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Strategies for pest control in sorghum in India

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Abstract. Host-plant resistance in conjunction with natural enemies and cultural practices should form the backbone of future pest control programmes. Sources of resistance to *Atherigona soccata* Rond., *Chilo partellus* Swin. and *Contarinia sorghicola* Coq. have been identified. Efforts should be made to incorporate resistance into plants with good agronomic background and to strengthen the level of resistance. Resistance to pests and grain yield should be given equal consideration in the development and release of new cultivars. Cultivars with loose panicles may be developed for areas endemic to head bugs and head caterpillars. Pest avoidance through timely planting as decided by pest-population dynamics and rainfall patterns, balanced fertilizer application, clean cultivation, and proper crop combinations should be popularized among the farmers to reduce crop losses. Readily available and inexpensive insecticides may be used as and when necessary based on economic thresholds.

Introduction

Sorghum is the third most important cereal crop in India after rice and wheat. Grain yields on peasant farms are generally low (500–800 kg/ha) mainly because of insect pest damage. Nearly 12% of the actual crop produce is lost because of insect pests (NCEAR, 1967), and earhead pests alone cause a minimum annual crop loss valued at Rs.972 million (Leuschner and Sharma, 1983).

Nearly 150 insect species have been reported as pests on sorghum (Reddy and Davies, 1979; Jotwani *et al.*, 1980) of which 31 are of potential economic importance (Table 1). Shoot fly, *Atherigona soccata* Rond., stem borer, *Chilo partellus Swin.*, armyworm, *Mythimna separata* Wlk., midge, *Contarinia sorghicola* Coq., headbug, *Calocoris angustatus* Leth., and head caterpillars, *Heliothis armigera* Hb., *Eublema* spp. and *Cryptoblabes* spp., can be considered the major pests in India. This paper summarizes current knowledge on various pest control components and formulates a future strategy for pest control in sorghum in India.

Current pest control recommendations and their use in farmer's fields

Most farmers consider pest control unnecessary until the damage becomes visible and threatens to reduce crop yields substantially. A number of pest control recommendations involving cultural practices, insecticides, and in some cases resistant varieties have been developed. Our experience shows that farmers pay little attention to pest control on sorghum and many other crops in the semi-arid regions. The farmers' pest control operations rarely go beyond adopting various cultural practices, growing less susceptible traditional cultivars, and occasionally dusting or spraying with readily-available cheap insecticides. The main factors that seem to restrict the adoption of effective pest control measures are low cost-benefit ratios, non-availability of inputs such as fertilizers and pesticides, and ignorance of the potential benefits of pest control.

In traditional farming systems, farmers may adopt such pest management practices as optimum sowing dates, high seeding rate, weeding, interculture, mixed cropping, and crop rotations. However, they are unlikely to adopt modern pest control practices until production levels justify the extra input involved.

Pest control components in the sorghum agro-ecosystems

Cultural practices

A number of crop husbandry practices which directly or indirectly help reduce pest damage have become an integral component of farming systems. The need for ecologically sound, effective, and economic methods for pest control has prompted renewed interest in cultural methods. The merit of many of these traditional farm practices has been confirmed by learning why farmers do what they do, but some practices still remain to be thoroughly investigated and understood. Cultural practices to suppress pest populations are best suited for sorghum growing regions because: (1) they have become an integral component of crop-husbandry practices; (2) they involve no additional costs and (3) they do not disturb natural enemies of the pests concerned.

Tillage. Ploughing after harvest and before planting reduces the numbers and carryover of such insects as white grubs, *Holotrichia* sp., grasshoppers, *Hieroglyphus banian* Fab., *H. nigrorepletus* Bol., *Colemania sphenerioides* Bol., hairy caterpillar, *Amsacta moorei* Butl., and stem borer, *C. partellus* Swin., by exposing them to parasites, predators, and such adverse weather factors as high temperatures and low relative humidity (Gahukar and Jotwani, 1980).

