CP760

CHANGING SCENARIO IN INSECT PEST PROBLEMS AND THEIR MANAGEMENT ON SORGHUM AND MILLETS

S.L. TANEJA

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

ABSTRACT

With the introduction of high-yielding varieties and hybrids, insect-pest associated losses have increased in sorghum. Sorghum shoot fly, *Atherigona soccata* Rondani and midge, *Contarinia sorghicola* Coq., which were known to occur in low numbers previously, have become major pests. Other pests such as shoot bug (*Peregrinus maidis* Ashm.), aphid (*Rhopalosiphum maidis* Fitch. and *Aphis sacchari* Zehnt.), and armyworm (*Mythimna separata* Walker), which were earlier considered as minor pests, are gaining importance in many sorghum-growing areas. In the recent years, pests such as pyrilla (*Pyrilla perpusilla* Walker), grey weevil (*Myllocerus* spp.), blister beetles (*Cylindrothorax* spp., *Mylabris* spp.), and root bug (*Stibaropus minor* Fab.) in pearl millet, pink borer (*Sesamia inferens* Walker) and earhead worm (*Helicoverpa armigera* Hb.) in finger millet and shoot flies (*Atherigona* spp.) in other minor millets are becoming serious in many millet-growing areas in India. Chemical control against sorghum pests gained momentum in the seventies, and several insecticides have been recommended. Host-plant resistance has become one of the major components in pest management, and resistance has been incorporated into reasonably good agronomic backgrounds for some of the major pests of sorghum. Current emphasis has been to integrate various control options into management packages to minimize the pest-induced losses. Insect pest situation and the control options with the changing cropping patterns are discussed.

INTRODUCTION

Sorghum and pearl millet are the major food and feed crops in the dry semi-arid tropics. In India, these two crops are grown on over 27 million hectares with a production of over 16 million tonnes (AICSIP, 1991; AICMIP, 1991). Over the past 30 years, the area under these crops in India has not changed, while the production has gone up from 12 to 16 million tonnes. The major breakthrough in the yield increase in these crops occurred through the introduction of hybrids and improved varieties, and their adoption by the farmers. Insects pests are one of the major production constraints in these crops. Although both these crops are attacked by a number of insect pests, pest-affected losses are much higher in sorghum than in millets. In subsistence agriculture, losses caused by insect pests were not realized because the production levels as well as insect infestations were low. With the introduction of high-yielding cultivars and use of better inputs, the production levels have improved. These changes have also provided conducive environment for pest multiplication, resulting in substantial losses in grain yield and quality. Sorghum shoot fly, *Atherigona soccata* Rondani and midge, *Contarinia sorghicola* Coq. which were previously known to occur in low numbers, have become major pests in modern agriculture. Other pests such as shoot bug (*Peregrinus maidis* Ashm.), aphids (*Rhopalosiphum maidis* Fitch. and *Aphis sacchari* Zehnt.), and armyworm, (*Mythimna separata* Walker), which were earlier considered as minor pests, are gaining importance in many sorghum-growing areas.

There have also been changes in the pest control approaches over the last 3-4 decades. Before the introduction of high- yielding varieties and hybrids, farmers used to follow cultural practices, such as early sowings, crop rotations, intercropping, etc., to reduce insect damage. With high input technology, chemical control was considered as a solution to pest control, and a number of insecticides were recommended and used. However, realizing the demerits of total reliance on chemicals, efforts were made to look for other methods of pest control, particularly host-plant resistance and biological

Recently, major emphasis has been to integrate various control components into an Integrated Management (IPM) system to minimize pest associated losses. Sharma (1985c, 1987) has reviewed the information on insect pests of sorghum and their management strategies in India. In this paper, information on the changes in pest situation of sorghum and millets and their control options has been reviewed and discussed.

