HOST-PLANT RESISTANCE IN THE MANAGEMENT OF SORGHUM STEM BORERS

S.L. Taneja

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ICRISAT Patancheru P.O. Andhra Pradesh 502 324, India

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ABSTRACT

Of the 23 stem borers infesting sorghum, *Chilo partellus*, *Busseola fusca*, *sesamia cretica*, *S. calamistis*, *Eldana saccharina* and *Diatraea* spp. are the important species occuring in various sorghum growing areas of the world. Host-plant resistance offers an economic, effective and long term solution to manage these 'internal feeders' either alone or in conjuction with cultural, biological and chemical methods of control. The development of host-plant resistance in crop plants requires: (1) the detailed knowledge on the bio-ecology of the pest and its relationship with host plant, (2) development of an effective and reliable screening technique(s), (3) reliable criteria for measuring resistance, (4) identification of strong and stable source(s) of resistance, and (5) incorporation of gene(s) for resistance into the elite background. This paper deals with all the outlined aspects related to stem borers in general and *Chilo partellus* in particular and also discusses the scope of host-plant resistance in the integrated management of stem borers in sorghum.

*Sorghum Entomologist, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru P.O. Andhra Pradesh, 502 324.

INTRODUCTION

Sorghum is an important cereal crop in the Semi-Arid Tropics(SAT). In India it is grown both during the rainy (kharif) and the post rainy (rabi) season. In Central and Southern India, sorghum is cultivated for grain purpose while in North India it is primarily grown as a fodder crop. In the recent years, more emphasis is being given in developing dual type sorghum cultivars to meet both grain and fodder requirements. Nearly 150 insect species have been reported as pests or potential pests of sorghum (Young and Teetes, 1977; Seshu Reddy and Davies, 1979a; FAO 1980). However, the most widespread and devastating insect pests of sorghum in the SAT are shoot fly, many species of stem borers, armyworm, midge, head bugs and head caterpillars.

Stem borers constitute the most widely distributed and serious group of insect pests of sorghum in the world. Plant damage is caused in the larval stage by feeding in the leaf whorls or in the stem. Due to their internal feeding habits, they are protected to a large extent from natural enemies (predators and parasites) and unfavourable environmental conditions. For the same reason, they are difficult to control by insecticides. Host-plant resistance offers an economic, efficient and long term solution to manage these types of insects either alone or in conjuction with other control methods. Host-plant resistance has several advantages such as: avoids environmental pollution, compatibility with beneficial agents, integrates effectively with other pest control tactics and no additional production costs to the farmer. In this paper, attempts have been made to present an overview of host-plant resistance and its potential in the management of stem borers in sorghum

Distribution of borer species

Twenty three species of stem borers are known to infest sorghum (Table 1) which belong to several genera within two families (Tams and Bowden, 1953; Ingram, 1958; Nye, 1960; Harris, 1962; Bleszynski, 1970; Sandhu and Ramesh Chander, 1975). Most important borer species attacking sorghum in various regions are: Chilo partellus and Sesamia inferens in Asia; Busseola fusca, C. partellus, Sesamia calamistis and Eldana saccharina in Africa; Sesamia cretica in Mediterranean Europe and Middle East; and Diatraea spp. in Southern United States, Mexico and New World Tropics (Young, 1970; FAO, 1980).

Distribution of different stem borer species is influenced by the altitude, rainfall and temperature. In warmer and lower altitude areas, Chilo partellus is the most important stem borer, however, it has been recovered at altitudes ranging from 70 to 5,500 ft (Seshu Reddy, 1983). Ingram (1958) reported that C. partellus could not live above 4000 ft in western Uganda or 5000 ft in eastern or northern Uganda. Nye (1960) also found it in the coastal and plateau regions of East Africa upto 5000 ft. Busseola fusca was found to be the dominant stem borer species in cooler and high altitude areas above 3570 ft. Nye (1960) reported that this species was distributed in areas over 2000 ft and is unable to tolerate the warmer temperatures occurring below 2000 ft in East Africa. In West Nile, B.fusca was common above 4000 ft (Ingram, 1958). Sesamia calamistis was recovered in many areas of Kenya from sea level upto 4700 ft (Seshu Reddy, 1983), but in East Africa Nye (1960) recorded this borer at all altitudes from sea level to 8000 ft. Eldana saccharina was found on sorghum and maize in Western and Nyanza Provinces of Kenya upto 5000 ft (Seshu Reddy, 1983). Ingram (1958) indicated that E. saccharina was not a pest of any importance in East Africa while Girling (1978) found it in maize, sorghum and sugarcane and commented that it was becoming a serious pest in East Africa too.

Crop losses

Early attack of borers may kill young plants (dead hearts) reducing the crop stand while the yield of more mature plants may be reduced by larval feeding in the leaves and stems. Stem tunnelling weakens stems, which may cause lodging and also interferes with the supply of nutrients to the developing grains and result in chaffy heads (head without grains). Trehan and Butani (1949) reported borer infestation 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 a 0.9 g average decrease 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, 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).