Fertilizer and nutrient balance. The extent and nature of fertilizer application influences the susceptibility of the crop to insects. During the 1983 rainy season, unfertilized plots of CSH 1 at ICRISAT Center suffered heavy shoot fly damage compared with fertilized plots. Nitrogenous fertilizers are reported to decrease *A. soccata* Rond. incidence in sorghum (Reddy and Narashimarao, 1975; Chand *et al.*, 1979) possibly by increasing plant vigour. However, Kundu

Table 1. Insect and mite pests of sorghum

Common name	Scientific name		Nature of damage	Pest status
SOIL PESTS				
White grub	*Anomala polita* Blanch.	(Coleoptera: Melonthidae)	Feed on roots	Minor
White grub	*Holotrichia consanguinea* Blanch.	(Coleoptera: Melonthidae)	Feed on roots	Minor
False wireworm	*Gonocephalum dorsogranosum* Frm.	(Coleoptera: Tenebrionidae)	Feed on germinating seeds, seedlings and roots	Minor
False wireworm	*Gonocephalum vagum* Stev.	(Coleoptera: Tenebrionidae)	Feed on germinating seeds, seedlings, and roots	Minor
SEEDLING PESTS				
Flea beetle	*Chaetocnema* sp.	(Coleoptera: Curculionidae)	Feed on leaves	Minor
Flea beetle	*Phyllotreta chotanica* Duv.	(Coleoptera: Curculionidae)	Feed on leaves	Minor
Shoot fly	*Atherigona soccata* Rond.	(Muscidae: Diptera)	Feed on the growing point and produce a deadheart	Major
Pink stem borer	*Sesamia inferens* Walk.	(Noctuidae: Lepidoptera)	Larvae feed on leaves and stem producing shot holes, deadheart, and later stem-tunnelling	Major More serious on the post-rainy season crop
Spotted stem borer	*Chilo partellus* Swin.	(Pyralidae: Lepidoptera)	Larvae feed on leaves and stem producing shot holes, deadheart and later stem-tunnelling	Major More serious on fodder sorghum in North India and occasionally on the main crop in South India
FOLIAGE PESTS				
Grey weevil	*Myllocerus* spp.	(Curculionidae: Coleoptera)	Feed on leaves	Minor
Maize aphid	*Rhopalosiphum maidis* Fitch.	(Aphididae: Hemiptera)	Sucks sap from the whorl leaves and the earhead	Minor. Occasionally serious
Shoot bug	*Peregrinus maidis* Ashm.	(Delphacidae: Hemiptera)	Sucks sap from the whorl leaves and the earhead	Minor. Becomes serious during dry periods, and particularly so on the rabi crop
Red hairy caterpillar	*Amsacta moorei* Butl.	(Arctiidae: Lepidoptera)	Feed on leaves	Minor
Armyworm	*Mythimna separata* Walk.	(Noctuidae: Lepidoptera)	Feed on leaves	Major
Leaf folder	*Marasmia suspicalis* Wlk.	(Pyralidae: Lepidoptera)	Fold the leaves and feed inside on the green matter	Minor. Occasionally becomes serious
Leaf folder	*Marasmia trapezalis* Gue.	(Pyralidae: Lepidoptera)	Fold the leaves and feed inside on the green matter	Minor. Occasionally becomes serious
Deccan wingless grasshopper	*Colemania sphenerioides* Bal.	(Acridiidae: Orthoptera)	Feed on leaves and the milky grain	Minor
Paddy grasshopper	*Hieroglyphys banian* Fab.	(Acridiidae: Orthoptera)	Feed on leaves and the milky grain	Minor
Paddy grasshopper	*Hieroglyphus nigrorepletus* Bol.	(Acridiidae: Orthoptera)	Feed on leaves and the milky grain	Minor
Mite	*Oligonychus indicus* Hirst.	(Acarina: Tetranychidae)	Sucks sap from the leaves	Minor. Becomes serious during dry periods assuming the status of a regular pest
EARHEAD PESTS				
Blister beetle	*Cylindrothorax tenuicollis* Pall.	(Coleoptera: Meloidae)	Feed on inflorescens	Minor
Blister beetle	*Mylabris pustulata* Thunb.	(Coleoptera: Meloidae)	Feed on inflorescens	Minor
Midge fly	*Contarinia sorghicola* Coq.	(Cecidomyiidae: Diptera)	Feed on the developing ovary	Major
Headbug	*Calocoris angustatus* Leth.	(Miridae: Hemiptera)	Sucks sap from the developing grain	Major
Painted bug	*Bagrada cruciferarum* Kirk.	(Pentatomidae: Hemiptera)	Sucks sap	Minor. Occasionally becomes serious
Red cotton bug	*Dysdercus koenigi* Fab.	(Pyrrhocoridae: Hemiptera)	Sucks sap	Minor. Occasionally becomes serious
Head caterpillar	*Celama analis* W. and W.	(Noctuidae: Lepidoptera)	Feed on developing grain	Minor. Occasionally becomes serious
Head caterpillar	*Eublema silicula* Swin.	(Noctuidae: Lepidoptera)	Feed on developing grain	Minor. Occasionally becomes serious
Head caterpillar	*Heliothis armigera* Swin.	(Noctuidae: Lepidoptera)	Feed on developing grain	Major. Becoming serious on compact headed genotypes
Head caterpillar	*Cryptoblabes gnidiella* Mill.	(Pyralidae: Lepidoptera)	Feed on developing grain	Minor
Thrips	*Haplothrips ganglebaueri* Sch.	(Thripidae: Thysanoptera)	Feed on developing grain	Minor

