Host plant resistance to sorghum stem borer

S.L. Taneja, B.L. Agraval, and V.K. Henry

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Sorghum is an important cereal crop in the Semi-Arid Tropics. In India, it is grown during the rainy (kharif) and the postrainy (rabi) seasons. Grain yields under farmers conditions are generally low (500-800 kg ha^{-1}). One of the reasons for low yields is crop damage by insect pests. Nearly 150 insect species have been reported on sorghum (Young and Teetes 1977; Seshu Reddy and Davies 1979b), of which the most widespread and economically important pests are shoot fly, stem borers, army worm, midge, head bugs, and head caterpillars.

Stem borers constitute the most widely distributed and serious group of insect pests on sorghum in the world. Among the stem bores, *Chilo partellus* Swinhoe is the predominant species in Asia and Africa, *Busseola fusca* Fuller, *Sesamia calamistis* Hampson, and *Eldana saccharina* Walker in Africa, *Sesamia cretica* Laderer in Mediterranean Europe and Middle East, and *Diatraea* spp. in southern U.S., Mexico, and New World Tropics (Young 1970; FAO 1980).

Stem borers are internal feeders and so are not much affected by natural enemies (predators and parasites), unfavourable environmental conditions, or insecticides. Host plant resistance can offer an economic, efficient, and a long term solution to manage these pests

*Cereal Improvement Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru. A.P. 502 324. India.

either alone or in combination with other methods of control. In this paper, an attempt has been made to review the work done on host plant resistance to the spotted stem borer (Chilo partellus) in India.

Nature of damage and biology

Chilo partellus attacks sorghum from 2 weeks after germination until crop harvest and affects all above ground plant parts. The first symptoms of attack are the 'shot holes' or irregular-shaped holes on the leaves, caused by the early instar larval feeding in the whorl. The older larvae leave the whorl and bore into the stem. In young plants, the larvae destroy the growing point and cause the characteristic 'deadheart' symptoms. However, in older plants, the larvae feed inside the stem causing extensive tunneling. It may also tunnel the peduncle and move upto the panicle. Thus while early attack by borers may kill young plants by causing deadhearts, thereby reducing the crop stand, the attack during later stages results in reduced yield due to larval feeding inside the stems. Tunneling weakens stems, which may cause lodging and also interferes with supply of nutrients to the developing grains resulting in chaffy panicles.

The spotted stem borer female lays eggs in batches (50-100 eggs $batch^{-1}$) mostly on the basal leaves of sorghum plants. Eggs hatch in about 4-6 days. The larval period is mostly spent in the leaf whorls and stems, which lasts for 2 to 3 weeks. Pupation takes place in the stem or in soil and it takes about a week for adult emergence. Thus, the insect completes one life cycle in about a month and 3-4 overlapping generations in a crop season. In northern India, the larvae enter into diapause during the winter (December-March) in stalks and stubbles, however, in southern India where temperatures do not fall too low in winter, it remains active throughout the year. Besides sorghum, Chilo partellus infests maize, pearl millet, rice, and sugarcane, and also some wild plants, namely, Sorghum halepense, S. verticilliflorum, Penisetum purpureum and Panicum maximum.

Crop losses

Although severe stem borer infestations in sorghum have been recorded at number of locations in India (Table 1), there has been little quantitative estimation of the resultant crop losses. Trehan and Butani (1949) reported borer infestatin upto 70%, but estimated that the overall average infestations in Maharashtra do not exceed 5%. In a field study with 73.6% Chilo affected plants, the grain loss was estimated to be about 100 lb per acre. Pradhan and Prasad (1955) reported an average decrease of 0.9 g in yield per plant with each unit increase in percentage of stem length injured. Overall losses due to stem borers may be 5 to 10% in many sorghum growing areas in India, especially where early attack causes loss in plant stand. The avoidable grain losses due to stem borer on a susceptible sorghum hybrid (CSH 1) and a variety (Swarna) have been estimated to be 55 to 83% in India (Jotwani et al. 1971b; Jotwani 1972).

Experiments conducted at ICRISAT Center have indicated that protection against stem borer in early growth stages contributed to the maximum yield increase in sorghum hybrid CSH 1 (Taneja 1986). The avoidable losses estimated by comparing yields in plots with intensive protection and no protection ranged between 50 and 100% during 1982-85 (Table 2). To know the insect density and stage of crop at infestation that results in significant reduction in grain yield, plants were infested with laboratory reared insects (eggs and larvae) at 15, 20, 30, 40 and 50 days after crop emergence (DAE). Stem borer damage (deadhearts), grain yield, and avoidable losses in various treatments during 1986 are given in Tables 3 and 4. The results indicated that maximum damage and subsequent grain yield reduction and losses occured when the crop was infested with eggs or larvae at 15 DAE. There was no significant affect when the crop was infested after 30 DAE.

Host-plant resistance

An effective host plant resistance program must be based on series of stepwise activities. It deals with the identification of pest status of a particular insect, studies on the bio-ecology and behaviour in relation to crop and environment, development of an effective and reliable screening technique, reliable criteria for measuring resistance, identification of stable sources of resistance, mechanisms and genetics of resistance, and finally incorporation of resistance into elite agronomic backgrounds.

The earliest report on sorghum cultivars resistant to spotted stem borer (Chilo partellus) is by Trehan and Butani (1949). Pant et al. (1961) and Swarup and Chaugale (1962) reported certain sorghum varieties to be relatively less damaged by the stem borer than others. A systematic screening of the world sorghum collection against stem borer was started in 1962 in India under the cooperative efforts of the Accelerated Hybrid Sorghum Project ICAR, the Entomology Division of the Indian Agricultural Research Institute, and the Rockefeller Foundation (Singh et al. 1968; Pradhan 1971; Jotwani 1978). This work has been continued by the All India Coordinated Sorghum Improvement Project (AICSIP) and the International Crops Research Institute for the Semi Arid Tropics (ICRISAT)

Selection criteria

The symptoms of stem borer attack in sorghum are leaf injury, deadheart formation, and stem and peduncle tunneling. All these symptoms of attack are not necessarily related to the grain yield loss. Although leaf injury is the first indication of borer attack, it has no clear relationship with yield loss (Singh et al. 1983). Leaf injury score varies over time because the plant recovers by producing new leaves However Singh and Sajjan (1982) observed a positive relationship between leaf injury score and grain yield loss in maize.