INSECT PEST SITUATION IN SORGHUM

Over 150 insect species are reported to feed on sorghum (Seshu Reddy and Davies, 1979; Jotwani *et al.*, 1980). However, only a dozen of them cause economic damage. Insect infestations fluctuate over seasons and locations depending on abiotic and biotic factors which affect the crop as well as insects. In general, insect pest infestations in sorghum have increased with the introduction of high-yielding varieties and hybrids since the mid-sixties. One of the factors in the slow adoption of high- yielding genotypes has been their greater susceptibility to insect pests. Although there have been reports of insect infestations in sorghum since the fifties, their seriousness was realized only after the release of the first commercial hybrid CSH 1 in 1965 (Pradhan, 1971; Jotwani, 1978). This hybrid, besides being high yielding, was highly susceptible to shoot fly and midge, which also gained importance as other high-yielding cultivars susceptible to insects were released.

There have been fragmented reports of pest infestations in farmers' fields until 1975. In the mid-seventies, a specific survey and surveillance project was included in the entomological research of the All India Coordinated Sorghum Improvement Project (AICSIP) and since then, regular surveys are conducted in different areas. The following summary of the sorghum pest situation in India has been compiled mainly from the information available in AICSIP Progress Reports (AICSIP, 1976-91), published literature and personal communication with the sorghum workers in different regions.

The most widely distributed sorghum pests in India which cause economic damage in the farmers' fields are; shoot fly, stem borer, sorghum midge, earhead bug, armyworm and aphids (Gahukar and Jotwani, 1980). Other species that cause severe damage in some locations and in some seasons/years are locust, white grubs, head caterpillars, shoot bug, pyrilla, blister beetles, cutworms and mites in the rainy (*kharif*) season; and flea beetle, delphacids and wireworms in the postrainy (*rabi*) season (AICSIP, 1976-91). Pest infestations in sorghum have been reported from Delhi, Udaipur, Indore, Surat/Navsari, Akola, Parbhani, Rahuri, Palem/Hyderabad, Bijapur, Dharwad and Coimbatore. Pest infestations in the farmers' fields (Table 1) have been averaged over a 5-year period (1976-80, 1981-85 and 1986-90). Insect infestations have been ranked on 1 - 3 scale, where 1 = > 25% infestation, 2 = 10-25% infestation and 3 = <10% infestation. Average infestation levels were computed only for the locations where data were available. Table 1 indicates that shoot fly and stem borer infestations have been reported from all the 10 centers, while sorghum midge from eight, head bugs and armyworm from seven each, and aphids from six centers. Individual pest situation over the last 15 years (1976-90) is reported below.

Shoot Fly

Shoot fly is a serious pest in the seedling stage during the postrainy season and during the rainy season when the sowings are delayed. In the late rainy season, heavy infestations have been recorded from Maharashtra (Parbhani and Rahuri), Andhra Pradesh (Palem), Karnataka (Dharwad), Gujarat (Surat) and Delhi. Moderate levels of infestation are reported from other places except Coimbatore, where

infestation has been low. In general, shoot fly infestation has increased from the late seventies (score 2.0) to the late eighties (score 1.5). Increased infestation has been reported from six out of 10 locations (Table 1). In the early rainy season, there was a 3-fold increase in shoot fly infestation (10% in 1976-80 to 30% in 1986-90) in Central Maharashtra (Parbhani). However, in Gujarat, Karnataka and Tamil Nadu, the infestation levels remained static at <10% (AICSIP, 1976-91). In the postrainy season, heavy infestations occur in Maharashtra (Rahuri and Parbhani) and Karnataka (Bijapur). In this season also, there was an increase in infestation levels over time.

Table 1. Insect pest situation in sorghum (1-3 score)* in different locations in India, 1976-90