et al. (1978) observed no effect of nitrogenous fertilizers on shoot fly damage. Channabasavanna *et al.* (1969) reported a decrease in shoot fly damage after the application of phosphatic fertilizers, but Venugopal *et al.* (1977a) and Rajashekhara *et al.* (1973) found no such evidence. Nitrogenous fertilizers also decrease *C. partellus* damage (Lakshminarayana and Subba Rao, 1975). These differences in fertilizer response may be due to genotypic variation. Shoot fly damage is also affected by the influence of herbicides on plant growth (L. R. House, 1984, personal communication).

Soil moisture. Soil moisture influences crop damage through its effect on plant vigour and growth. Plants growing under drought stress suffer higher damage from *A. soccata, C. partellus* and *P. maidis* Ashm. In rainfed agriculture, however, there is little scope for manipulating soil moisture content except by moisture-conserving practices and irrigation.

Time of sowing. Sowing time considerably influences the extent of insect damage. Normally, farmers plant sorghum with the first good monsoon showers. Synchronous sowing of cultivars in similar maturity groups over large areas in a short span of time helps reduce yield losses caused by shoot fly (Jotwani *et al.*, 1970; Thimmaiah *et al.*, 1973b; Ramnath *et al.*, 1974), midge (Hardas *et al.*, 1972; Jotwani *et al.*, 1972b), and head bug (Thimmaiah *et al.*, 1972). In Tamil Nadu there is an old adage among farmers "Inform your neighbour before you plant sorghum lest his crop be destroyed by shoot fly and headbugs".

Plant density. The traditional practice of using a high seeding rate helps to maintain optimum plant stands and reduce *A. soccata* damage (Gahukar and Jotwani, 1980). During the 1981–82 post-rainy season at ICRISAT Center, plots of CSH 5 thinned 30 days after emergence, suffered less shoot fly infestation than plots thinned 10 days after emergence. Shoot fly damage is higher when plant populations are low (Davies and Reddy, 1981).

Interculture. During interculture, the pupae of *A. soccata* and *M. separata*, and larvae of *Holotrichia* sp., *Gonocephalum* spp., *M. separata* etc., are exposed to parasites, predators, and other adverse environmental factors.

Weeding. Timely weeding helps reduce damage from some insects. Many common weeds act as hosts for oviposition, provide better ecological niches, and places for insects to hide, thus shielding them from natural enemies and insecticide sprays. Crops that are free from weeds suffer lower armyworm damage than weed-infested crops (Sharma *et al.*, 1982).

Field sanitation. Collecting and burning stubble and chaffy earheads reduces the carryover of *C. partellus* and *C. sorghicola*. Stalks from the previous season should be fed to cattle or burnt before the onset of monsoon rains to reduce the carryover of stem borer (Gahukar and Jotwani, 1980).

Fallowing and close season. Fallowing reduces the carryover and build up of pest populations from one season to the next. Strict observance of a closed season during summer can possibly reduce the carryover of *A. soccata* and *C. angustatus*.

Crop rotation. Crop rotation is another means of reducing pest infestation. It breaks the continuity of the food chain of oligophagus pests. Sorghum is generally rotated with cotton, groundnut or sugarcane. This may halt any increase in the populations of *A. soccata, C. sorghicola* and *C. angustatus*.

Cropping systems. A carefully-selected cropping system (intercropping or mixed cropping) can help reduce pest incidence or minimize the risks involved in monocultures. Sorghum is generally intercropped with pigeonpea, cotton, cowpea, safflower or other pulses. *Atherigona soccata* and *C. sorghicola* damage is reduced when sorghum is intercropped with leguminous crops (Hardas *et al.*, 1980).

Biological control

In sorghum, the scope for total biological control appears limited because the cropping period is short and there is no crop continuity to sustain the natural enemies and their hosts. Natural enemies of important pests of sorghum are listed in Table 2. Future attention should focus on: identifying natural enemies and studying their activity periods, efficiency, and usefulness, and studying farming systems, crop combinations, and crop cultivars that encourage the activity of natural enemies.

