resistance to shoot fly.**

Egg laying	Trichomes	Resistance mechanism	No of selections made	
			77R	78K
No	No	Escapes	201 (39.8%)	73 (6.7%)
Yes	No	Antibiosis	123	515
No	Yes	Ovipositional nonpreference	100	106
Yes	Yes	Mechanical	79	400
Approximate proportion of nontrichomed : trichomed			40 : 60	50 : 50

be identified at the seedling stage (Table 2). Oviposition nonpreference could be identified by the lack of eggs on trichomed plants. Antibiosis occurs when eggs are laid in the absence of trichomes but no deadhearts occur. Recovery resistance refers to a situation in which the main plant is killed and the crop develops from tillers. Escapes are suspected when there are no eggs and no trichomes.

This system of identification of resistant plants in the seedling stage with selection for better agronomic types at maturity was tried first in the post-rainy season of 1977. The gains using this system for the last 3 years have been quite rapid and very encouraging. Good progress has been made in evolving several diverse breeding lines with levels of shoot fly resistance exceeding that of the original source material and in fairly good agronomic backgrounds.

### Mechanism of Resistance

Nonpreference is an important mechanism of resistance. Sometimes it is operative even in the absence of a preferred host(s) (Wongtong and Patanakam 1975; Jotwani et al. 1974). One deterrent to oviposition in sorghum is the presence of trichomes (microscopic hairs) on the abaxial surface of leaves of resistant genotypes (Maiti and Bidinger 1979). Their presence on the abaxial surface is highly associated with oviposition nonpreference ( $r = -0.8$ ) and is also a highly heritable trait ( $h^2 = 0.9$ ) (Omori, unpublished). Varying trichome intensity does not influence oviposition nonpreference. It is controlled by a single recessive gene (Gibson and Maiti, unpublished). The possibility of other deterring factors is not ruled

out. Sometimes, trichomes also offer mechanical resistance by interfering with the migration of the maggot towards the growing point (Reddy and Abraham, unpublished). In a preliminary analysis, the trichomes and unknown antibiotic factors seem to contribute equally towards shoot fly resistance (Table 2).

ICRISAT physiologists noticed that most shoot fly resistant varieties have a *glossy* (pale green, smooth, shining leaves) expression in the seedling stage. It was then observed that most of ICRISAT's advanced shoot fly resistant breeding material was unconsciously selected for this glossy trait. Tarumoto (1980) indicates that glossy is controlled by a single recessive gene. The level of resistance has been found to be greatest when both the glossy and trichome traits occur together (about 80% of the time) (Fig 1). The resistance of glossy genotypes differ with the intensity of glossiness.

A component analysis was done on Omori's unpublished observations to assess the complexity of shoot fly resistance and to quantify the contribution of major factors to shoot fly resistance. Four traits—trichome density, glossy intensity, eggs/plant, and percent deadhearts—were considered. Correlations were obtained both at the genotypic and phenotypic levels and the results are presented in Table 3. Highly significant correlations were found among all four traits. Shoot fly incidence was found to be highly and negatively associated with the glossy and trichome traits. The high correlation noticed between glossy and number of eggs/plant is evidence of contribution to oviposition nonpreference.

These correlations were partitioned into direct

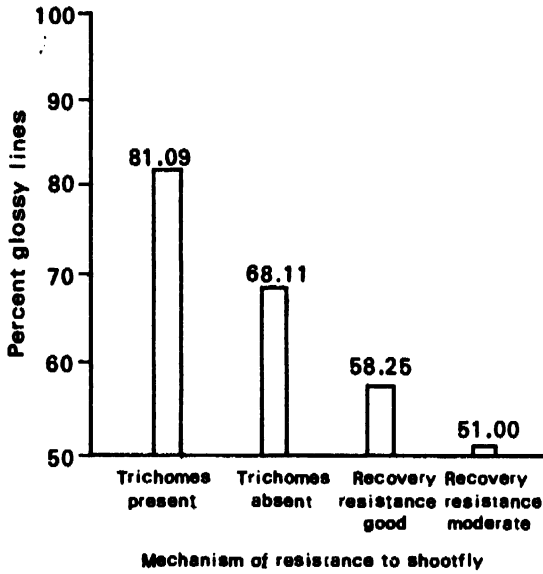


Figure 1. Percent glossy shoot fly breeding lines with and without trichomes and with recovery resistance.