A crop loss experiment conducted at ICRISAT on sorghum hybrid CSH 1 indicated that crop protection against stem borer in the early growth stages contributed to the maximum yield increase (Fig.1). Dead hearts caused by the stem borer resulted in significant reduction in yield. Correlation between the dead hearts and the yield was found to be negative ($r = -0.9^{**}$). Stem tunnelling upto 60% in any portion of the stem (bottom, middle and top) did not show reduction of grain yield in CSH 1 (Taneja and Leuschner, 1985).

Host-Plant Resistance

Most of the work on host-plant resistance to sorghum stem borers has been carried out on Chilo partellus. The earliest report on sorghum cultivars resistant to stem borer is by Trehan and Butani (1949). Pant et al (1961) and Swarup and Chaugale (1962) reported some sorghum varieties to be less damaged by stem borer. A systematic screening of the world sorghum collection against stem borer was initiated in 1962 in India (Singh et al., 1968b; Anonymous, 1971 and 1978). Since then, the screening is being continued by the All India Coordinated Sorghum Improvement Project (AICSIP) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

The development of host-plant resistance requires detailed information in the following aspects: (1) knowledge on the bio-ecology of the insect and its relationship with host plant, (2) reliable criteria for measuring resistance, (3) development of an effective and reliable screening technique(s), (4) identification of strong and stable sources of resistance, (5) genetics of resistance, and (5) incorporation of genes for pest resistance into elite background(s).

Bio-ecology and insect-host relationships

Most of the stem borer species produce similar symptoms on attacked plants. Young larvae of Chilo partellus, Busseola fusca and Diatraea saccharalis feed in the leaf whorl causing pin holes and elongated lesions on the leaves. Older larvae bore and feed in the stem causing 'dead hearts', and stem tunnelling. Larvae of Sesamia cretica S. calamistis and S. inferens penetrate directly into the stem causing 'dead hearts' and tunnelling.

In most of the borer species (Chilo, Busseola, Sesamia, Diatraea, Eldana), eggs are laid in batches on the leaves which hatch in about 4-6 days. The larval period which is mostly spent inside the stems lasts for about 2 to 3 weeks. Pupation takes places mostly in the stems and the adult emerges within a weeks' time. Thus the whole life cycle is completed in about a month. Three to four generations have been recorded in a single crop growing season. In areas where one crop per year is taken, the insect enters into diapause in the larval stage during off season in stalks and stubbles. In southern India, where environmental conditions are equitable, Chilo remains active throughout and upto ten generations develop during the year. In case of D. saccharalis, the larvae girdle the stalk near the ground and hibernates below the level of girdling. Besides sorghum, a number of cultivated and wild host plants have been reported (Ingram, 1958; Nye, 1960; Harris, 1962; Young and Teetes, 1977; FAO, 1980). Maize, pearl millet, rice, sugarcane are the major cultivated hosts, while Sorghum *halepense*, *S. verticilliflorum*, *Penisetum purpureum*, *Panicum maximum* are some of the wild host species.

Selection criteria

Stem borer attack in sorghum causes leaf feeding, dead heart formation, stem and peduncle tunnelling. All these symptoms of attack are not necessarily related to the grain yield loss. Brar (1972) reported that leaf injury caused by stem borer 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 tunnelling was not related to grain yield reduction in sorghum (Singh et al, 1983; Pathak and Olela, 1983; Taneja and Leuschner, 1985). Singh et al (1968b) indicated that dead heart formation was the most stable criterion for differentiating degrees of stem borer resistance. Taneja and Leuschner (1985) observed a highly significant and negative correlation between dead hearts and grain yield of sorghum (r = -0.9**). Thus maximum weightage should be given to 'dead heart' parameter for differentiating degree of stem borer resistance followed by leaf injury and stem tunnelling.

Screening techniques

An efficient and reliable screening technique should ensure uniform and desired level of insect pressure at the most susceptible stage of the crop. These requirements can be achieved either by selecting a location where the pest occurence is adequate and regular (hot spot) or by testing the material under artificial infestation with laboratory-reared insects.

Screening under natural infestation at a 'hot spot' 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, Hisar, in North India has been identified as a 'hot spot' for stem borer (Chilo partellus) screening under natural infestation. At this location severe borer infestation has been recorded for several years on sorghum planted during the first fortnight of July (Taneja and Leuschner, 1985).