	Shoot fly			Stem borer			Midge			Head bugs			Armyworm			Aphids		
	76-80	81-85	86-90	76-80	81-85	86-90	76-80	81-85	86-90	76-80	81-85	86-90	76-80	81-85	86-90	76-80	81-85	86-90
Delhi	3	3	1	2	3	3	3	2	2	-	3	-	-	-	-	-	1	1
Udaipur	1	2	2	2	2	1	3	3	3	-	-	-	2	-	-	-	3	-
Indore	2	1	2	1	1	2	2	3	3	-	-	-	3	3	3	-	3	-
Surat	2	1	1	1	2	1	2	2	1	3	2	1	3	-	-	-	-	3
Akola	2	3	2	1	1	2	2	3	3	-	3	-	2	1	2	-	-	-
Parbhani	2	1	1	3	3	2	3	3	3	-	2	1	-	3	2	-	-	-
Rahuri	2	1	1	3	3	3	3	3	2	3	2	3	2	1	-	3	1	3
Palem	2	1	1	3	3	2	-	-	-	-	-	2	-	-	-	-	-	3
Dharwad	2	1	1	3	3	2	2	1	1	1	3	2	1	1	2	3	3	3
Coimbatore	2	3	3	3	2	3	-	-	-	2	3	2	-	-	-	-	-	3
Total	10	10	10	10	10	10	8	8	8	4	7	6	6	5	4	2	5	6
Mean	2.0	1.7	1.5	2.2	2.3	2.1	2.5	2.5	2.3	2.3	2.5	1.8	2.1	1.8	2.2	3.0	2.2	2.6

*Score 1=>25% infestation;2=11-25% infestation;3=1-10% infestation;(-)=zero infestation/no report

Stem Borer

There are two species of stem borers that infest sorghum in India. Spotted stem borer, *Chilo partellus* Swinhoe, is widely distributed in all sorghum-growing areas. Pink borer, *Sesamia inferens* Walker is restricted to Madhya Pradesh. *S. inferens* also infests sorghum during the postrainy season in Maharashtra, Andhra Pradesh and Karnataka. Severe borer infestations in the farmers' fields are reported from Madhya Pradesh, Rajasthan, Gujarat and northern Maharashtra (Akola). In other states, borer infestation is low to medium. The overall infestation levels have not changed between the late seventies and eighties. However, borer infestation has increased in Rajasthan, Central Maha rashtra (Parbhani), Andhra Pradesh and Karnataka, and decreased in Delhi, Madhya Pradesh and northern Maharashtra, while in Gujarat, Western Maharashtra (Rahuri) and Tamil Nadu, the borer situation has not changed over time.

Sorghum Midge

Severe midge infestation has been reported from Gujarat, Tamil Nadu, Karnataka and lately from Delhi and western Maharashtra (Rahuri). Low infestation occurs in Rajasthan, Madhya Pradesh and northern Maharashtra (Akola). There has been a trend of increased midge infestations over time. Midge infestation in Maharashtra, a major sorghum growing state, has been managed with timely and uniform planting of sorghum in the rainy season. Karnataka is endemic for midge damage, where the infestation may exceed 50%.

.d Bug

.tead bug infestation is negligible in Delhi, Rajasthan and Madhya Pradesh, while medium to high infestation occurs in Gujarat, western and central Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu. In general, there has been an increase in bug infes tation over time with the introduction of cultivars with semicompact and compact panicle.

Armyworm

The oriental armyworm, *Mythimna separata* Walker is the major armyworm species infesting sorghum and pearl millet in India. Armyworm infestation has been medium to severe in Maharashtra, and Karnataka, where it occurs quite regularly. Although its infestation has remained static over the last 15 years, it occurs in epidemic levels and results in the defoliation of sorghum over a large area.

Aphids

.ry low or negligible aphid infestation on sorghum was reported up to the seventies. There has been an increase in aphid infes tation since the early eighties and severe infestations of *Rhopalosiphum maidis* have occurred in Delhi and *Aphis sacchari* Zehnt. in western Maharashtra and Karnataka. Low infestation also occurs in Rajasthan, Madhya Pradesh and Gujarat.

Other insect pests that occurred occasionally in different areas are given in Table 2. Various species of head caterpillars are reported from Delhi, Madhya Pradesh, Gujarat, Maharashtra and Karnataka; *Pyrilla* from Delhi, Madhya Pradesh and Gujarat, and mites from Delhi, Rajasthan, Madhya Pradesh, Gujarat, Maharashtra, Karnataka and Tamil Nadu. In the postrainy season, the major pests of sorghum are the shoot bug (delphacid), which causes the 'Chitka' disease, and the flea beetle.