Host-plant resistance

The best plant protection for the future should be one based on host-plant resistance (Frankel and Bennet, 1970). This method is particularly relevant to subsistence farming systems of the semi-arid tropics. Breeding for pest resistance has received little attention in the past, but now the importance of breeding not only for yield, but for quality, adaptability, and pest resistance is being increasingly recognized. According to Blum (1972) plant breeders, in general, appear to lack an understanding of insects and their hosts and tend to regard the insect populations as a fixed environmental parameter, with all the consequent implications. The release of superior but otherwise susceptible crop varieties in the tropics will not achieve real yield potential (Pradhan, 1973). However, cultivars that help increase crop yields (e.g. CSH 1) but change the pest complex should be watched carefully and the newer pest problems countered effectively until cultivars with adequate levels of resistance are developed (L. R. House, 1984, personal communication).

Plant resistance as a method of pest control offers many advantages in sorghum growing regions; for some insect species it is the only way of effective pest control. The most attractive feature of using resistant cultivars is that virtually no skill in pest control application techniques or cash investment is involved. But resistant cultivars are not a panacea for all pest problems (Painter, 1951). They are

Table 2. Natural enemies recorded on some important insect pests of sorghum

Scientific name		Stage attacked	Reference
A. *Atherigona soccata* Rond.			
Abrolophus sp.	(Erythracidae: Prostigmata)	Preys on larvae	Reddy and Davies (1979)
Aprostocetus sp.	(Eulophidae: Hymenoptera)	Larval parasite	Pradhan (1971), Kundu *et al.* (1971a), Kishore *et al.* (1976, 1977b), Jotwani (1978)
Callitula bipartitus Frq.	(Pteromalidae: Hymenoptera)	Larval parasite	Kundu *et al.* (1971b)
Callitula sp.	(Pteromalidae: Hymenoptera)	Larval parasite	Pradhan (1971), Kishore *et al.* (1977b) Jotwani (1978)
Crataepiella sp.	(Eulophidae: Hymenoptera)	Pupal parasite	Feddy and Davies (1979)
Diaulinopsis sp.	(Eulophidae: Hymenoptera)	Larval parasite	Kishore *et al.* (1977b), Jotwani (1978)
Ganaspis sp.	(Eucoilididae: Hymenoptera)	Larval parasite	Kishore *et al.* (1977b), Shivpuje (1977), Jotwani (1978)
Hemiptarsensus sp.	(Eulophidae: Hymenoptera)	Larval parasite	Kishore *et al.* (1977b), Jotwani (1978)
Monelta sp.	(Diapriidae: Diptera)	Larval parasite	Taley and Thakare (1979), Taley (1978)
Odonteucoila sp.		Larval parasite	Shivpuje (1977)
Psilus sp.	(Diapriidae: Diptera)	Larval parasite	Kishore *et al.* (1977b)
Rhoptromeris sp.	(Cynipidae: Hymenoptera)	Larval parasite	Taley and Thakare (1979), Taley (1978)
Spalangia indicus Walk.	(Pteromalidae: Hymenoptera)	Larval parasite	Taley and Thakare (1979), Taley (1978)
Tetrastichus nyemitawus Roh.	(Eulophidae: Hymenoptera)	Larval parasite	Reddy and Davies (1979), Taley (1978)
Tetrastichus sp.	(Eulophidae: Hymenoptera)	Larval parasite	Raodeo *et al.* (1972) Kishore *et al.* (1976)
Trichogramma australicum Gir.	(Trichogrammatidae: Hymenoptera)	Egg parasite	Taley (1978)
Trichogramma japonicum Ashm.	(Trichogrammatidae: Hymenoptera)	Egg parasite	Anonymous (1981)
Trichogrammatoidea sp.	(Trichogrammatidae: Hymenoptera)	Egg parasite	Anonymous (1981)
Trichopria sp.	(Diapriidae: Diptera)	Larval parasite	Taley and Thakare (1979), Taley (1978)
B. *Chilo partellus* Swinhoe			
Adoxomyia heminopla Wiedemann	(Stratiomyidae: Diptera)	Larval parasite	Anonymous (1981)
Apanteles flavipes Cameron	(Braconidae: Hymenoptera)	Larval parasite	Pradhan (1971)
Apanteles sp.	(Braconidae: Hymenoptera)	Larval parasite	Roome and Padhgam (1977)
Bracon chinensis Szepl.	(Braconidae: Hymenoptera)	Larval parasite	Pradhan (1971), Reddy and Davies (1979)
Brumoides suturalis F.	(Coccinellidae: Coleoptera)	Preys upon larvae	Sandhu (1977)
Carcelia sp.	(Tachinidae: Diptera)	Larval/ex-larval parasite	Anon (1981)
Ceraphron jijiensis Ferr.	(Ceraphronidae: Hymenoptera)	Larval parasite	Pradhan (1971)
Chelonus sp.	(Braconidae: Hymenoptera)	Larval parasite	Anonymous (1981)
Chlaenius hamifer Chaud.	(Carabidae: Coleoptera)	Preys on larvae	Sandhu (1977)
Coccinella septempureteta Linn.	(Coccinellidae: Coleoptera)	Preys on larvae	Sandhu (1977)
Coccinella undecimpunctata Linn.	(Coccinellidae: Coleoptera)	Preys on larvae	Jotwani *et al.* (1972a)
Enicospilus sp.	(Ichneumonidae: Hymenoptera)	Larval parasite	Anonymous (1981)
Eurytoma sp.	(Eurytomidae: Hymenoptera)	Attacks larvae	Pradhan (1971)
Glyptomorpha deesae Cameron	(Braconidae: Hymenoptera)	Pupal parasite	Reddy and Davies (1979)
Halidaya luteicornis Walk.	(Tachinidae: Diptera)	Larval parasite	Reddy and Davies (1979)
Hyperchalcidia scudanensis Steffan	(Chalcididae: Hymenoptera)	Pupal parasite	Reddy and Davies (1979)
Invreia sp.	(Chalcididae: Hymenoptera)	Pupal parasite	Reddy and Davies (1979)
Menochilus sexmaculata Fab.	(Coccinellidae: Coleoptera)	Preys on larvae	Jotwani and Verma (1969), Sandhu (1977)
Microplitis sp.	(Braconidae: Hymenoptera)	Larval parasite	Anonymous (1981)
Palexorista sp.	(Tachinidae: Diptera)	Larval parasite	Anonymous (1981)
Pseudalsomyia sp	(Tachinidae: Diptera)	Larval/pupal parasite	Reddy and Davies (1979)
Schizophora sp.		Attacks larvae	Pradhan (1971)