Screening of sorghum under artificial infestation (laboratory- reared insects) has been carried out by many workers in India. For this purpose, Chilo partellus has been reared on natural food (Singh et al., 1983) and on synthetic diet (Chatterji et al 1968; Dang et al. 1970; Laxminarayana and Soto, 1971; Siddiqui and Chatterji, 1972; Siddiqi et al. 1977, Sharma and Sarup, 1978; Seshu Reddy and Davies, 1979b). Taneja and Leuschner (1985) reported details of rearing methods, field infestation and evaluation for Chilo partellus resistance in sorghum. Screening of sorghum for Diatraea spp. resistance under artificial infestation is carried out at CIMMYT, Mexico (Mihm, 1985). Sesamia inferens (Chatterji et al. 1969), Busseola fusca (van Rensberg and Walter, 1983), and Diatraea saccharalis (Dinther and van Goozens, 1970, Miskimen, 1965) have been reared on artificial diet for field infestation.

Identification of Resistant Sources

A number of sorghum germplasm lines and their derivatives have been reported to be resistant to stem borer (C. partellus) by various workers in India and elsewhere (Singh et al. 1968b; Anonymous, 1971; Jotwani et al. 1974; Kundu and Jotwani, 1977; Anonymous, 1978; Jotwani et al. 1979; Singh et al. 1980; Dalvi et al. 1983; Singh et al. 1983; Sharma et al. 1983; Taneja and Leuschner, 1985). Fig.2 shows the flow of material for the identification of resistant sources followed at ICRISAT, which explains the stepwise evaluation and selection of plant material. Out of nearly 12 000 germplasm lines tested for more than three seasons, 61 lines have been found to be less susceptible (Table 2). Of these, IS 5470, IS 5604, IS 8320 and IS 18573 have been found to be stable over locations. Twenty eight lines showed less than 40% borer incidence with moderate level of stability as compared to 70% incidence on sorghum hybrid CSH 1. Geographically, 36 of these lines originated from India, eight from Nigeria, seven from USA, four from Sudan, two from Uganda and one each from Ethiopia and Zimbabwe. Taxonomically, 84% of the resistant lines belong to _Durra_, 10% _Durra membraceum_, 4% _bicolor_ and 2% _guinea bicolor_. In addition, selections from other 9 000 germplasm lines are under various stages of resistance testing.

Mechanism of Resistance

Although, ovipositional non-preference, is not a strong resistance mechanism against stem borers, but 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). The main mechanisms of resistance to _Chilo partellus_ in sorghum have been antibiosis and tolerance (Pant et al., 1961; Kalode and Pant, 1967a; 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 dead heart formation and stem tunnelling, and tolerance to leaf and stem feeding contribute to stem borer (C. partellus) resistane in sorghum. Marked differences in the establishment of first instar larvae among resistant and susceptible cultivars have been reported by Chapman et al. (1983) and Bernays et al. (1983). Surface waxes on the plant leaf and stem probably affect the movement of first instar larvae, and some wax components act as feeding deterrents (Woodhead, 1982). 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.

Genetics of Resistance

The expression of resistance in a plant to an insect species depends upon the genotype of the plant, the genotype of the insect and the genetic interaction between the plant and insect. Genetics of resistance to European corn borer, Ostrinia nubilales (Chiang and Hudson, 1973), corn earworm, Heliothis zea (Keaster et al. 1972) and fall army worm, Spodoptera frugiferda (Widstrom et al. 1972) demonstrate that resistance is inherited quantitatively. Little information is available on the inheritance of stem borer resistance in sorghum. Rana and Murty (1971) reported that resistance to stem borer is polygenically inherited. They found that resistance to primary damage (leaf feeding) was generated by additive and additive x additive type of gene action while additive and non-additive type gene action were important for secondary damage (stem tunnelling). 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 tunnelling was governed predominately by additive gene action (Pathak and Olela, 1983). It was also noted that the inheritance pattern of primary and secondary damage were different. Haji (1984) found that resistance to _Chilo partellus_ was polygenically governed. The epistatic gene affects were more pronounced under artificial borer infestation. He also noticed that under natural infestation, resistance was controlled by additive and dominance major gene affects. Cytoplasmic influences appeared to be present, which may play an important role for the inheritance of stem borer resistance.

Breeding for Resistance

The quantitative nature of inheritance of resistance to stem borers makes the breeding task difficult. This becomes more difficult when both resistance and yields are a quantitatively controlled traits and are to be put together. Both pedigree and population breeding have been used to incorporate resistance into good agronomic background. Pedigree breeding has been used at ICRISAT as a short term approach to quickly breed for resistance (Agarwal and House, 1982). The use of broad based, random mating pest resistant populations is an appropriate long term approach for breeding sorghums resistant to stem borers and is being attempted at ICRISAT.

Starks and Dogget (1970) described the breeding methodology to incorporate resistance to stem borer in sorghum. They concluded that an effective method of developing cultivars possessing resistance to C. partellus should involve population breeding. All plants in a composite population or the S1 lines from a composite population should be infested with egg masses 20 days after plant emergence. The crop should then be evaluated for yield using recurrent selection. At ICRISAT, a shoot pests (shoot fly and stem borer) population is in the process of development using ms3 and ms7 male sterility genes (Agarwal and House, 1982; Agarwal and Abraham 1985). Once this population is improved for characters like height, maturity, grain quality and resistence, S2 testing will be used as outlined in Fig.3. Major selection pressure is placed on resistance to shoot pests so that only undamaged plants are advanced to the next generation.