and indirect effects using a standardized partial regression coefficient technique. Although glossy is highly associated with shoot fly resistance it has

very little direct effect on shoot fly resistance (i.e.,  $r_g = -0.935$  and  $p_g = -0.166$ ). This indicates that the high correlation which was observed is the result of other traits and hence the glossy appearance may be an indicator trait for some other trait that contributes to resistance (Fig 2).

The presence of glossy trait has been found to be negatively correlated with yield ( $r = -0.453$ ). The reason for this requires further investigation. There are fairly good indications that glossy contributes to reduced infestation by the flea beetle and also the shoot bug (*Perigrinus maidis*) (Woodhead, personal communication). Recent observations at ICRISAT suggest that it also contributes to seedling drought resistance (Maiti, personal communication). It appears that the glossy expression could play an important role in the simultaneous incorporation of resistance to several traits.

### Genetics

Genetic studies conducted to date indicate that the nonpreference mechanism is the predominant one and it is quantitatively inherited with a predominance of additive gene action (Rao et al.

Table 3. Genotypic and phenotypic correlation coefficients between factors contributing resistance to shoot fly.

Factors		Trichome intensity	Glossy intensity	No. of eggs / plant	Deadhearts
Trichome intensity	rg	1.0000	0.8330**	-0.6973**	-0.8174**
	rp	1.0000	0.8289**	-0.4946**	-0.7190**
	h <sup>2</sup>	0.995/			
Glossy intensity	rg		1.0000	-0.8255**	-0.9351**
	rp		1.0000	-0.5848**	-0.8177**
	h <sup>2</sup>		0.9890		
No. of eggs / plant	rg			1.0000	0.9971**
	rp			1.0000	0.7334**
	h <sup>2</sup>			0.5008	
% Deadhearts	rg				1.0000
	rp				1.0000
	h <sup>2</sup>				0.7752

rg = Genotypic correlation coefficients  
 rp = Phenotypic correlation coefficients  
 h<sup>2</sup> = Heritability  
 \*\* = Significant at 1% probability level.