Stem tunneling by borer is also not related to grain yield reduction in sorghum (Singh et al. 1983; Pathak and Olela 1983; Taneja and Leuschner 1985). However, the stem and peduncle damage can be critical under two situations i) breakage of stem or peduncle due to tunneling and ii) interference with nutrient supply by destroying the plant vascular system in the stalk resulting in chaffy panicles. These two situations depend on the critical stage of crop at the time of infestation and borer density. A recent observation in Burkina

Paso has indicated that the peduncle tunneling by stem borers resulted in significantly low grain yield in most of the genotypes in a trial (Table 5).

The most critical damage by the stem borer that results in significant grain yield loss is the formation of deadhearts resulting in low plant stand. Taneja and Leuschner (1985) observed highly significant and negative relationship between number of deadhearts and grain yield of sorghum (r = -0.9). Singh et al. (1968) indicated that percent deadheart as parameter of stem borer attack was the most stable criterion for differentiating degrees of resistance. Therefore resistance screening should be mainly based on deadhearts while stem tunneling and leaf injury can be subsidiary criteria. In AICSIP trials of screening for stem borer resistance, deadheart parameter was of prime consideration upto 1969, whereafter only leaf injury score and stem tunneling are being recorded.

Screening techniques

Development of an effective and reliable screening technique that ensures uniform and desired level of insect pressure at the most susceptible stage of the crop is the back bone of host-plant resistance program. These requirements can be met either by selecting a location where the pest occurs regularly with adequate severity (hot spot location) or by testing the material under artificial infestation with laboratory reared insects. Other agronomic practices such as planting time, use of diapausing insect population, trap crops, fertilization, irrigation, etc. can also be used to increase the insect infestation. A three step screening methodology was adopted for stem borer resistance testing in AICSIP (Pradhan 1971). The first step was a general screening carried out in a single row plot with one replication under natural infestation. The selected materials were then entered in a multi row replicated trial under natural infestation. The final step has been the confirmation of resistance which was carried out in a replicated trial by artificial infestation. At ICRISAT, a similar methodology is used with some modification, utilizing heavy natural infestation at Hisar and artificial infestation at ICRISAT Center (Fig 1)

Screening under natural infestation at a hot spot location requires the study of population dynamics of the insect so that planting time can be adjusted in such a way that the susceptible stage of the crop coincides with the peak activity period of the insect For instance at Hisar, severe borer infestation has been recorded for several years (1979-86) on sorghum planted during first fortnight of July. In AICSIP, the initial work on stem borer resistance was concentrated at few locations (Delhi, Udaipur, and Indore), where natural stem borer incidence was high There has been increase in the number of testing locations since 1977. A review of the stem borer infestation data for 9 years on the most susceptible sorghum genotype (Tables 6,and 7) indicated that (i) during none of the years, sufficient infestation occurred at all the locations. During 4 out of 7 years, the effective locations were less than 50% in terms of leaf injury (score of 5 on 1-9 scale), and during 6 out of 9 years in terms of stem tunneling, (ii) at none of the locations was the incidence sufficient during all the years. At 5 locations out of 9, the effective years were less than 50% with moderate borer incidence (leaf injury score of 5 on 1-9 scale). In case of stem tunneling, at 6 locations out of 10, the effective years were less than 50%. This indicates that the pest attack was often too low at some of the testing locations and/or the susceptible stage of the crop did not synchronize with the peak activity period of the insect.

Screening of sorghum under artificial infestation using laboratory reared insects has been carried out by many workers in India. For this purpose, stem borer has been reared on natural food (Singh et al. 1983) or on synthetic diet (Chatterji et al. 1968; Dang et al. 1970; Siddiqui et al. 1977; Seshu Reddy and Davies 1979b). In AICSIP, the laboratory reared insects have been either released as first instar larvae using camel hair brush (Singh et al. 1983) or as blackhead egg masses in the leaf whorls (Jotwani 1978). At ICRISAT Center, we are able to screen about 2-3 ha of sorghum each season by infesting individual plant with 5-7 laboratory reared first instar larvae at 15-20 days after the crop emergence. The details of rearing method, field infestation and evaluation for stem borer resistance has been described by Taneja and Leuschner (1985).

Identification of resistant sources

General screening of sorghum germplasm for stem borer resistance was carried out under natural infestation at Delhi during 1964-1969, wherein 8557 lines were screened and 1375 lines were selected for further testing (Table 8). The main selection criterion was percent deadhearts.

Retesting of selected germplasm accessions was carried out at Delhi, Udaipur and Poona during 1966-76 and a number of accessions were selected for confirmation of resistance (Table 9). The resistance in selected genotypes was confirmed by artificial infestation at Delhi, Udaipur, Indore and Kanpur (Table 10). Following 26 genotypes were most promising: IS Nos. 1044, 1056, 1115, 1151, 4424, 4552, 4651, 4689, 4747, 4764, 4776, 4782, 4827, 4841, 4875, 4934, 4994, 5030, 5031, 5470, 5837, 6041, 3096, 7273, 8314, 9136. In addition, four wild sorghum EX 11, IS 14, EX 1118 and I 31 were found resistant to stem borer at Rahuri.