There are three basic units in pest resistance breeding approach as outlined in Fig.3 (Agarwal and House, 1982). Unit 1 involves the strengthening of source material, unit 2 the development of agronomically elite lines, and unit 3 the crossing of material identified in units 1 and 2. Unit 3 segregating material is advanced with continuous testing using different levels of insect pressure. Jotwani et al. (1974) bred two Chilo partellus resistant varieties E 302 and E 303 by successfully incorporating resistance from a local cultivar BP 53 into agronomically desirable high yielding lines. Several derivaties in the breeding nursery also exhibited high level of resistance to Chilo (Anonymous, 1978; Singh et al. 1980, Prem Kishore, 1984b). Singh et al. 1980 concluded that inspite of the low heritable nature of stem borer resistance, it is possible to develop cultivars stable for resistance by continuous selection under high infestation in advanced generations of agronomically improved progenies of susceptible (high yielding) x resistant crosses.

Host-Plant Resistance in Integrated Pest Management

Integrated pest management deals with the use of a variety of pest suppression measures that adversely affect the pest density and damage and favours crop production. There are several ways by which host-plant resistance can be used in an integrated pest management program. Ideally, resistant cultivars would provide a complete and permanent control. However, such high levels of resistance can rarely be achieved in high yielding cultivars and usually result in the development of insect biotype which will be able to injure the previously resistant cultivars. Also a cultivar resistant to one pest species may be susceptible to other species. Thus host-plant resistance should be used as a component of integrated pest management in conjuction with other control measures.

Resistant Cultivars and Economic Thresholds

Economic threshold level (ETL) is the pest density at which control measures should be adopted to prevent the increasing pest density from reaching the level that causes economic damage. An insect resistant cultivar may lower of pest density or raise of the economic threshold level depending on the type of resistance. Antibiosis and non-preference result in lowering the pest density whereas tolerance type of resistance raises the ETL (Teetes, 1982). In case of stem borers infesting sorghum, antibiosis and tolerance are the main resistance mechanisms, thus it lowers the pest density as well as raises the economic threshold level (Fig. 4).

Antibiosis type of resistance in sorghum to C. partellus as expressed by the high mortality in the early larval stages or the low survival rate (Jotwani et al. 1978, Lal and Pant 1980b) will reduce the borer density by inducing a constant level of suppression in each pest generation (Table 3). It will reduce the rate of population increase and retard population growth. The ETL is therefore not reached or reached at a later point in time depending on the level of resistance (Fig. 5). If a large area is occupied by a resistant cultivar, the reduction in pest density will be cumulative over time (Table 3). The total pest number within the area will become smaller each succeeding year. Lengthening of the larval period on resistant cultivars have also been reported (Anonymous, 1978), which implies that number of generations per season/year get reduced and thus suppressing the pest density several times (Table 4). This incorporation of resistance character not only increases the economic injury level, but also delays the time when that level is reached (Teetes, 1982) as demonstratd in Fig.6.

Resistant Cultivars and Cultural Control

Growing of resistant cultivars in combination with the adoption of recommended cultural methods of control will further suppress the stem borers population buildup and thus keeps the borer population below economic threshold levels.

The following agronomic practices have been found to have some potential in reducing the stem borers population in sorghum and increasing those of beneficial insects.

1. Destruction of crop residues and alternate hosts (Duerdan, 1953; Aikin, 1957; Ingram, 1958; Bowden, 1976; Girling, 1978)

2. Tillage and mulching (Du Plessis and Lea, 1943, Kaufmann, 1983)

3. Time of Planting (Swaine, 1957, National Academy of Science, 1969, Bowden, 1976).

4. Multiple and intensive cropping (Bytinski-Salz, 1965)

5. Intercropping (Kaufmann, 1983, Ogwaro, 1983)

6. Fertilizer use (Singh and Shekhawat, 1964; Kalode and Pant, 1967b; Singh and Singh, 1969; Singh et al. 1968a, Starks et al. 1971)

7. Irrigation (Chowdry and Sharma, 1960).

Resistant cultivars and biological control

Although the scope of biological control appears to be limited in sorghum because of non continuity of the crop to sustain natural enemies and their hosts, but growing of resistant cultivars may increase the effectiveness of natural enemies. Resistant cultivars help in the efficiency of bio-control agents by (1) lengthening the larval period of stem borers (Anonymous, 1978) thus providing more time for natural enemies to find their prey, and (2) by exposing the young larvae outside the feeding sites for a longer period (Chapman et al. 1983) and thus making them vulnerable to more bio-control agents.