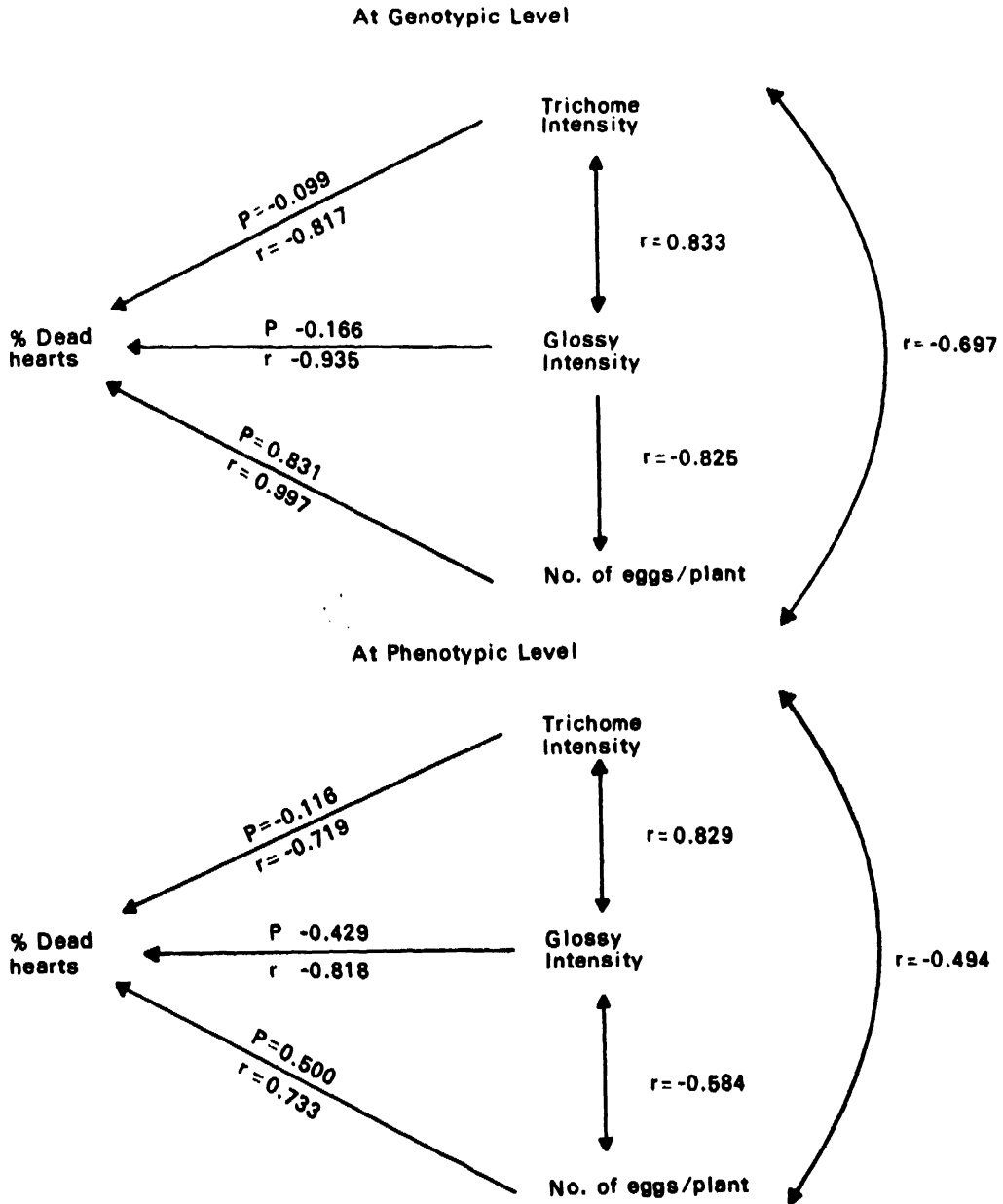


Figure 2. Path analysis of factors contributing resistance to shoot flies.

1974; Sharma et al. 1977). Rao et al. (1974) found that hybrids are generally superior to parents. Further studies of Balakotaiah et al. (1975) conducted on large  $F_2$  populations revealed that the frequency distribution of different mortality classes closely fits the normal curve and the inheritance of shoot fly resistance is predominantly additive. Based on backcrosses,  $F_1$ s, and advanced generation progenies, Rana et al. (1975)

found the heritability of shoot fly resistance to be around 25%. Rana et al. (1980) reported that the  $F_1$  is almost intermediate between the two parents. Resistance was found to be partially dominant under low to moderate shoot fly pressures but not under heavy infestation conditions. In this study resistance was also found to be polygenic in nature and governed by genes with predominantly additive effects.

The analysis of the genetics of resistance to shoot fly done by Borikar and Chopde (unpublished) indicated that both additive and nonadditive components of gene action are important for shoot fly deadhearts under low pressures. However, the deadheart percentage is predominantly controlled by additive gene action under moderate to high shoot fly pressures. Heritability ranged from 15 to 25% depending on shoot fly pressure. In general, oviposition preference is controlled by additive genetic factors. The heritability studies also revealed that the genetics of deadhearts and eggs/plant is influenced by the level of shoot fly population. It therefore appears that genetic studies and breeding for shoot fly resistance must be associated with population pressure. Selection for shoot fly resistance preferably should be made in conditions of high infestation.

## Stem Borer

The stem borer attacks all stages of the crop from about 4 weeks after germination, and it attacks all parts of the plant except the roots. In the early stage, the larvae feed on the leaves in the whorl of the plant and often cause deadhearts. Late attack results in stem tunneling and boring of the peduncle which may result in breakage of chaffy heads.