Table 2 (continued)

Scientific name		Stage attacked	Reference
Stenobracon dessae Cam.	(Braconidae: Hymenoptera)	Attacks larvae	Pradhan (1971)
Sturmiopsis inferens Tns.	(Tachinidae: Diptera)	Larval parasite	Reddy and Davies (1979)
Telenomus Sp.	(Scelionidae: Hymenoptera)	Egg parasite	Roome and Padhgam (1977)
Tetrastichus ayyari Rohwer	(Eulophidae: Hymenoptera)	Pupal parasite	Reddy and Davies (1979)
Trathala flavoorbitalis Cam.	(Ichneumonidae: Hymenoptera)	Larval parasite	Reddy and Davies (1979)
Trichogramma chilonis Ishii	(Trichogrammatidae: Hymenoptera)	Egg parasite	Anonymous (1981)
Triohogramma sp.	(Trichogrammatidae: Hymenoptera)	Egg parasite	Roome and Padhgam (1977)
Xanthopimpla stemmator	(Ichneumonidae: Hymenoptera)	Pupal parasite	Pradhan (1971), Reddy and Davies (1979)
C. *Marasmia suspicalis* Walk.			
Chlaenius bioculatus Chd.	(Carabidae: Coleoptera)	Preys on larvae	Reddy and Davies (1979)
Goniozus Sp.	(Bethylidae: Hymenoptera)	Larval parasite	Anonymous (1981)
Elasmus previcornis Gahan.	(Elasmidae: Hymenoptera)	Larval parasite	Anonymous (1981)
D. *Mythimna separata* Walk.			
Apanteles ruficrus Haliday	(Braconidae: Hymenoptera)	Larval parasite	Pradhan (1971), Sharma *et al.* (1982)
Carcella (teneral specimen) sp.	(Tachinidae: Diptera)	Ex-larval parasite	Sharma *et al.* (1982)
Carcelia (senometopia) sp.	(Tachinidae: Diptera)	Ex-larval parasite	Sharma *et al.* (1982)
Disophrys albopiloseflus Cameron	(Braconidae: Hymenoptera)	Larval parasite	Anonymous (1981)
Exorista xanthaspis Wiedemann	(Tachinidae: Diptera)	Larval/ex-larval parasite	Sharma *et al.* (1982)
Metopius rufus Cameron	(lohneumonidae: Hymenoptera)	Larval parasite	Reddy and Davies (1979)
Metopius sp.	(Ichneumonidae: Hymenoptera)	Larval/ex-larval parasite	Sharma *et al.* (1982)
Palexorista solennis Walker	(Tachinidae: Diptera)	Larval parasite	Sharma *et al.* (1982)
Palexorista spp.	(Tachinidae: Diptera)	Larval parasite	Sharma *et al.* (1982)
Rogas sp.	(Braconidae: Hymenoptera)	Larval parasite	Anonymous (1982)
E. *Olygonychus indicus* Hirst			
Scolothrips indicus Priesn.	(Thripidae: Thysanoptera)	Preys on nymphs and adults	Reddy and Jagadish (1977)
Stethorus pauperculus Wse.	(Coccinellidae: Coleoptera)	Preys on nymphs and adults	Reddy and Davies (1979)
F. *Pelopidas mathias* F.			
Apanteles (*glomeratus* group)	(Braconidae: Hymenoptera)	Larval Parasite	Reddy and Davies (1979)
Brachymeria sp. (Euploeae West wood)	(Chalcididae: Hymenoptera)	Pupal parasite	Reddy and Davies (1979)
Thecocarcelia sp.	(Tachinidae: Diptera)	Pupal parasite	Reddy and Davies (1979)
G *Psalis pennatula* F.			
Apanteles sp. (glomeratus group)	(Braconidae: Hymenoptera	Larval parasite	Anonymous (1982)
Carcelia sp.	(Tachinidae: Diptera)	Larval parasite	Reddy and Davies (1979)
Enicospilus erythrocerus Cameron	(Ichneumonidae: Hymenoptera)	Larval parasite	Reddy and Davies (1979)
H. *Rhopalosiphum maidis* Fitch.			
Aphidencyrtus aphidovorus Mayr.	(Encyrtidae: Hymenoptera)	Attacks nymphs and adults	Radke and Barwad (1978)
Brumoides suturalis Fab.	(Coccinellidae: Coleoptera)	Preys on nymphs and adults	Reddy and Davies (1979)
Chrysopa sp.	(Chrysopidae: Neuroptera)	Preys on nymphs and adults	Reddy and Davies (1979)
Geocoris sp.	(Lygaeidae: Hemiptera)	Preys on nymphs and adults	Reddy and Davies (1979)
Illeis indica Timb.	(Coccinellidae: Coleoptera)	Preys on nymphs and adults	Reddy and Davies (1979)
Menochilus sexmaculatus Fab.	(Coccinellidae: Coleoptera)	Preys on nymphs and adults	Reddy and Davies (1979)
Xanthogramma scutellaris Fab.	(Syrphidae: Diptera)	Preys on nymphs and adults	Reddy and Davies (1979)