A number of predators and parasites attaking sorghum stem borers have been reported in literature. Trichogramma chilonis is the only egg parasite (Anonymous, 1981), while a large number of larval and pupal parasites and predators have been recorded on Chilo partellus (Jotwani and Verma, 1969; Anonymous, 1971; Jotwani et al. 1972; Sandhu, 1977; Seshu Reddy and Davies, 1979a; Anonymous, 1981).

Resistant cultivars and Chemical Control

Effectiveness of chemical control method increases when it is used in combination with resistant cultivars provided need based application is practiced. Effectiveness of chemical control in conjuction with growing resistant cultivars is increased because of the following reasons:

(1) Slower growth and lengthening of the larval period on resistant cultivars (Anonymous, 1978) increases the chances of borer larvae to come in contact with the chemical.

(2) More dispersal of early instar larvae on resistant cultivars (Chapman et al. 1983) make them more vulnerable to chemical contact.

(3) Since the ETL is raised and the pest density is suppressed by resistant cultivars, frequency of chemical application is reduced or no chemical application is required. Prem Kishore (1984a) reported no net monetory benefit with even two insecticide applications in 12 stem borer resistant lines while insecticide applied to a susceptible

hybrid CSH 1 increased the grain yield substantially. Similarly Prem Kishore and Govil (1982) recommended two resistant cultivars P 37 and P 151 for general cultivation without insecticide control against stem borer.

(4) Since sorghum is attacked by more then one insect species during its growing period, which attack at different growth stages, growing of resistant cultivars reduce the number of insecticide application. For example if stem borer and midge are the major pest problems in a particular region, growing of stem borer resistant cultivars will save chemical application against stem borer and only chemicals for midge control will be required.

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Table 1. Species of stem borers infesting sorghum in the world

Species	Family	Common name	Distribution
Acigona ignefusalis Hampson	Pyralidae		West Africa
Busseola fusca Fuller	Noctuidae	Maize stalk borer	Africa
Busseola segeta Bowden	"	-	East Africa
Chilo agamemnon Bleszynski	Pyralidae	-	
Chilo diffusilineus J.de Joannis	"	-	
Chilo infuscatellus Snellen	"	Yellow top borer	Indian sub continent, Taiwan Java, Korea
Chilo orichalcociliellus Strand	"	-	East Africa
Chilo partellus Swinhoe	"	Spotted stem borer	East Africa, Indian Sub continent, Sri Lanka, Thailand, West Africa
Diatraea grandiosella Dyar	"	Southern Western corn borer	South western US Mexico, New world
Diatraea lineolata Walker	"	-	New world
Diatraea saccharalis F.	"	Sugarcane borer	Southern U.S. New world Tropics
Elasmopalpus lignosellus Zell.	"	Lesser corn stalk borer	North, Central and South America
Eldana saccharina Walker	"	Sugarcane borer	West & East Africa
Ematheudes spp.	"	-	
Maliarpha sepratella Rag	"	Green striped borer	
Ostrinia nubilalis Hbn	"	European corn borer	North east & Central U.S. Europe, W.Asia, Asia minor, the Caucasus, China
Procerus venosatus Walker	"		
Sesamia botanephaga Tams & Bowden	Noctuidae	-	West & East Africa
Sesamia critica Lederer	"	Sorghum borer	South & Eastern Europe, Morocco, Middle East
Sesamia calamistis Hampson	"	Pink borer	Africa
Sesamia inferens Walker	"	Pink stem borer	Indian sub continent, S.E. Asia, China, Japan, Phillippines.
Sesamia penniseti Tams & Bowden	"	-	Africa
Sesamia poephaga Tams & Bowden	"	-	Africa

Table 2. Sorghum germplasm lines identified as less susceptible to stem borer at ICRISAT

Pedigree	Origin	Stemborer incidence (%)
IS 1044	India	32.9
1082	India	45.3
1119	India	42.4
2122	USA	35.8
2123	USA	30.6
2146	USA	46.1
2168	USA	50.4
2195	India	43.8
2205	India	40.6
2263	Sudan	38.1
2269	USA	48.6
2291	Sudan	21.7
2309	Sudan	33.8
2312	Sudan	33.3
4273	India	63.9
4546	India	43.9
4637	India	41.4
4756	India	38.1
4776	India	38.0
4881	India	41.0
4981	India	48.3
5075	India	49.5
5253	India	53.4
5429	India	41.1
5469	India	28.3
5470	India	35.5
5480	India	37.9
5538	India	33.1
5566	India	32.9
5571	India	35.3
5585	India	35.2
5604	India	23.3
5622	India	41.0
7224	Nigeria	44.4
8320	India	33.6
8811	Uganda	56.4
10711	USA	38.7
12308	Zimbabwe	38.0
13100	India	36.8
13674	Uganda	33.9
17742	India	44.6
17745	India	44.4
17747	India	51.4
17750	India	47.5
17948	India	43.6
17966	India	45.4
18333	India	48.1
18366	India	53.7
18551	Ethiopia	36.0
18573	Nigeria	24.0
18577	Nigeria	34.9
18578	Nigeria	40.6
18579	Nigeria	34.6
18580	Nigeria	49.8
18584	Nigeria	40.5
18585	Nigeria	48.8
18662	India	39.0
18677	India	45.8
20643	USA	47.6
SB 8530		39.0
PB 8253		59.4
CSH-1		70.3