## Source Material

During the 70s, Jotwani and his colleagues systematically field screened the sorghum germplasm collection for *Chilo* resistance, and tested the first 10 000 accessions at several locations in India. They confirmed the resistance of promising lines by inoculation. Twenty-six lines were found relatively less susceptible to *Chilo*. Most of them were of Indian origin with the exception of IS-3096 from the USA., IS-7273 from Nigeria, and IS-9136 from Kenya.

ICRISAT breeding stocks and the germplasm accessions not tested by Jotwani and his colleagues, were tested at ICRISAT in 1980 at several locations in India using natural or artificial infestation. Of the 10 744 germplasm lines screened, 289 lines have shown less susceptibility to *Chilo* and are being tested further. Some lines have been found to have low susceptibility to both shoot fly and stem borer. IS-4660, IS-18427,

and IS-18479 are tolerant to both *Chilo* and *Busseola* (Seshu Reddy, personal communication).

## Stem Borer Screening

Varying degrees of success in terms of screening for resistance to borer have been observed. A high natural *Chilo* infestation is found at several research stations in India. At the ICRISAT site, due to lack of uniformity, natural infestation has been discarded. Instead ICRISAT entomologists have developed an artificial diet giving recovery of 74% adults. A technique for releasing these larvae over the whole nursery through a dispenser makes it possible to screen three hectares of material each season. Testing by inoculation during the post-rainy season, where the growth of the plants is slower because of low temperatures, is more effective than in the rainy season. Shoot fly becomes a problem in the early seedling stage and reduces the plant stand. It is not possible to use chemical protection against shoot fly because of residual effects on young *Chilo* borers. It has been necessary to remove shoot fly eggs manually from seedlings every alternate day during the shoot fly susceptible stage—a cumbersome, laborious, and costly process.

Hissar in North India has been identified as a good hot spot for *Chilo* during the rainy season and has proved to be a good location for testing purposes. Sowings made in the first week of July receive uniform and massive attack of *Chilo*. Pantnagar and Bhavanisagar are other good locations where there is a moderate incidence of *Chilo* during the rainy (late July sowing) and late summer (March sowing) seasons, respectively. Effective screening with varying levels of *Chilo* from natural and inoculated situations is now possible.

## Mechanism of Resistance

Information on factors contributing to stem borer resistance is limited. Jotwani (1976) observed that tolerance and antibiosis are operating in resistant cultivars. Evidence for antibiosis was furnished by Kalode and Pant (1967). Jotwani (1978) reported that the development of *Chilo partellus* was retarded on three selected resistant cultivars, i.e., IS-1151, IS-4764, and IS-4776. On these three lines there was higher mortality in the early larval stage, the larval period was increased, and the

percent pupation was less on resistant cultivars compared with the susceptible hybrid CSH-1. Phenols and cyanides have been found not to play a significant role in resistance while waxes may play a role by way of obstructing larval migration (Sue Woodhead and Chapman, personal communication). More biochemical studies on borer resistance are under way at ICRISAT. If some simple, easily detectable mechanisms are identified, it will help in selecting resistant genotypes more effectively and efficiently.

## Genetics

Rana and Murty (1971) reported that resistance to stem borer is polygenically inherited. The  $F_1$  hybrids were intermediate for primary damage (leaf feeding) but better than the mid-parent for secondary damage (stem tunneling). Resistance to primary damage was found to be governed by additive and additive x additive type of gene action while additive and nonadditive type gene actions were important for secondary damage. The inheritance patterns of primary and secondary damage were different.

## Midge and Head Bugs

Midge is a small, bright, orange-red, rapidly multiplying fly that lays eggs inside the floret during flowering. The maggot feeds on the developing seed and prevents seed set. Earhead bug is severe at the milk and dough stages of seed development. The nymphs suck the seed, and grain yield and quality are drastically affected. Its damage varies from slight to extreme reduction of seed size.