At ICRISAT, stem borer resistance work started in 1979 using artificial infestation (Seshu Reddy and Davies, 1979b). Later on, testing of the material was also started at Hisar under natural infestation. Out of nearly 16 000 germplasm accessions tested over several seasons, 72 genotypes have been found to be resistant (Table 11). Most of these sources are of Indian origin, however some genotypes are from Nigeria, USA, Sudan, Uganda, E. Germany, Pakistan, Yemen Arab Republic, and Zimbabwe. Stability analysis of 61 resistant genotypes tested over six seasons has indicated that the most stable genotypes in terms of resistance were IS Nos. 5470, 5604, 8320, and 18573 (Taneja and Leuschner, 1985). The following 24 genotypes showed borer resistance with moderate level of stability: IS Nos. 1044, 2122, 2123, 2263, 2291, 2309, 2312, 4756, 4776, 5469, 5480, 5538, 5566, 5571, 5585, 10711, 12308, 13100, 13674, 18551, 18577, 18579, 18662, and SB 8530. The resistant sources identified at ICRISAT have also been tested in AICSIP trials and following genotypes have shown promise during 1979-1985. IS Nos. 1082, 1119, 2123, 2195, 2205, 2309, 2312, 5469, 5604, 7224, 12308, 17966, 18551, 18573, 18577, 18578, 18579, 18580, 18584, and 1867[illegible].

Resistance mechanisms and associated factors

Although ovipositional non-preference is not a strong resistance mechanism against stem borers, some cultivars have been reported to be less preferred by the Chilo partellus moths for egg laying (Rana and Murty 1971; Lal and Pant 1980a; Singh and Rana 1984; ICRISAT 1986). The main mechanisms of resistance to Chilo partellus in sorghum have been antibiosis and tolerance (Pant et al. 1961; Kalode and Pant 1967; Jotwani et al. 1971a; Jotwani 1976; Pathak and Olela 1983; Singh and Rana 1984). High mortality in early larval stages (Jotwani et al. 1978) and low survival rate of the larvae (Lal and Pant 1980b) have been reported in resistant cultivars. Dabrowski and Kidiavai (1983) have found that ovipositional non-preference, reduced leaf feeding, low deadheart formation and stem tunneling, and tolerance to leaf and stem feeding contribute to stem borer (C. partellus) resistance in sorghum. Low sugar content (Swarup and Chaugale 1962), amino acids, total sugars, tannins, total phenols, neutral detergent fibre (NDF), acid detergent fibre (ADF), lignins (Khurana and Verma 1982 and 1983) and high silica content (Narwal 1973) have all been reported to be associated with C. partellus resistance in sorghum. Firm attachment of leaf sheaths to stem have been reported to reduce the number of larvae boring into the stem (Katiyar 1963).

There have been marked differences in the establishment of first instar larvae among resistant and susceptible cultivars (Chapman et al. 1983; Bernays et al. 1983). Results obtained from a collaborative project between TDRI and ICRISAT have indicated that the main factor influencing the initial climb leading to establishment in the whorl is positive phototaxis. Differences in success between cultivars is affected by a combination of several physical and chemical plant characteristics. It was found that :

1. Resistant plants have upright, narrow and erect leaves that cause little shadow and cause larvae to move out onto them and disperse.
2. Pronounced ligules and ligular hairs on resistant lines provide traps for climbing larvae
3. Tendency of sheaths to become detached from the culm also acts in a similar way
4. Trichomes along the leaf edge differ in size and distribution on resistant and susceptible lines.
5. A chemical factor has been identified in the gas chromatographic profile of the surface wax of sorghum plants that is associated with disorientation of climbing larvae on resistant cultivars.

To study the factors associated with stem borer resistance, plant growth parameters and insect growth parameters were monitored at regular intervals on 20 genotypes with varying degrees of resistance during rainy and postrainy seasons at ICRISAT (ICRISAT 1986). The results have indicated that early panicle initiation and faster internode elongation were associated with resistance to stem borer (Fig. 2). Among the insect biological parameters, significant differences in number of larvae in the leaf whorls and stem, larval mass and survival rate were observed in some of the resistant genotypes (Table 12). Thus, a combination of factors in a particular genotype have been found to be associated with overall resistance to stem borer.

Breeding for resistance

Breeding for stem borer resistance started in 1966 in India, when a number of resistant parents were included in the breeding program (Pradhan 1971). Since then a number of identified sources of resistance have been utilized by crossing with dwarf exotic types that were highly susceptible to borer but were agronomically desirable parents. A number of promising derivatives and their parents have been given in Table 13. BP 53, a borer resistant parent has produced good number of derivatives particularly when crossed with IS 2954. Other good resistant sources have been Aispuri, M 35-1 and Karad Local. Stem borer resistant sources have also been utilized in developing high yielding varieties and hybrids in AICSIP (Table 14).

Stem borer resistance program was initiated at ICRISAT in 1977 with the following objectives : (1) to strengthen the sources of resistance by accumulating diverse genes from different sources, (2) to transfer resistance into improved and adapted cultivars, and (3) to generate basic genetic information for formulating an effective breeding program.

To meet the first objective, population breeding approach was chosen. A shoot pest (shoot fly and stem borer) population has been developed using ms_3 and ms_7 male sterility genes. As many as 175 genotypes (85 stem borer resistant sources and their derivatives, 76 shoot fly resistant sources and their derivatives and 14 elite genotypes) have been fed into this population. This population has been random mated six times and there has been improvement for stem borer resistance. Now we plan to advance it by using cyclic S_2 recurrent selection as outlined in Figure 1.

Transfer of resistance into improved genotypes was initiated through pedigree breeding approach (Fig. 1). A number of resistant sources have been utilized (Table 15) and the most productive ones are IS Nos. 1082, 3962, 5604, and 5622. The most promising derivatives are PB Nos. 10365-1, 10337-1, 10445, 10446, 12034-1, 12687-8, 12689-1 and 12693-2. A number of shoot fly resistant lines have also shown promise against stem borer. These are PS Nos. 14413, 14454, 18527, 18601-2, 18822-4, 19663-2, and 21113-1.

The performance of 135 fertile derivatives (S_2) of the shoot pest population and 130 advanced progenies from pedigree breeding were compared for stem borer resistance at ICRISAT Center under artificial infestation and at Hisar under natural infestation. In general, the population derivatives had better levels of resistance under both types of infestations compared to progenies derived through pedigree breeding. Six percent of the population derivatives showed good level of borer resistance as compared to only 0.6 per cent of the pedigree progenies.