Table 2 (continued)

Scientific name		Stage attacked	Reference
I. *Spodoptera exigua* Hb.			
Carcelia illota Curran	(Tachinidae: Diptera)	Larval parasite	Anonymous (1981)
Disophrys sp.	(Braconidae: Hymenoptera)	Larval parasite	Anonymous (1981)
Metopius sp.	(Ichneumonidae: Hymenoptera)	Larval parasite	Anonymous (1981)
Microchelonus eurvimaculatus Cameron	(Braconidae: Hymenoptera)	Egg parasite	Anonymous (1981)
Peribaea orbata Wied.	(Tachinidae: Diptera)	Larval parasite	Anonymous (1981)
Sturmiopsis inferens Tns.	(Tachinidae: Diptera)	Larval parasite	Anonymous (1981)
J. *Contarinia sorghicola* Coq.			
Apanteles sp.	(Braconidae: Hymenoptera)	Larval parasite	Reddy and Davies (1979)
Aprostocetus sp.	(Eulophidae: Hymenoptera)	Larval parasite	Jotwani (1978)
Daryhelea sp.	(Ceratopogonidae: Diptera)	Predator	Reddy and Davies (1978)
Eupelmus popa Gir.	(Eupelmidae: Hymenoptera)	Larval parasite	Gowda and Thontadaraya (1977) Thontadaraya *et al.* (1981)
Orius maxidentex Ghauri	(Anthocoridae: Hemiptera)	Predator on adults	Thontadaraya *et al.* (1981)
Scymnus nubilus Muls.	(Coccinellidae: Coleoptera)	Predator on adults	Thontadaraya *et al.* (1981)
Tapinoma indicum Forel.	(Formicidae: Hymenoptera)	Predator on adults	Taley and Garg (1976)
Tetrastichus coimbatorensis	(Eulophidae: Hymenoptera)	Larval parasite	
Tetrastichus diplosidis Crawt.	(Eulophidae: Hymenoptera)	Larval parasite	Thontadaraya *et al.* (1981)
Tetrastichus sp.	(Eulophidae: Hymenoptera)	Larval parasite	Garg and Taley (1977a), Gowda and Thontadaraya (1977)
K. *Calocoris angustatus* Leth.			
Componotus compresses Linn.	(Formicidae: Hymenoptera)	Predator	Hiremath (1983)
Componotus Paria Emery	(Formicidae: Hymenoptera)	Predator	Hiremath (1983)
Cephalosporium sp. (Fungus)	(Moniliaceae: Moniliales)	Parasitic fungus	Hiremath (1983)
Rhinocoris fuscipes Fab.	(Reduviidae: Hemiptera)	Predator	Hiromath (1983)
Nematode		Parasite	Sharma (unpublished)