## Source Material

Systematic testing for resistance to midge was initiated by Wiseman and his colleagues in 1968 in Texas. Johnson et al. (1973) reported good levels of resistance to midge in Ethiopian converted materials (Zera-zera type). To date, nearly 125 midge resistant lines have been identified, and they are well documented in the literature. These midge resistant lines belong to different countries (Sudan, Ethiopia, Uganda, India, and Pakistan) and taxonomic groups (Zera-zeras, Caudatum Nigericans, Caffrorum Darso, Durra, and Durra Nigericans). Faris et al. (1979) evaluated Ethiopian

converted lines and AF-28 in Northeast Brazil for stability of midge resistance. AF-28 was found to be the most stable across sowing dates. Lines IS-2508C and IS-2757C showed moderate stability. Converted Ethiopian Zera-zera cultivars have shown promise on a global basis for resistance to midge. Other important lines used in the breeding program include S-Girl-MR-1, DJ-6514, and TAM-2566.

Relatively little progress has been made for the systematic identification of sources resistant to earhead bugs. Over 90 germplasm lines have been identified as promising against *Calocoris* at ICRISAT, but their resistance still needs to be confirmed. Several advanced breeding lines have been identified with reasonable levels of resistance. Most of them are derivatives of IS-12573C, a midge resistant line.

## Screening Techniques

The problem of managing the high levels of midge and head bug populations in the field for screening purposes remains unsolved. In the field, populations vary considerably. Under such a situation, the test entries that differ in days to flowering may not be equally infested. It is therefore necessary to separate test material into groups of similar flowering times. A susceptible check with the same time of flowering as the test group should be included. Because of these problems, several seasons of testing are required to confirm resistance.

Early planting of susceptible sorghums with a range of days to flowering helps in increasing and to some extent in maintaining constant midge and head bug populations in the test material. This approach is useful for the initial testing of a large amount of material. Later, the resistance of promising lines/genotypes can be confirmed by using a cage technique. Using this technique, Rosetto et al. (1975) found AF-28 to be resistant to midge whereas Sart was found to be susceptible. Page (1979) reported that converted lines IS-12608C and IS-12664C expressed significantly higher levels of resistance against midge than KS-19 and Alpha. Line Q-13828, which showed resistance to midge under field conditions, was susceptible under caged conditions. Several other workers have found the technique quite effective and useful for confirming resistance. Large-scale testing using this technique is not possible unless we learn how to rear the midge and the head bug.

## Mechanism of Resistance

Nonpreference and antibiosis are the major mechanisms operating in most sources of midge resistance. AF-28, a strong and stable source of midge resistance has been found to have fewer numbers of eggs than a susceptible cultivar indicating an oviposition nonpreference mechanism (Rosetto et al. 1975). Its tight glumes make oviposition difficult. Also, the closed tight glumes of IS-2260 and IS-2263 enable the lines to resist midge (Berquist et al. 1974). The level of attack on a cultivar may also be a function of the number of midge flies attracted to the head (Wiseman and McMillan 1968; AICSIP 1973).

An antibiosis mechanism has been noticed in several midge resistant varieties like AF-117, SC-239-14, SC-175-9, and SC-175-14 and SC-574-6 (Rosetto 1977). Gowda and Thontadarya (1978), Jotwani (1978) and Page (1979) also found antibiosis to be a mechanism of resistance to sorghum midge. Significant differences were noticed in the number of flies that emerge from the earheads of resistant genotypes compared with susceptible ones. Varying contents of tannin in the grain are a probable biochemical factor imparting resistance. A relatively high correlation was noticed between tannin content in the grain and midge incidence by Santos and Carmo (1973) and Santos et al. (1974).

According to earlier workers, short tight glumes and cleistogamy contribute to midge resistance. On the other hand, several recent studies have indicated the presence of resistance in non-cleistogamous sorghum lines also. Murty and Subramaniam (1978) found no relationship between length of glumes, presence of awns and rachis length with resistance. Instead, they found compactness of earheads associated with midge resistance.

## Genetics

Very little information is available on the genetics of midge resistance, and there is none on head bugs. Widstrom et al. (1972) studied the gene effects conditioning resistance to midge. Most of the crosses expressed highly additive gene effects. An exception was the S-Girl-MR-1 × 130 cross in which dominance conditioned susceptibility to midge injury. Epistatic effects were also noticed. More genetic studies are required to have a clear idea of the nature of inheritance and

the type of gene action before designing an effective breeding procedure.