Genetics of resistance

Rana and Murty (1971) and Haji (1984) reported that resistance to stem borer is polygenically inherited. They found that resistance to primary damage (leaf feeding) was governed by additive and additive x additive type of gene action while additive and non-additive type gene action were important for secondary damage (stem tunneling). Resistance to Chilo partellus for primary damage i.e. '% dead hearts' was governed by both additive and non additive type of gene actions while for secondary damage i.e. stem tunneling was governed predominately by additive gene action (Kulkarni and Murty 1981; Pathak and Olela 1983). It was also noted that the inheritance pattern of primary and secondary damage were different. The epistatic gene affects were more pronounced under artificial borer infestation (Haji 1984). He also noticed that under natural infestation, resistance was controlled by additive and dominant major gene affects. Cytoplasmic influences appeared to be present, which may play an important role for the inheritance of stem borer resistance.

Advanced yield trials

In AICSIP, all the advanced varietal and hybrid trails were evaluated for resistance to various sorghum pests for the purpose of identifying high yielding cultivars that are relatively less damaged by major pests. The trials for stem borer resistance evaluation were conducted at various locations under natural infestation conditions. A number of breeding lines have been reported to be less damaged by stem borer during 1975-85 (Table 16). The number of lines found promising were

120, 22, 5, 2, and 1 during one, two, three, four, and six years of testing, respectively. However, some of these genotypes, when tested at Hisar under heavy natural stem borer infestation during 1985-86, were highly susceptible (>80% deadhearts as against <40% in resistant Check IS 2205)(Table 17).

Effectiveness of resistance

Effectiveness of resistance can be measured either by recording the yield potential of a genotype under insect infestation, or estimating avoidable losses under protected and unprotected conditions. Prem Kishore and Govil (1982) reported that two resistant genotypes P 37 and P 151 can yield substantially without insecticidal control against stem borer. There have been no net monitory benefit with even two insecticide applications in 12 stem borer resistant genotypes, while insecticide applied to a susceptible genotype CSH 1 increased the grain yield substantially (Prem Kishore, 1984). Estimation of losses due to stem borer infestation under protected and unprotected conditions have indicated that the avoidable losses ranged between 1.8 and 24.5 % on resistant genotypes as compared to 24.7 and 50.0 % on susceptibles during 1974-79 (Table 18).

Summary and conclusions

Although a lot of work on host plant resistance to stem borer has been carried out in India and elsewhere, there is still a scope for improvement. Studies on the following aspects should be intensified :

1. Estimation of losses due to stem borer - actual loss in terms of

quantity and quality of grain and fodder in improved and local cultivars under farmers situation

2. Determination of economic threshold level.

3. Screening technique

- Natural infestation at specific locations which will involve studies on the population dynamics, planting time, use of overwintering population, fertilizers, etc.

- Artificial infestation where the facilities are available.

4. Selection criteria for measuring resistance. Deadhearts should be given prime importance followed by stem tunneling and leaf injury.

5. There should be a provision for testing of insect resistant genotypes with reasonable yield potential.

6. Developing cultivars with multiple pest resistance

7. In addition to host plant resistance, other methods of control such as cultural, biological and chemical should be looked into for Integrated Pest Management.

8. Generate more genetic information on individual resistance factors/mechanisms.

9. generate nonrestorer resistant lines for developing resistant hybrids.

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Table 1. Reports of stem borer severity on sorghum in India, 1975-85

1975	- 60-70% damage in Rajasthan on CSH 1, 302 and local - 80-100% infestation in Indore, Ujjain, Dewas, Sehore, Ratlam, and Mansoor districts of Madhya Pradesh
1977	- Heavy incidence of sorghum stem borer at Udaipur (Rajasthan)
1978	- Severe damage in Madhya Pradesh and Navsari (Gujarat)
1979	- 100% peduncle infestation at Khandwa (Madhya Pradesh)
1980	- Severe peduncle damage on CSH 5 in Madhya Pradesh
1981	- 50% infestation in Madhya Pradesh, 75% at Akola and 48% at Nagpur (Maharashtra)
1982	- Severe infestation at Coimbatore (84% on TNS 31) and Hisar (90%)
1983	- Heavy incidence on early sown crop at Udaipur and 80% peduncle damage at Indore (Madhya Pradesh)
1984	- 54% deadhearts at Akola and heavy incidence at Delhi - Severe infestation on late-sown crop at Mysore and an early-sown crop at Surat

(Source : AICSIP Progress Reports, 1975-85)

Table 2. Effect of protection regimes on stem borer damage and grain yield in sorghum, Hisar, India, rainy season 1982-85

Year	Cultivar	Treatment	Borer damage (% dead-hearts)	Grain yield (kg ha^{-1})	Avoidable loss (%)
1982	CSH 1	Intensive protection[1]	10.5	3080	
		No protection	62.2	890	71.1
1983	CSH 1	Intensive protection	9.5	2830	
		No protection	60.1	480	83.1
1984	CSH 1	Intensive protection	25.2	5170	
		No protection	95.1	2600	49.7
	ICSV 1	Intensive protection	28.0	4250	
		No protection	100.0	330	92.2
	IS 2205	Intensive protection	33.9	1870	
		No protection	47.6	900	51.9
1985	ICSV 1	Intensive protection	2.6	5190	
		No protection	80.3	0	100.0
	PS 28157-1	Intensive protection	2.8	5670	
		No protection	60.5	10	99.8

1. Intensive protection implies to application of carbofuran granules at sowing, and in leaf whorls, 15, 30, and 45 days after crop emergence (DAE) in 1982-83; 15, 30, and 45 DAE in 1984; 15, 25, 35, 45, and 55 DAE in 1985

Table 3. Stem borer damage, grain yield, and avoidable losses in relation to age of the crop at insect infestation time on two sorghum genotypes, ICRISAT Center, rainy season, 1985