Table 2. Occasional insect pests in farmers' fields at different locations in India

Location	Season	Insect pests
Delhi	Rainy	Head caterpillars, *Pyrilla*, Mites
Udaipur	Rainy	Blister beetle, Mites
Indore	Rainy	Head caterpillars, *Pyrilla*, Delphacids, Hairy caterpillars, Blister beetle, Cut worm, Mites
Surat	Rainy	Head caterpillars, *Pyrilla*, Mites
ola	Rainy	Head caterpillars, Ground beetles
Parbhani	Rainy	Head caterpillars
	Postrainy	Wire worms, Delphacids, Flea beetles
Rahuri	Rainy	Shoot bug, Head caterpillars, Mites, White grubs
	Postrainy	Flea beetles, Shoot bug
Palem	Rainy	Mites, Shoot bug
Dharwad	Rainy	Head caterpillars, Mites
	Postrainy	Shoot bug
Coimbatore	Rainy	Shoot bug, Mites
	Postrainy	Shoot bug

INSECT PEST SITUATION IN MILLETS

Seven species of common millets grown in India are; Pearl millet (*Pennisetum gluacum* (L.) R. Br.), Finger millet (*Eleusine coracana* (L.) Gaertn.), Foxtail millet (*Setaria italica* (L.) P. Beauv.), Little millet (*Panicum sumatrense* Roth-ex Roem. & Schult.), Proso millet (*Panicum miliaceum* L.), and Barnyard millet (*Echinochloa crusgalli* (L.) P. Beauv.). In India, millets are generally free from major insect pest problems compared with other cereals such as sorghum, rice and maize. However, it is common to find severe pest infestations on millets. Serious outbreaks and locally important endemic pests have been reported from time to time. Among the millets, a large number of insect- pest species causing economic damage have been reported in pearl millet, while a few species cause economic damage on other millets. A comprehensive account of pest problems on millets and their control has been given by Sharma and Davies (1988).

The pearl millet insect pest situation in various states in India has been summarized in Table 3. This information has been compiled from the surveys conducted by the All India Coordinated Millet Improvement Project (AICMIP) scientists in farmers' fields (AICMIP, 1980-92). The major insect pests of pearl millet in Rajasthan are white grub (*Holotrichia* spp.), blister beetles (score 1), root bug, shoot fly, grey weevil, leaf roller (*Marasmia trapezalis* Gua.) and chaffer beetle (*Anthracophora* sp., *Chiloloba acuta* W., *Oxycetonia* spp.) (score 2). pyrilla, grey weevil (score 1), earhead worms, stem borer and leaf roller (score 2) are important pests in Delhi. In Madhya Pradesh, the pests of major concern are grey weevil (score 1), grasshopper (*Acrida* sp., *Chrotogonus* spp., *Hieroglyphus* spp., *Oedaleus* spp.), , leaf roller and earhead caterpillar (score 2). Jassids (score 1), shoot fly, grasshopper and blister beetles (score 2) are important in Gujarat while in Maharashtra, none of the pests is of economic importance. Midge, *Geromyia pennisetii* Felt. has been reported to cause severe damage in Tamil Nadu. Most of these pests became important only in the eighties, except white grubs in Rajasthan.

Table 3. Insect pest situation in pearl millet in different states in India

State	Insect pest															
	WG	RB	SF	JS	PR	FB	SB	GH	GW	LR	CH	BB	EC	HC	AW	MG
Rajasthan	1	2	2	-	-	-	-	-	2	2	2	1	-	-	-	-
Delhi	-	-	3	-	1	-	2	-	1	2	-	-	-	1	3	-
Madhya Pradesh	-	-	-	3	-	3	-	2	1	2	3	3	2	3	-	-
Gujarat	3	-	2	1	-	3	3	2	-	3	-	2	-	-	-	-
Maharashtra	-	-	3	-	-	-	3	-	-	-	-	-	3	3	-	-
Tamil Nadu	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	2