## Breeding For Shoot Fly, Borer, Midge, and Head Bug Resistance

The quantitative nature of inheritance of resistance to shoot fly, stem borers, and midge makes the breeding problem difficult. This problem is made even more difficult because yield is also a quantitatively controlled trait. The complexity of the problem further increases when breeding simultaneously for resistance to more than one trait.

The success achieved in maize at CIMMYT in transferring resistance to corn borer and the work of Hanson et al. (1972) in developing alfalfa varieties possessing multiple resistance by using recurrent selection suggest that this approach is valuable. The use of broad-based, random-mating pest-resistant populations should be an appropriate long-term approach for breeding sorghums resistant to several major insects. Pedigree breeding methods, on the other hand, are useful for short-term gains and for transferring resistance for a single pest.

Based on the stage at which damage occurs and the type of damage caused, the four pests discussed in this paper have been placed into two groups: (1) shoot pests (shoot fly and stem borers) and (2) earhead insects (midge and head bugs).

Two pest-resistant populations, one for shoot pests and the other for head pests, are in the process of development using  $ms_3$  and  $ms_4$  male-sterility genes. After their development, they will be tested for the first few years using a low to moderate insect pressure and then be subsequently advanced, using mass selection. Once the populations are improved for characteristics like height, maturity, grain quality, and resistance,  $S_2$  testing will be used as outlined in Figure 3. Major selection pressure is placed on resistance to the shoot pests so that only undamaged plants are advanced to the next generation.

Affected plants cannot be discarded before flowering in the head pest populations as they can be in the shoot pest populations, since the damage occurs only after that period. The recurrent selection system will involve  $S_2$  testing; selection in both  $S_1$  and  $S_2$  families will be under insect pressure. The half-sibs will be tested under