Age of crop at infestation (DAE)[1]	ICSV 1			PS 28157-1		
	Borer deadhearts (%)	Grain yield ($t\ ha^{-1}$)	Avoidable loss (%)	Borer deadhearts (%)	Grain yield ($t\ ha^{-1}$)	Avoidable loss (%)
Larval infestation						
15	73	0.90	64.3	70	1.27	51.0
20	29	1.40	44.0	19	1.71	35.0
30	13	1.67	44.7	13	1.98	15.4
40	3	2.44	5.4	2	2.41	1.2
SE		±0.10			±0.10	
CV(%)		12			12	
Egg infestation						
15	50	1.06	51.4	44	1.31	42.3
20	26	1.32	42.6	17	1.68	21.9
30	17	1.43	31.3	10	1.85	18.9
40	4	2.14	2.7	3	2.26	7.0
50	7	2.21	1.0	3	2.19	8.4
		±0.14			±0.14	
CV(%)		15			15	

[1] DAE=Days after crop emergence

Table 4. Stem borer damage, grain yield, and avoidable losses in relation to insect density on two sorghum genotypes, ICRISAT Center, rainy season, 1986

	ICSV 1			PS 28157-1		
Insect density	Borer deadhearts (%)	Grain yield (t ha^{-1})	Avoidable loss (%)	Borer deadhearts (%)	Grain yield (t ha^{-1})	Avoidable loss (%)
Larval infestation (larvae $plant^{-1}$)						
0	5	2.65	-	4	2.50	-
1	14	2.04	23.0	14	2.27	9.2
2	21	1.78	32.8	20	2.07	17.2
4	30	1.64	38.1	23	1.96	21.6
8	37	1.27	52.1	37	1.49	40.4
12	39	1.29	51.3	35	1.43	42.8
SE		±0.15			±0.15	
CV(%)		12			12	
Egg infestation (% plants with single egg mass)						
0	5	2.20	-	3	2.30	-
10	13	1.90	13.6	8	2.10	8.7
20	19	1.66	24.6	13	1.91	17.4
30	24	1.56	29.1	19	1.81	21.3
50	28	1.40	36.4	22	1.60	30.4
SE		±0.10			±0.10	
CV(%)		15			15	

Table 5. Stem borer infestation in peduncle and grain yield of panicles with and without borer damage in sixteen genotypes, Farako-Ba (Burkina Faso), 1986

Genotype	% plants with damage	Grain yield (g) 5 panicles^{-1} without borer damage	Grain yield (g) 5 panicles^{-1} with borer damage	% economic loss[1]
ICSV 200IN	36.9	287.5	265.0	2.8
ICSV 202IN	8.3	280.0	237.5	1.2
ICSV 126IN	33.5	367.5	286.2	7.4
ICSV 247IN	31.0	283.7	225.0	6.4
ICSV 2IN	26.1	337.5	282.5	4.2
ICSV 111IN	35.1	290.0	251.2	4.7
M 24544	24.0	211.2	171.2	4.5
M 24581	13.7	321.2	257.5	2.7
M 24791	15.3	277.5	250.0	1.5
S 34	14.0	327.5	240.5	3.7
Framida	3.3	375.0	308.2	0.5
ICSV 1002BF	20.1	343.7	281.2	3.6
ICSV 1049BF	34.2	275.0	233.7	5.1
Gnofing	-	362.5	337.5	-
Ouedezoure	-	273.7	232.5	-
ICSH 1	28.5	350.0	292.5	4.6
SE		±3.739		
CV(%)		10.5		

[1] % economic loss =

$$\frac{\text{Grain yield without borer damage} - \text{Grain yield with borer damage}}{\text{Grain yield without borer damage}} \times \text{\% plants with borer damage}$$

(Source: Progress Report 1986, ICRISAT/USAID/SAFGRAD Project Ouagadougou Burkina Faso (West Africa))

Table 6. Testing locations for stem borer resistance screening in AICSIP, 1977-85

	Leaf injury		Stem tunneling	
Location	No. years tested	No. effective years[1]	No. years tested	No. effective years[1]
Delhi	7	4	9	6
Indore	6	4	9	1
Udaipur	5	0	8	3
Navsari	5	4	6	0
Akola	5	2	8	6
Hyderabad	4	0	5	2
Dharwad	5	1	8	4
Coimbatore	3	0	3	3
Rahuri	4	2	5	0
Parbhani	-	-	6	1

[1] Effective screening implies a minimum score of 5 for leaf injury (1-9 scale) and 25% tunneling on the susceptible genotype

(Source: AICSIP Progress Reports, 1977-85)

Table 7. Years of effective screening for stem borer resistance in AICSIP trials, 1977-85

Year	Leaf injury: No. of locations tested	Leaf injury: No. of effective locations[1]	Stem tunneling: No. of locations tested	Stem tunneling: No. of effective locations[1]
1977	-	-	8	1
1978	7	2	5	1
1979	7	4	8	5
1980	6	3	9	6
1981	6	4	9	3
1982	9	4	10	5
1983	5	0	7	1
1984	-	-	6	1
1985	4	0	7	1

[1] Effective screening implies a minimum score of 5 for leaf injury (1-9 scale) and 25% tunneling on the susceptible genotype

(Source: AICSIP Progress Reports, 1977-85)

Table 8. General screening of sorghum germplasm for stem borer resistance under natural infestation

Year	No. of accessions screened	No. of accessions selected	Selection criteria[1]	Incidence on susceptible
1964	3492)			
1965	461)	507	DH	80% (32-100%)
1967	890	74	LI, ST	ST=58%
1968	2906	794	LI, DH, ST	DH=32%, ST=30%
1969	808	0	LI, DH	

[1]Selection criteria: LI=Leaf injury, DH=Deadhearts, ST=Stem tunneling

(Source: Singh et al. 1968; Pradhan, 1971)

Table 9. Screening of sorghum germplasm accessions for stem borer resistance under natural infestation in replicated trials, AICSIP 1966-76