WG: White grub; RB: Root bug; SF: Shoot fly; JS: Jassid; PR: *Pyrilla*; FB: Flea beetle; SB: Stem borer; GH: Grass hopper; GW: Grey weevil; LR: Leaf roller; CH: Chafer beetle; BB: Blister beetle; EC: Earhead caterpillar; HC: Hairy caterpillar; AW: Armyworm; MG: Midge

Score 1 = >25% infestation; 2 = 11-25% infestation; 3 = 1-10% infestation; (-)= no report

Important pests of minor millets causing some losses are pink borer, earhead worms, dusky cotton bug (*Oxycarenus* sp.) and painted bug (*Bagrada crusiferarum* Kirk.) in finger millet; shoot fly, armyworm, leaf beetle and leaf miner in foxtail millet; shoot fly, aphid, jassid, earhead bug and grasshopper in little millet; shoot fly in proso millet; shoot fly, armyworm, gall fly and jassid in Kodo millet; and shoot fly and armyworm in barnyard millet.

Avoidable losses due to insect pests in pearl millet over a 3-year period (1988-90) were estimated to be 18.2% (14.3 - 21.4%) in different high-yielding varieties and hybrids (AICMIP, 1991). Avoidable losses caused by shoot fly have been reported to the extent of 9.2-39.0% in little millet (Selvaraj *et al.*, 1974), 23.3-59.3% in pearl and proso millets (Natarajan *et al.*, 1973, 1974) and 35.3% in pearl millet (Singh and Jotwani, 1973). Blister beetles resulted in avoidable losses of 6.8% in pearl millet (Ramamurty *et al.*, 1970).

CONTROL OPTIONS

Cultural Control

A number of cultural practices are followed to reduce the pest infestations in sorghum and millets. These are: (i) Early and uniform planting for shoot fly, midge and head bugs (Jotwani *et al.*, 1970; Hardas *et al.*, 1972; Ramnath *et al.*, 1974), (ii) High seed rate for shoot fly (Gahukar and Jotwani, 1980), (iii) Collecting and burning stubbles for stem borer and chaffy panicles for midge (Gahukar and Jotwani, 1980), (iv) Destruction of alternate hosts for shoot fly and stem borer, (v) Ploughing after crop harvest and before planting to reduce carryover of white grubs, grasshoppers, hairy caterpillars and stem borers (Gahukar and Jotwani, 1980), (vi) Intercropping sorghum with leguminous crops to reduce shoot fly and midge damage (Hardas *et al.*, 1980), (vii) Piling and burning of trash at dusk in fields to attract and kill white grub adults (Yadava *et al.*, 1973), and (viii) Proper and timely weeding of crop for oriental armyworm (Sharma and Davies, 1982). The most significant contribution of early and uniform planting over a large area has been in the management of shoot fly and midge in Maharashtra (Jotwani, 1982).

Biological Control

Much information has been generated on biocontrol agents of sorghum pests during the last decade (Seshu Reddy and Davies, 1979; Pradhan, 1971; Jotwani, 1978). The most important natural enemies are *Apanteles flavipes* Cameron, *Bracon chinensis* Szepl., and *Trichogramma chilonis* Ishii for stem borer; *Tetrastichus diplosidis Crawt., and Orius maxidentex* Ghauri for midge; *T. chilonis* and *Aprostocetus* for shoot fly, and Nuclear Polyhedrosis Virus (NPV), *Apanteles ruficrus* Haliday, and a nematode, *Steinernema feltiae* Filipjev for oriental armyworm. Laboratory rearing and field release of natural enemies particularly *Trichogramma, Apanteles* and nematode, *S. feltiae* have been undertaken at Dharwad with various degrees of success (AICSIP, 1986-91). Release of 4-6 lakhs of *T. chilonis* per acre resulted in 70-80% parasitization of shoot fly eggs. Similar levels of parasitization have also been observed in spotted stem borer with the release of 6-10 lakhs of *T. chilonis* per acre. Release of 1000 adults of *Apanteles* per acre caused 32.5% parasitization in *C. partellus*. Introduction of nematode (*S. feltiae*) suspension in the leaf whorl of sorghum also resulted in 80-90% mortality of oriental armyworm. Knowledge of the biological control agents of millet insects is very limited. A number of biocontrol agents have been recorded from millet pests which are also pests of other cereals. Sharma and Davies (1988) reviewed the available information on the biological control of millet pests.