1/ Mean of six replicated trials

Table 3. Theorietical rate of increase by borer population on a susceptible and two resistant cultivars that reduce population size by 25% and 50% respectively, in each generation. Assume fivefold rate of increase per generation (Adapted from Knipling, 1964)

Generation	Number of insects per hectare		
	Susceptible cultivar	Resistant cultivar 1	Resistant cultivar 2
FIRST YEAR			
Parent	100	100	100
F1	500	375	250
F2	2 500	1 406	625
F3	12 500	5 273	1 562
F4	62 500	19 775	3 906
Assume all insects enter diapause at the end of first year of which only 5% survive			
SECOND YEAR			
Parent	3 125	988	195
F1	15 625	3 705	488
F2	78 125	13 893	1 219
F3	390 625	52 101	4 047
F4	1 953 125	195 380	7 617

Table 4. Theorietical rate of increase by borer population on a susceptible and two resistant cultivars that reduce one generation with same and 50% reduction in population size per generation, respectively. Assume fivefold rate of increase per generation (Adapted from Knipling, 1964)

Generation	Number of insects per hectare		
	Susceptible cultivar	Resistant cultivar 1	Resistant cultivar 1
FIRST YEAR			
Parent	100	100	100
F1	500	500	250
F2	2 500	2 500	625
F3	12 500	12 500	1 562
F4	62 500	-	-
Assume all insects enter diapause at the end of first year of which only 5% survive			
SECOND YEAR			
Parent	3 125	625	78
F1	15 625	3 125	195
F2	78 125	15 625	975
F3	390 625	78 125	4 875
F4	1 953 125	-	-
End of Second year	1 953 125	78 125	4 875