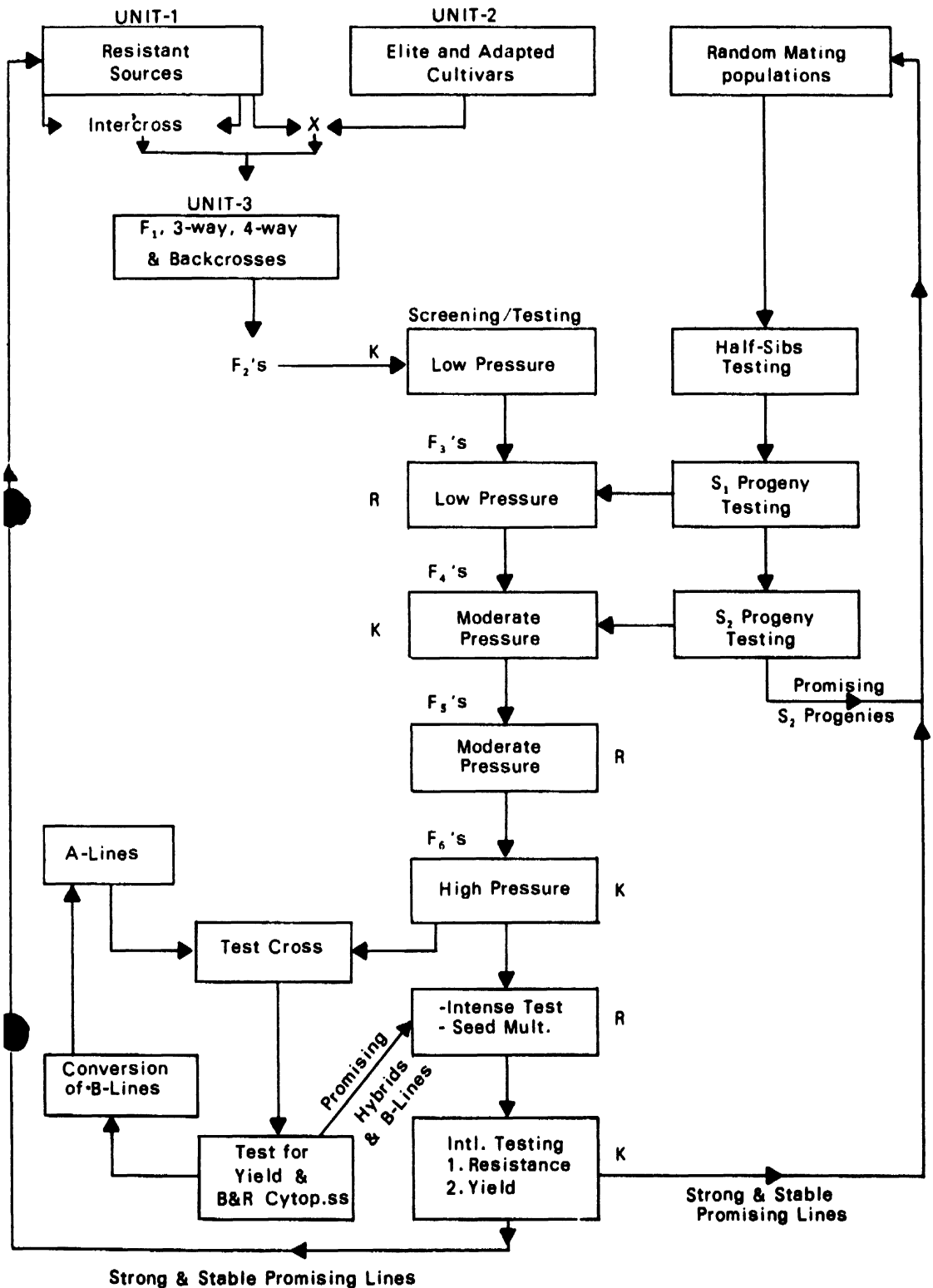


Figure 3. Proposed scheme for pest resistance breeding in sorghum.

protection and normal management during the main crop season, and selections will be made for height, maturity, and grain quality. While testing  $S_1$  progenies during the post-rainy season, simultaneous selections for grain size and charcoal rot can be made.  $S_2$  progenies will be tested in the main rainy season using moderate insect pressure.

During recombination, new promising derivatives with confirmed resistance can be incorporated into the populations to increase the frequency of genes for resistance and agronomic elite-ness. New sources of resistance which are agronomically poor should not be directly included in the population so that the agronomic features of the populations are not adversely affected. The source material for other traits, preferably with B cytoplasm, may also be fed into these populations so as to increase the variability and opportunities for simultaneous incorporation of other traits.

Promising  $S_2$  progenies may be advanced and purified under continuous insect pressures. Later their B and R cytoplasmic reaction, combining ability, and performance for both yield and resistance can be tested. The best derivatives may be used as improved sources, as resistant cultivars, or as hybrid parents, and then some can be fed back into the populations. Lines showing B reaction, and having appropriate height, flowering time, and good combining ability may be converted into resistant female stocks for the production of resistant hybrids.

In due course, when the gene frequency for resistance and agronomic traits improves, the populations can be pooled to bring together resistance for all four pests.

Besides population breeding, pedigree breeding is also currently being used as a short-term approach to quickly breed for resistance to individual pests and to meet immediate requirements. The procedures for handling donor parents, making the crosses, growing and screening for resistance, agronomic traits, and grain quality are outlined in Figure 3. There are three basic units to this approach. Unit 1 involves the strengthening of source material, Unit 2 the development of agronomically elite lines, and Unit 3 the crossing of material in units 1 and 2. Unit 3 segregating material is advanced with continuous testing using lower insect pressures in early generations and increasing insect pressures as gene frequencies for insect resistance increase. Advanced promising entries with resistance

should be tested internationally if the parents are reasonably well adapted.

In the last few years, good progress has been made in developing breeding material with reasonably good agronomic backgrounds and resistance to shoot fly, midge, and earhead bugs. The development of such materials for stem borer will take more time.