Host-Plant Resistance

Since the inception of AICSIP and ICRISAT, major emphasis of entomological research in sorghum has been on host-plant resistance. Efficient and reliable techniques are now available for effective resistance screening against major sorghum pests using natural and artificial insect infestations

(Sharma *et al.*, 1992). Various techniques used for different pests are;

Shoot Fly. Delayed sowing, planting of infester rows, use of fish meal, and cage screening.

Stem Borer. Sowing dates at hot-spot locations, and artificial infestation.

Midge. Delayed and staggered sowing, planting of infester rows, use of diapausing population, use of sprinkler irrigation in the postrainy season, and headcage testing.

Head Bugs. Delayed sowing, planting of infester rows, and headcage technique.

In the initial years, a large collection of germplasm mate rial was screened, and a number of lines resistant to different pests were identified (Singh *et al.*, 1968; Pradhan, 1971; Jotwani, 1978; Sharma, 1985a,b; Taneja and Leuschner, 1985a,b). The resistant sources have been used in breeding programs to incorporate resistance into good agronomic backgrounds. At present, a number of reasonably high-yielding genotypes are under various stages of testing (Sharma *et al.*, 1992; Jotwani, 1982). Some of these are ICSV 197, ICSV 743, and ICSV 745 for midge; ICSV 705, ICSV 708, and M 35-1 for shoot fly, and ICSV 700, E 302, E 303, E 601, E 602, E 603, and E 604 for stem borer.

The All India Coordinated Millet Improvement Project (AICMIP) has been working on host-plant resistance to millet pests since sixties. Most of the resistance screening work has been done using natural infestations. A concerted effort has been made to screen the germplasm and breeding materials against shoot fly, stem borer, grey weevil, leaf roller, blister beetles, pyrilla, grosshopper, earhead bug, earhead caterpillar, armyworm and jassids (Pradhan, 1971; Jotwani, 1978; AICMIP, 1980-92). A number of resistant lines have been reported for white grubs (Pradhan, 1971), stem borer (Sandhu *et al.*, 1976, Kundu *et al.*, 1980, Kishore and Jotwani, 1980), shoot fly (Natarajan *et al.*, 1973, Appadurai *et al.*, 1981), grey weevil (Kishore and Jotwani, 1980), and pyrilla (Jotwani, 1978).

Chemical Control

Chemical control of sorghum pests in India began in the sixties with the introduction of hybrids, which were highly susceptible to all the major pests. Many chemicals have been tested against all the pests and some of them have been recommended for use on farmers' fields. Insecticides have mainly been recommended for the control of shoot fly, stem borer, midge, head bugs, head caterpillars and delphacids.

Shoot Fly. Shoot fly was the first insect on sorghum against which many insecticides have been tested. Three methods of chemical application have been used for shoot fly control; soil application of granules at sowing, seed treatment and foliar application. Soil application of systemic insecticides has been found effective, but it is not being used by farmers mainly because of the high costs involved. Seed treatment with insecticides has also been found effective against shoot fly, and this has reduced the cost of insecticide application. Shoot fly infestation is also reduced by using mixtures of treated and untreated seed. Various insecticides found effective against shoot fly since 1965 are given in Table 4 (Sandhu and Young, 1974; Singh and Jotwani, 1975; Kundu *et al.*, 1978; Thobbi *et al.*, 1979; Sukhani and Jotwani, 1980; Sadakathulla, 1981a; Mote, 1982). The two most effective chemicals, carbofuran and phorate, used today as soil application are the same as those used in the sixties. Cartap has recently been found to be effective as soil application against shoot fly (AICSIP 1985-91). Carbofuran, chlorpyriphos and monocrotophos continue to be effective for seed treatment. In addition, carbosulfan (FMC 35001), cartap, furathiocarb and posse have recently been recommended for seed treatment.