Year	Accessions screened	Accessions selected	Selection criteria	Incidence on susceptible	Most promising selections
1966	488	57	LI,DH,ST	-	IS Nos.1034, 1099, 1151, 1499, 5479
1967	104	73	LI,DH, ST	DH-38% ST-50%	IS Nos. 1034, 1044, 1087, 1115, 1137, 1151, 3950, 4522, 4569, 4776, 4912, 4994, 5030
1968	91	42	LI,DH, ST	DH-30% ST-28%	IS Nos.1044, 5030, 5606, 5615, 5656
1969	151	40	LI,ST	ST-72%	IS Nos. 1151, 4246, 4307, 4339, 4868, 4870, 5072, 5599, 5629, 5653, 5662
"	100	16	LI,DH	DH-29%	IS Nos. 1005, 1019, 1509, 1522, 1594, 4522, 4780, 4793,4797, 4833, 4866, 4870, 4897, 4912, 5615, 5701
1973	28	13	LI,ST	ST-23%	JML-2, AKL-5, Gangapuri, NCL-3, PCL-3, Aispuri
1976	23	23	LI,ST	-	VZM-2B, P 151, SPV 61

(Source: Singh et al. 1968; Pradhan, 1971; Jotwani, 1978)

Table 10. Confirmation of stem borer resistance in sorghum lines under artificial infestation, AICSIP 1966-1975

Year	No. lines screened	No. lines selected	Selection criteria[1]	Incidence on susceptible	Most promising selections
1966	5	5	DH	-	IS Nos. 1034, 1099, 1151, 1499, 5479
1968	59	36	LI, DH, ST	DH-18% ST-34%	IS Nos. 1099, 1115, 1458, 3967, 4118, 4283, 4316, 4522, 4651, 4776, 4780, 4897, 5115, 5469, 5613, 5656
	17	7	LI, DH, ST	DH-9% ST-33%	IS Nos. 1044, 1115, 1151, 4764, 4776, 4994, 5030
1969	20	6	LI, ST	ST-76%	IS Nos. 1056, 4552, 4651, 4747, 4782, 5470
1972	8	7	LI, ST	ST-87%	IS Nos. 4424, 4689, 4827, 4841, 4875, 4934, 5031
1973	98	25	LI, ST	ST-65%	IS Nos. 2122, 4329, 4799, 5251, 6046, 6101, 6119
1975	25	12	LI, ST	ST-37%	-
	12	6	LI, ST		GIB, BP 53, Aispuri, Nag-B, SPV 16 and R 147B

[1] LI=Leaf injury; DH=Deadhearts; ST=Stem tunneling

(Source: Pradhan, 1971; Jotwani, 1978)

Table 11. Sources of resistance to sorghum stem borer identified at ICRISAT, 1979-86

Origin	IS Number
India	1044, 1082, 1119, 2195, 2205, 2375, 2376, 4273, 4546, 4637, 4756, 4757, 4776, 4881, 4981, 5075, 5253, 5429, 5469, 5470, 5480, 5538, 5566, 5571, 5585, 5604, 5619, 5622, 8320, 13100, 17742, 17745, 17747, 17750, 17948, 17966, 18333, 18366, 18662, 18667, 21969, 22039, 22091, 22145, 23411
Nigeria	7224, 18573, 18577, 18578, 18579, 18580, 18584, 18585
USA	2122, 2123, 2146, 2168, 2269, 10711, 20643
Sudan	2263, 2291, 2309, 2312, 22507
Uganda	8811, 13674
E.Germany	24027
Ethiopia	18551
Pakistan	9608
YAR	23962
Zimbabwe	12308

(Source: Taneja and Leuschner, 1985)

Table 12. Factors associated with stem borer resistance in sorghum rainy season, ICRISAT Center, 1985

Genotype	Days for PI[1]	Shoot length (cm) 28 DAI[2]	% Larvae recovered in Whorl 1 DAI[2]	% Larvae recovered in Stem 10 DAI[2]	Larval weight (mg) 21 DAI[2]	Pupal weight (♂♂) (mg)	Insect recovery (%) 28 DAI[2]
IS 1044	53	15	54	9	92	109	28
IS 2123	33	21	54	7	93	110	15
IS 2205	39	13	57	16	103	101	9
IS 2269	33	11	40	17	127	107	22
IS 2309	30	14	53	35	85	94	8
IS 4776	40	9	44	10	109	99	20
IS 5469	33	26	57	11	98	107	25
IS 5538	56	6	56	12	99	100	22
IS 5585	33	19	41	9	85	103	15
IS 12308	17	50	25	31	89	95	21
IS 13100	25	46	39	7	88	89	18
IS 13674	28	24	64	24	101	100	26
IS 18333	53	10	58	21	85	103	10
IS 18551	38	12	62	10	109	89	23
IS 18573	56	6	77	10	140	95	20
IS 18577	51	8	41	21	84	98	21
IS 18579	40	8	42	13	92	101	15
IS 18580	40	11	57	12	99	109	19
ICSV 1	33	10	51	17	115	112	20
CSH 1	28	9	42	13	94	97	24
Mean			15	15	99	101	19
SE			±6.5	±4.3	±6.5	±6.5	±4.5
CV(%)			18	45	9	8	33

1. PI=Panicle initiation, 2. DAI=Days after infestation

Table 13. Most productive borer resistant source parents and their promising derivatives

Resistant source	Other parent	Promising derivatives
BP 53	IS 2954	Selection Nos. 165, 169, 174, 177, 300, 364, 384, 434, 446, 468, D Nos. 124, 167, 168, 172, 175, 244, 259, 350, 358, 365, 366, 367, 609, DU Nos. 98, 135, 245, 293, P Nos. 108, 151, 235, U 376
	IS 84	Selection No.602
	IS 3691	DU 291, U 369
	CK 60B	E 302, U Nos. 37, 218, 35, 373
	IS 3954	E 303
Aispuri	IS 3922	Selection Nos. 829, 835, D 832
M 35-1	IS 539	DU 19
	IS 531	U 83
IS 4906	CK 60A	P 37
IS 5837	CK 60A	P 82
IS 10327	CK 60A	P 90

(Source : AICSIP Progress Reports, 1972-85)