Many shoot fly resistant breeding lines are available with good levels of resistance. Some show better resistance than the best source materials (Table 4). Following the identification of trichome and glossy traits and the modification of the field screening technique, the exploitation of variability for shoot fly resistance in many genetic backgrounds has become possible. Several shoot fly resistant lines/progenies have been extracted directly from ICRISAT's advanced populations.

An array of promising midge resistant derivatives from crosses with AF-28, IS-12573C, 6514, and S-Girl-MR-1 has been evolved. Some lines have up to 90-95% seed set as compared with a maximum of 5% on the susceptible checks.

Several advanced lines with resistance to earhead bugs have been identified directly from midge resistant breeding material. IS-12573C is a frequent parent in most of these derivatives. Some have common resistance to both midge and earhead bugs. PHB-156 has good resistance and yields well. It is currently being used in Africa.

## Future Plans

In the future, our priority will be to breed for resistance first to stem borers, then midge, followed by shoot fly, and finally earhead bugs. It may be necessary to initiate a program for resistance to the armyworm *Mythimna*.

Development of A-lines and hybrids with resistance will be important objectives.

Screening procedures, particularly for midge and earhead bugs, require development before it is possible to effectively undertake large-scale screening activities. The identification of more "hot spots" for each major insect is essential.

More information on mechanisms and the genetics of traits contributing to resistance needs to be generated. A concentrated effort will be made on the identification of easily recognized, highly heritable, and simply inherited traits like glossy and trichomes.

**Table 4. Promising shoot fly resistant sorghum lines identified at ICRISAT Center in 1979/80 through screening and use of the glossy and trichomed traits.**

Pedigree	% Deadhearts
(IS-5622 × 2KX6)-2-1-1 1-1 4	54.1
(IS-5622 × WABC-1121 × CS 3541) -16-1-2-1-1-1	59.8
(IS-1034 × IS-3691) -2-3-2-1-1-1	59.8
(IS-5622 × CS-3541) 11-1 1-1-1	50.7
(GG × 370 × EN-3363)-8-1 1 1-1	59.7
(IS-5622 × WABC 1121 × PHYR) -7-1-1-1-1	57.9
(IS-84 × IS-1082)-3-1-1-1	58.0
(IS-1054 × CS-3687)-1-1-1-1	58.8
(0222 × CS-3541-10 × IS-3962) -3-1-1-1	52.9
(UCHV <sub>2</sub> × IS-1054)-1-1-1-1	50.7
(UCHV <sub>2</sub> × IS-1054)-2-1-1-1	58.6
(UCHV <sub>2</sub> × IS-3962)-4-1-1-1	53.9
(UCHV <sub>2</sub> × IS-3962)-6-1-1-1	31.7
(UCHV <sub>2</sub> × IS-3962)-8-1-1-1	52.7
(Rs/R-S <sub>7</sub> -188 × IS-2312) -1-1-1-3	56.0
(Rs/R-S <sub>7</sub> -188 × IS-2312)-1-1-1-5	50.0
(CSV-3 × IS-5622)-3-1-1	55.9
(SPV-29 × IS-3962)-1-2-1	46.0
(IS-1082 × SC-108-4-8) × SC-108 × SC-108-4-8)-1-1-1	55.4
(ESGPC × IS-12573C)-3-1-1-3	42.7
(ESGPC × IS-12573C)-3-2-3-	45.3
(ESGPC × IS-12573C)-4-1-1-	54.5
(IS-2816C × 5D × Bulk)-2-1- -1	42.3
(IS-2816C × 5D × Bulk)-2-2- -1	27.7
(IS-2816C × 5D × Bulk)-2-1- -1	60.0
IS-1054 (M35-1)	85.3
IS-5604	85.5
S-2312	90.7
IS-1082	89.3
CSH-1	100

A number of sources of resistance for each insect from different geographic origins and taxonomic groups have been identified but no information is available on their variability for genes conferring resistance. Once this information is available it will help us generate stronger source material. In the absence of such informa-

tion, we will be forced to use a large number of source lines which can be difficult to handle.

A search will continue to be made for varieties with resistance to more than one trait in order to hasten the development of elite varieties with multiple resistance.

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