The foliar application of insecticides is not found very effective mainly because the eggs laid on the under surface of leaves (Vedamoorthy *et al.*, 1965; Chachoria, 1972). Recently, shoot fly has been successfully controlled by the foliar applica tion of cypermethrin applied either by 'Electrodyn' or as high-volume spray (Taneja and Pal, 1992; Taneja and Henry, 1992). First application should be made within a week after crop emer gence and be repeated a week later. Foliar application of endosulfan, quinalphos, cypermethrin, cartap, posse and triazophos have also been found to be effective (AICSIP, 1985-91).

Stem Borer. Since the mid-sixties, a number of insecticides have been found effective against stem borers (Srivastava and Jotwani, 1976; Kishore and Jotwani, 1977; Venugopal *et al.*, 1977a; Kundu and Kishore, 1980) (Table 4).

Table 4. Effective chemicals for insect control in sorghum in India, 1965-90

Insecticide	SF	SB	AW	SH	AP	MGHB	HC
Acephate	••						
Aldicarb	••	••					
Bendiocarb	••						
BHC/Lindane	••	••	••	••		••••	••
Carbaryl	••	••	••	••		••••	••
Carbosulfan	••						
Carbofuran	••	••					
Cartap	••	••					
Chlorfenvinphos	••	••					
Chlorpyriphos	••	••					
Cypermethrin	••	••				••••	••
Cyfloxylate	••	••				••••	••
Decamethrin	••	••				••••	
DDT		••	••				
Diazinon	••	••				••••	
Dichlorvos						••	••
Dimethoate	••	••	••	••	••	••	••
Disulfoton	••	••				••	
Endosulfan	••	••			••	••••	••
Endrin	••	••	••				
Fenvalerate	••	••					
Formothion	••				••		
Malathion	••	••	••			••••	
Mephosfolan	••	••					
Methyl demeton	••				••	••	
Monocrotophos	••	••				••	••
Parathion	••	••					
Permethrin		••				••••	••
Phenthoate		••					
Phorate	••	••					
Phosalone	••					••••	
Posse	••						
Quinalphos	••	••			••	••	••
Tetrachlorfenvinphos					••		
Thiometon	••						
Triazophos	••						

SF = Shoot fly; SB = Stem borer; AW = Armyworm; SH = Shoot bug; AP = Aphids; MG: Midge; HB = Head bug; HC = Head caterpillar

However, whorl application of carbofuran and cartap, foliar application of endosulfan, cyperme thrin, permethrin, cyfloxylate and cartap; and dusting with BHC and fenvalerate have been recommended. Whorl application of granules is very effective against *C. partellus*, where the early instar larvae feed in the whorls for 1-2 weeks, before boring into the stem. Effective borer control was achieved with two applications at an interval of 10-15 days, the first application being made 25-30 days after crop emergence.

Sorghum Midge and Head Bugs. During the early seventies, many insecticides were reported to be effective against sorghum midge (Venugopal *et al.*, 1977b, Mogal *et al.*, 1980; Sadakathulla, 1981b; Bhanot *et al.*, 1982) and head bugs (Sunderaju *et al.*, 1977; Kulkarni and Parmeshwarappa, 1978; Subba Rao *et al.*, 1980; Table 4). At present, the commonly used insecticides are BHC, carbaryl, endosulfan, malathion and quinalphos. In the early eighties, synthetic pyrethroids (permethrin, fenvalerate, decamethrin and cypermethrin) were also found to be effective against these pests (AICSIP, 1980-91).

Millet Pests. Very little emphasis has been placed on developing chemical control schedules for millet pests because of low pest severity, low cost/benefit ratios and subsistence production. Three types of insecticide formulations (granules, dusts and sprays) have been tested (Table 5).