Table 14. Stem Borer Resistant Sources Utilised in AICSIP

Resistant Source	Genotype
Aispuri and its derivatives	CSV 5, SPV Nos. 14, 58, 80, 96, 99, 101, 102, 104, 105, 107, 108, 110, 115, 168, 265, 270, 271, 374, 378, 475, 513, 516, 716, 727, 743, 744, CSH 7R
IS 3541 (CS 3541)	CSV 4, SPV Nos. 60, 104, 122, 126, 245, 292, 297, 303, 312, 346, 351, 354, 371, 386, 741
M 35-1 (IS 1054)	CSV 7R, SPV Nos.19, 270, 364, 440, 510, 727
GM 1-5	SPV Nos. 9, 33, 34, 183, 268
Karad Local	CSV Nos. 2, 6, SPV Nos. 8, 13, 17
BP 53 (IS 1055)	CSV 3, 26, 70, 513, 688
PD 3-1	CSH 8R

(Source : AICSIP Progress Reports, 1975-85)

Table 15. Stem borer resistant sources utilised at ICRISAT and their promising derivatives

Resistant source	Derived genotype
IS 1082	PS 14413, PB 10791, PB 12446
IS 2312	PS 19338, PB 12693
IS 3962	PS 18601, PS 18822, PB 12611, PB 12631
IS 5604	PS Nos. 18527, 19336, 27623 PB Nos. 10365, 12040, 12497, 12687, 12689
IS 5622	PS Nos. 14454, 19295, 19663, 21113, 30768, 30769, 31376, PB Nos. 10337, 10445, 10446
IS 13681	PB 12049, PB 12050
RS/R Pop.	PB Nos. 12034, 12037, 12052, PS 28060
Shoot Pest Pop.	PB Nos. 12339, 12342, 12346, 12380, 12387, 12413

(Source: ICRISAT, unpublished)

Table 16. List of promising stem borer-resistant high-yielding breeding lines tested during different number of years in AICSIP, 1975-85

1 year	CSV Nos. 5,6, SPV Nos. 8, 9, 13, 14, 17, 19, 33, 34, 37, 41, 42, 60, 61, 80, 84, 99, 101, 102, 110, 115, 122, 129, 141, 168, 181, 183, 185, 187, 188, 193, 233, 245, 270, 271, 292, 312, 364, 371, 374, 422, 440, 488, 490, 491, 499, 503, 510, 513, 515, 516, 541, 543, 544, 615, 662, 666, 669, 678, 688, 707, 716, 727, 732, 733, 740, 741, 743, 744, SPH Nos. 4, 6, 10, 20, 33, 58, 80, 103, 120, 156, 164, 175, 176, 185, 196, 225, 233, 277, 289, 331, 334, 356, 361, 363, 364, 366, 369, 370, 377, 379, 381, 385, 388, 389, 390, 391, 392, 393, 394, 398, 400, 401, 403, MSH Nos. 37, 41, 42, 51, 61, CSH Nos. 1, 6
2 years	SPV Nos. 29, 58, 70, 96, 107, 108, 224, 265, 268, 297, 303, 315, 354, 378, 386, 459, 462, 475, 679, SPH Nos. 30, 42, CSH 5
3 years	CSV 11, SPV Nos. 104, 247, CSH 8R, CSH 9
4 years	SPV 105, SPV 346
6 years	SPV 126

(Source: AICSIP Progress Reports, 1975-85)

Table 17. Evaluation of AICSIP Yield Trials for stem borer reaction at Hisar, rainy seasons, 1985-86

Borer damage (% deadhearts)	Genotype
>90% (67)	CSV Nos. 10, 11, SPV Nos. 346, 615, 671, 677, 679, 690, 692, 694, 707, 708, 709, 710, 733, 735, 736, 738, 739, 740, 741, 745, 746, 747, 749, 752, 753, 754, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 773, 775, 776, 778, SPH Nos. 301, 350, 351, 364, 365, 366, 367, 368, 371, 373, 374, 375, 380, 383, 386, 387, PSYH Nos. 2, 3, CSH 5
80-90% (34)	SPV Nos. 475, 544, 669, 670, 678, 711, 734, 742, 748, 755, 777, 779, SPH Nos. 221, 296, 329, 335, 348, 361, 362, 363, 369, 372, 378, 379, 381, 382, 384, 385, MSH Nos. 50, 61, 62, PSYH 1, CSH 1, CSH 9
70-80% (17)	SPV Nos. 462, 732, 737, 743, 744, 750, 751, 772, SPH Nos. 196, 295, 336, 376, 389, 390, 393, 411, MSH 55
60-70% (5)	SPV 774, SPH Nos. 264, 391, 392, CSH 6
50-60% (2)	SPH 289, 377

(Source: ICRISAT, unpublished)

Table 18. Avoidable losses due to stem borer infestation on resistant and susceptible genotypes based on protected and unprotected conditions (1974-1979)

	Avoidable loss (%)[1] in					
Genotype	1974	1975	1976	1977	1978	1979
447	-	-	-	22.9	-	-
E 302	10.1	3.4	6.2	11.8	6.6	10.3
E 303	18.2	4.9	2.6	8.3	11.4	4.6
E 333	-	-	-	9.9	-	-
P 37	10.4	6.7	13.6	8.3	8.6	10.0
P 151	-	9.0	7.4	16.5	8.0	8.6
U 358	24.5	11.8	1.8	13.9	1.2	8.1
Swarna	47.0	24.7	46.4	38.8	-	-
CSH 1	-	-	-	-	43.6	50.0

[1] $$\text{Avoidable loss (\%)} = \frac{\text{Grain yield under protection} - \text{Grain yield under nonprotection}}{\text{Grain yield under protection}} \times 100$$

(Source : Jotwani, 1978; Prem Kishore and Govil, 1982)