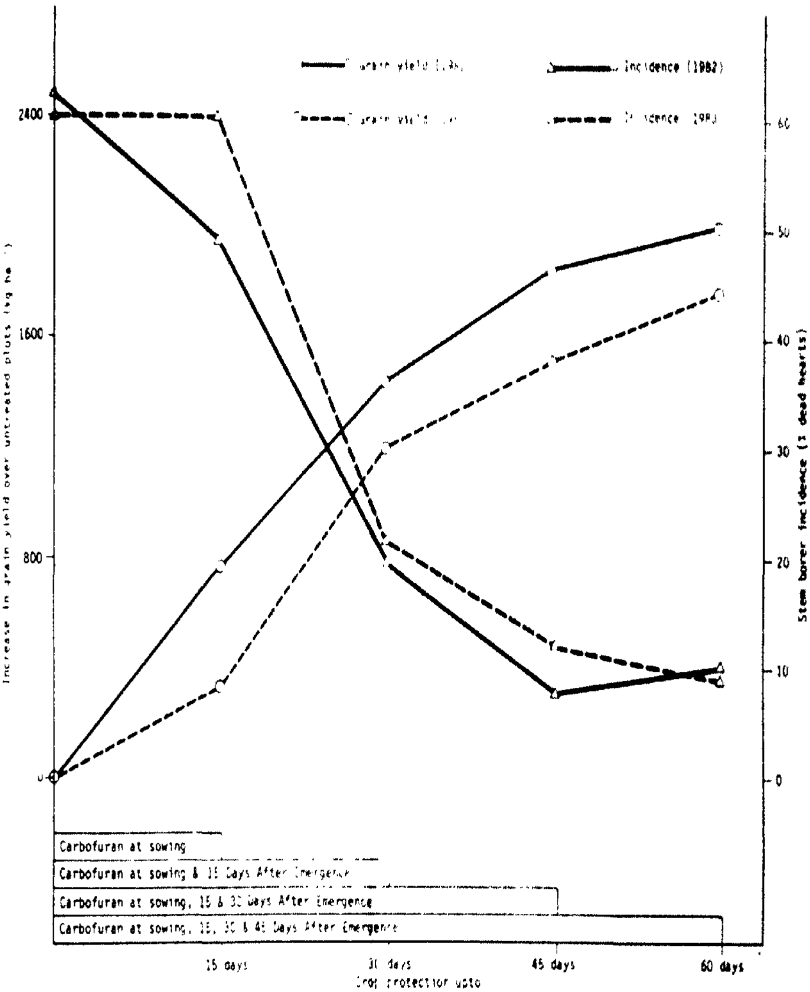

Fig.1. Effect of stem borer infestation on grain yield of sorghum hybrid CSH 1

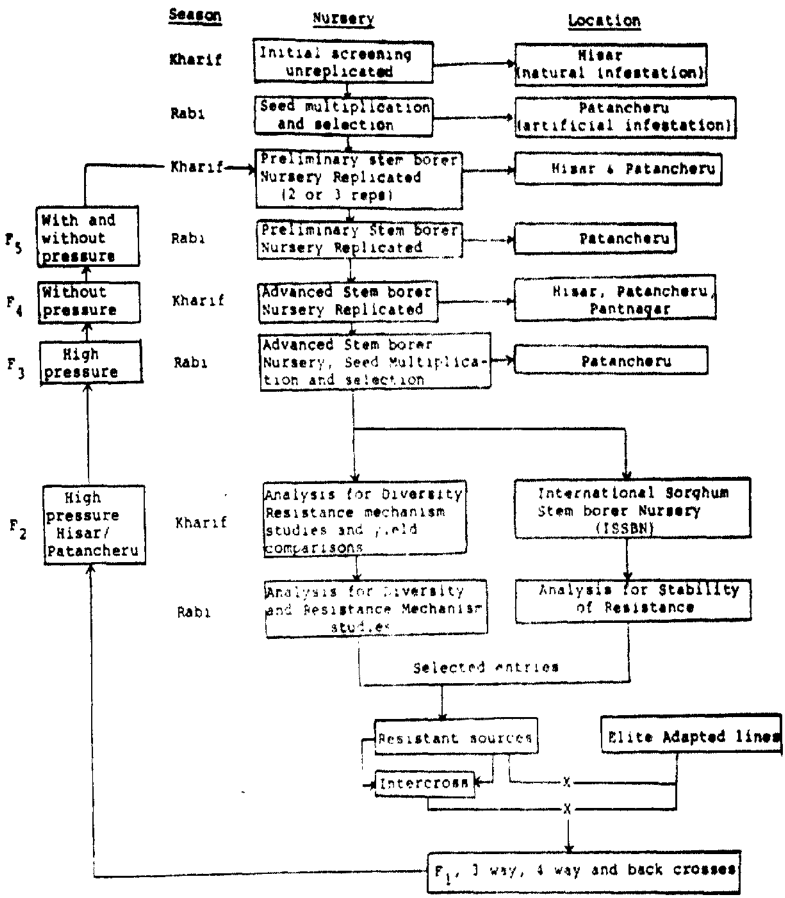

Fig.2. SCREENING FOR STEM BORER RESISTANCE IN SORGHUM AT ICRISAT

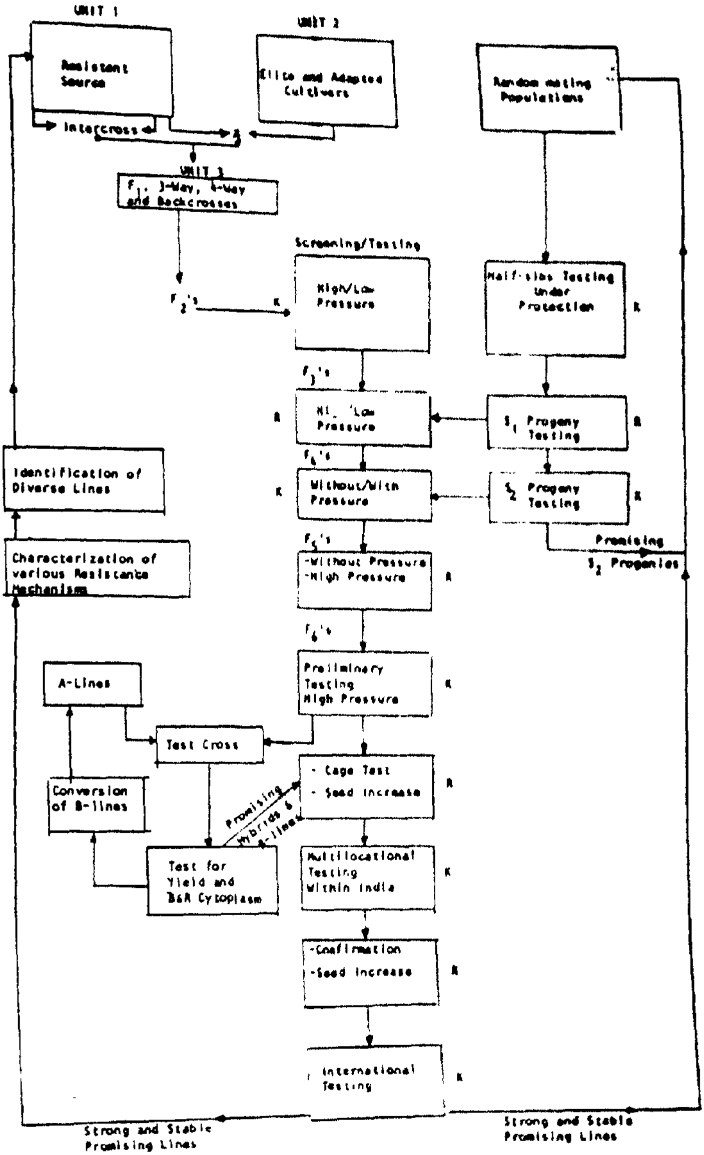

FIG 3 SCHEME FOR PEST RESISTANCE BREEDING IN SORGHUM

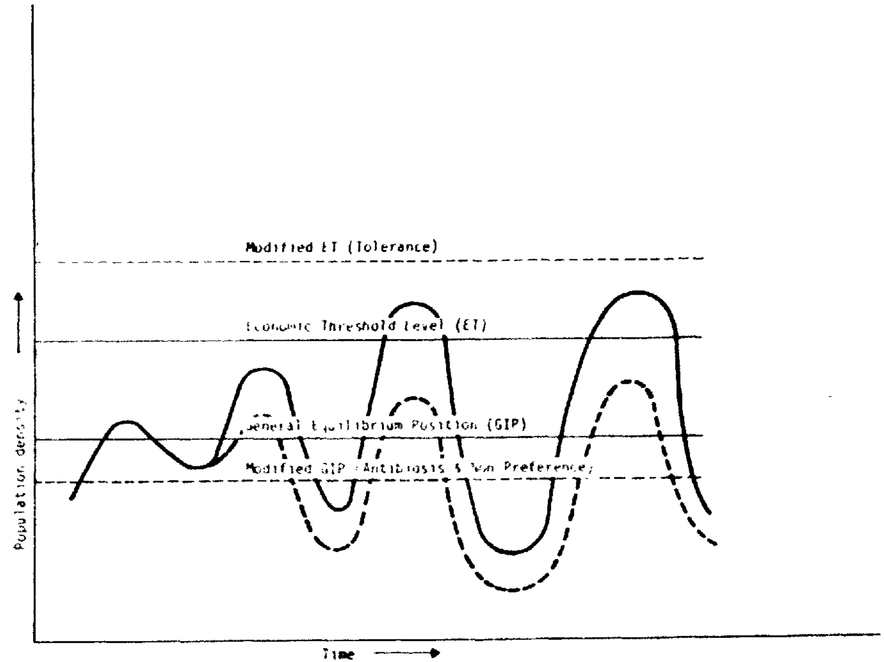

Fig.4. Schematic illustration of the fluctuation of theoretical insect population