Table 2 (continued)

Scientific name		Stage attacked	Reference
L. *Heliothis armigera* Hb.			
Apanteles sp.	(Braconidae: Hymenoptera)	Larval parasite	Anonymous (1981)
Campoletis chloridae Uchida	(Ichneumonidae: Hymenoptera)	Larval parasite	Anonymous (1981)
Disophrys sp.	(Braconidae: Hymenoptera)	Larval parasite	Anonymous (1981)
Carcelia illota Curran	(Tachinidae: Diptera)	Larval parasite	Anonymous (1981)
Eriborus argenteopilosus Cameron	(Tachinidae: Diptera)	Larval parasite	Anonymous (1981)
Eriborus toichanteratus Morley	(Tachinidae: Diptera)	Larval parasite	Anonymous (1981)
Exorista xanthaspis Wied.	(Taohinidae: Diptera)	Larval parasite	Anonymous (1981)
Delta companiforme F.	(Eumenidae: Hymenoptera)	Preys on larvae	Anonymous (1981), Pawar *et al.* (1984)
Delta conoideus G.	(Eumenidae: Hymenoptera)	Preys on larvae	Anonymous (1981), Pawar *et al.* (1984)
Goniophthalmus halli Mes.	(Tachinidae: Diptera)	Larval parasite	Anonymous (1981), Pawar *et al.* (1984)
Menochilus sexmaculatus F.	(Coccinellidae: Coleoptera)	Preys on larvae	Anonymous (1981), Pawar *et al.* (1984)
Microchelonus curvimaculatus Cameron.	(Braconidae: Hymenoptera)	Larval parasite	Anonymous (1981), Pawar *et al.* (1984)
Overmis albicans Sieb.		Larval parasite	Anonymous (1981), Pawar *et al.* (1984)
Palexorista laxa Curran	(Tachinidae: Diptera)	Larval parasite	Anonymous (1981), Pawar *et al.* (1984)
Palexorista solennis Walk.	(Tachinidae: Diptera)	Larval parasite	Anonymous (1981), Pawar *et al.* (1984)
Paromius gracilis Rambur	(Lygaeidae: Hemiptera)	Preys on larvae	Anonymous (1981), Pawar *et al.* (1984)
Sturmiopsis inferens Tns.	(Tachinidae: Diptera)	Larval parasite	Anonymous (1981), Pawar *et al.* (1984)
Temelucha sp.	(Ichneumonidae: Hymenoptera)	Larval parasite	Anonymous (1981), Pawar *et al.* (1984)
Trichogramma chiloris Ishii.	(Trichagrammatidae: Hymenoptera)	Egg parasite	Anonymous (1981), Pawar *et al.* (1984)
Trichogrammatoidea bactrae sp. *fumata* Nag.	(Trichogrammatidae: Hymonoptera)	Egg parasite	Anonymous (1981), Pawar *et al.* (1984)
Tropiconabis capsiformis Germar	(Nabidae: Hemiptera)	Preys on larvae	Anonymous (1981), Pawar *et al.* (984)
M. *Eublemma silicula* Swin.			
Apanteles sp.	(Braconidae: Hymenoptera)	Larval parasite	Anonymous (1981)
Phanerotoma hendecasisella Cameron	(Braconidae: Hymenoptera)	Larval parasite	Anonymous (1981)

* Reported as pest of wheat in Haryana (Singh, 1976).

most effective when carefully fitted into systems designed to control specific pests.

Sources of resistance. The search for pest-resistant sorghums began in the mid-1960s. Over the last 20 years, a number of germplasm lines resistant to important insect pests have been identified (Table 3). Reasonable levels of resistance to shoot fly, stem borer and midge have been reported. Many of these are currently being utilized in the All India Co-ordinated Sorghum Improvement Project (AICSIP) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to develop crop varieties with acceptable levels of yield and resistance. The search for resistance against headbugs and head caterpillars has been limited, and so far no sources of resistance have been identified. The loose panicled sorghums, which have long been suspected to be less susceptible to headbugs and head caterpillars, can be completely devoured when they flower during peak infestation periods of these insects. However, they do allow easier access to parasites and predators that may lower insect numbers under normal circumstances.