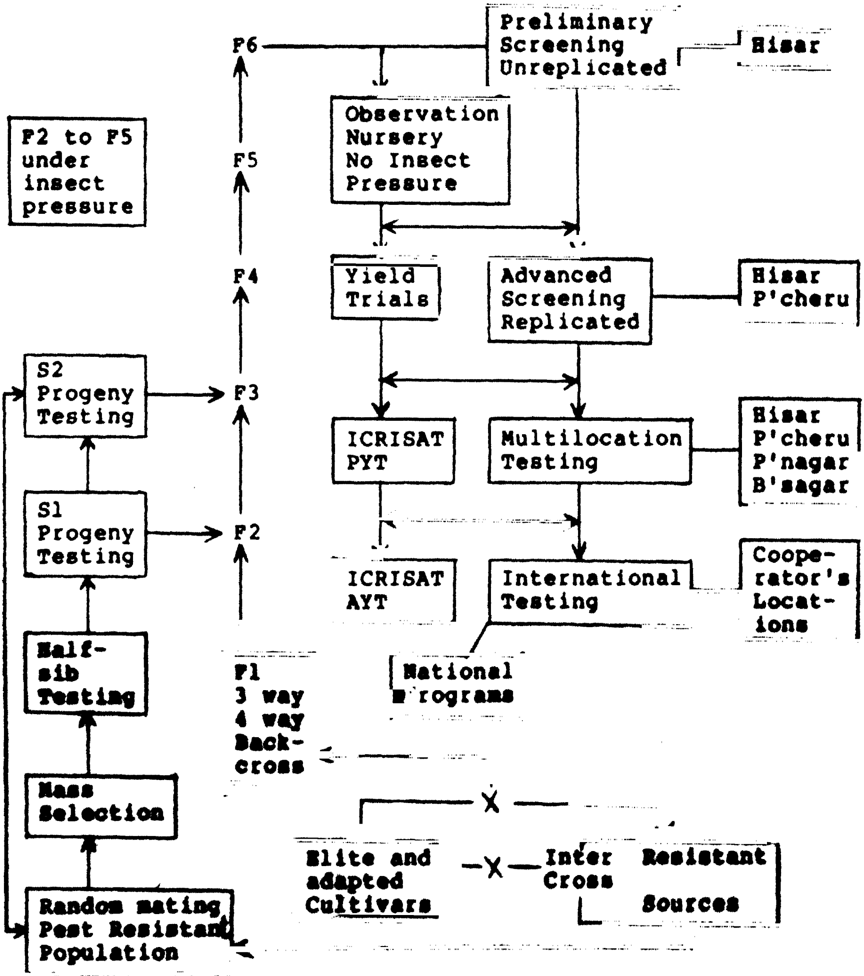

Fig 1. Screening and Breeding for Stem Borer Resistance

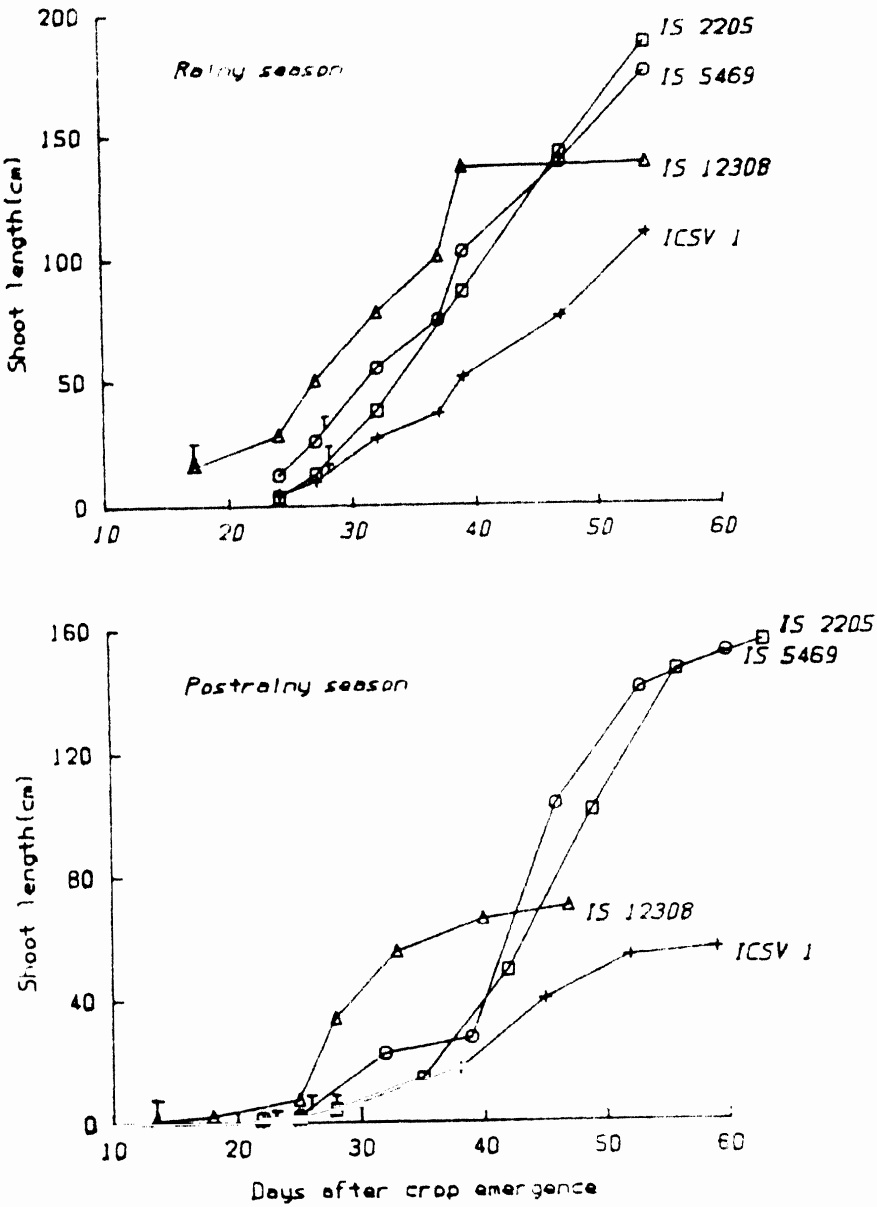

Figure 2. Shoot length and panicle initiation of four sorghum genotypes in relation to age of the crop, ICRISAT center, 1984-85