in relation to general equilibrium position, economic threshold and resistant cultivars

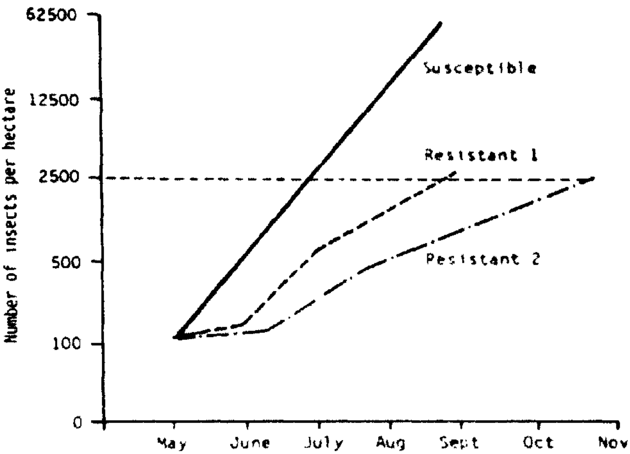

Fig.5. Theoretical population trends of a hypothetical insect population on susceptible variety, resistant variety 1 and resistant variety 2 (Adkisson and Dyck 1980

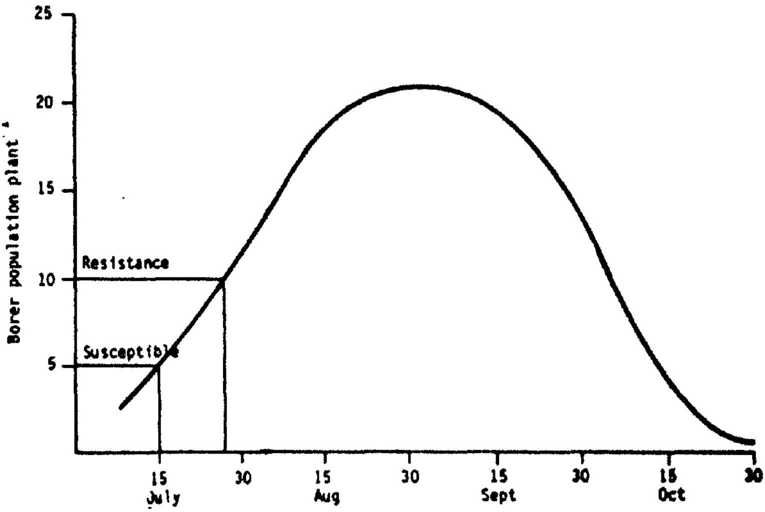

Fig.6. Hypothetical illustration of the influence of resistance in relation of time and insect density