Table 5. Effective chemicals for millet insect pest control in India

	Insect pests									
Insecticide	WG	SF	SB	RB	GW	HC	SH	PR	BB	CB
Granules										
Aldicarb		**								
Aprocarb		**								
Carbofuran		**								
Disulfoton		**								
Phorate	**	**								
Quinalphos	**	**								
Dusts										
BHC	**	**	**	**			**		**	
Carbaryl					**	**		**		
Endosulfan						**				
Fenitrothion									**	
Fenvalerate		**	**		**	**				
Malathion			**	**		**	**			
Methyl parathion					**	**				
Parathion						[illegible]			**	
Quinalphos			**	**		**	**			
Sprays										
Carbaryl							**	**	**	
Demeton methyl	**	**								
Demeton-s-methyle	**									
Dicrotophos						**				
Dimethoate								**		
Endosulfan			**	**			**		**	
Fenitrothion						**		**		
Malathion							**	**		
Mevinphos						**				
Monocrotophos						**				
Neem oil			**	**						
Repelin			**	**						

WG = White grub; SF = Shoot fly; SB = Stem borer; RB = Root bug; GW = Grey weevil; HC = Headcaterpillar; SH = Shoot bug; PR = *Pyrilla*; BB = Blister beetle; CB = Chafer beetle

Maximum numbers of insecticides have been tested against shoot fly followed by head cater ar, stem borer and grey weevil. Dust formulations are more effective than the granules or sprays. The insecticide most effective against several pests was BHC dust followed carbaryl (dust and spray), fenvalerate, malathion, quinalphos (dust) and endosulfan (spray). In experiments with white grub management, insecticides have been used in two ways: (1) incorporation of farm yard manure (FYM) and insecticide (BHC or aldrin dust) mixture (3:2) into the soil, and (2) keeping FYM and insecticide mixture (1.8 kg FYM + 1.2 kg insecticide) in heaps distributed in the field. Different chemicals used were; BHC, aldrin, malathion, quinalphos, endosulfan and heptachlor as dusts; and phorate, quinalphos and isofenphos as granules. These techniques have significantly reduced the white grub infestation in millets.

ECONOMIC INJURY LEVELS

In an integrated pest management package, insecticides should be applied based on the economic injury levels (EIL). In sorghum, the EIL's for the major pests have been worked out, though they may change with the type of cultivar, place, season, or economic value of the crop. For shoot fly, Rai *et al.* (1978) reported an EIL of 3.8-9.6%, 3.4-8.5%, and 5.9-15.0% infestation in CSH 1, CSH 5, and Swarna, respectively. Two to three flies per flowering panicle constitute the EIL for midge (Karanjkar and Chandurwar, 1981; AICSIP, 1988-89). For earhead bug, Sharma and Lopez (1989) reported an EIL of 1.3-1.4 bugs per panicle for CSH 1; 0.4 bugs for ICSV 1; and 0.2-0.6 bugs for CSH 5. In the case of stem borers, precise EIL has not been worked out because of the complexity of infestation and its effects on grain and fodder yields. It has been established that early infestation (when the crop is 2-3 weeks old) results in deadheart formation and significantly reduces the grain yield. Application of insecticides between 15 and 30 days after crop emergence results in effective protection and significant yield increase (Taneja and Nwanze, 1989).

FUTURE RESEARCH NEEDS

Survey and surveillance efforts should be intensified on a regular basis over large areas to assess the pest situation with changes in cropping systems, adoption of high-yielding cultivars, and use of higher inputs. Efforts should be made to integrate various control options into IPM packages to suit the subsistence and resource-poor farmers. Pest control programmes should be based on economic thresholds using reliable pest-monitoring techniques. Based on the population dynamics of various pests, sowing dates or insecticide applications can be adjusted to keep pests below economic injury levels.

Cultural control, biological control, host-plant resistance and chemical control should be integrated in an effective manner. Cultural controls such as sowing date, seed rate, fertilizer application, weeding, etc. should form major components of pest management. Similarly, cropping systems and cultivars that encourage natural enemies should be identified and fitted into pest control programmes. Use of pest-resistant cultivars should form a backbone of future pest management systems. Efforts should be made to develop, release, and popularise resistant cultivars in pest endemic areas. Chemical control should be used as a last resort; it should be need based and be used very judiciously. Insecticide effectiveness and selectivity should be looked into in addition to the dose and method of application.

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