Host-plant resistance in integrated pest control. Host-plant resistance can be used as a principal component of pest control, an adjunct to cultural, biological, and chemical control and as a check against the release of susceptible cultivars.

Principal control method. Plant resistance to insects was used as the principal control method before the advent of insecticides. In sorghum, this still seems to be the most practical method of keeping pest populations at low levels. A sorghum cultivar, DJ 6514, has been released for cultivation in midge-endemic areas of Karnataka State for the control of sorghum midge, while M 35-1, which is less susceptible to shoot fly, is widely cultivated in the post-rainy season. Resistant cultivers need to be developed for specific pests, areas and regions. Cultivars with adequate levels of resistance can be developed for shoot fly, stem borer, and midge.

The impact of resistant cultivars on insect population levels can be explained using the simple models of Knipling (1964). The possible effect of growing a moderately resistant cultivar (IS 12664C, half as susceptible as CSH 1) and a highly resistant cultivar (DJ 6514, six times less susceptible than CSH 1 to midge under no-choice conditions) (Sharma *et al.*, 1983) has been demonstrated in Table 4, as a hypothetical example. It is estimated that at the end of the first season, the insect population would be 18 times less on the moderately resistant, and over 1000 times less on the resistant cultivar. During the second year, the insect would be relatively rare on the resistant cultivar. The population on the moderately-resistant cultivar would remain the same but would none the less be several times less than that on the susceptible cultivar. Another advantage in growing a resistant cultivar is that the reduced rate of population increase can prolong the time required to reach economic thresholds (Figure 1). This is particularly true when there is prolongation of the developmental period and mortality during the immature stages. Further, the economic threshold of a resistant cultivar is much higher than that of a susceptible cultivar.

Although these models may exaggerate the usefulness of resistant cultivars, they do bring out the tremendous effect the resistant cultivars would have on insect numbers. As we know, the insect population structure will not follow the postulated trend because: (1) it is not possible to plant the same cultivar over large areas at the same time, (2) the same cultivar will not behave uniformly in space and time, (3) insect populations are highly variable and dynamic in nature and are influenced by many biotic and abiotic factors.

Resistant cultivars and chemical control. The most common form of integrated control involves the use of moderately-resistant cultivars and insecticides. The pest numbers are reduced in each generation and this process slows down the population growth of the insects (Painter, 1951). Even a moderately resistant cultivar in combination with insecticides can bring about a substantial reduction in pest numbers (Table 5). A moderately resistant variety (IS 12664C) may require insecticide applications in midge endemic areas or years. Assuming that one application of insecticide would reduce insect numbers by 90%, the combined action of the moderately resistant cultivar and the insecticide would produce a 24-fold difference in population between a highly susceptible (CSH 1) and a moderately resistant (IS 12664C) cultivar. Further, it would reduce the population carryover 31 times, and thus result in a substantial reduction in insect numbers in the following year.

Plant resistance may also enhance the effectiveness of the insecticides through better penetration of the insecticides to the target insect through modified plant morphology, e.g. loose earheads would allow better penetration of the insecticides meant to kill headbugs and head caterpillars and easy access to parasites and predators. Moderate resistance based on imbalanced nutrition or toxic substances may increase the susceptibility of insects to insecticides.

Resistant cultivars and biological control. Resistant cultivars are mostly compatible with biological control. The advantage of using resistant cultivars is that they can help preserve natural enemies through reducing the need to use pesticides. As pointed out earlier, efforts can also be made to identify and breed cultivars that encourage natural enemies.

Resistant cultivars and cultural control. Resistant cultivars can be used in conjunction with cultural control operations. This will have the same effect on the population dynamics of the pest species in question as the combined action of insecticides and resistant cultivars. For example, late planting of M 35-1 during the post-rainy season can substantially reduce shoot fly damage.

Table 3. Sources of resistance identified against important insect pests of sorghum

Insect	Cultivar	Remarks	Reference
Atherigona soccata	M 35-1 (IS 1054)	Less susceptible	Rao *et al.* (1972), Roshan Singh and Narayana (1978), Singh *et al.* (1978)
	Soaner	Also less susceptible to stem borer	Ghode (1971)
	5-4-1 (Mugati Jola)		Ramnath *et al.* (1974)
	IS 2123 and IS 5604	Shows antibiosis	Roshan Singh and Narayana (1978)
	Jhallowar and Vallabhnagar		Kundu and Sharma (1975)
	M 31-2B, MAL-B, XZM-2B		Lakshimarayana and Subba Rao (1978)
	IS 5469 and IS 5440	Highly stable	Singh *et al.* (1978)
	PJ 3K, *PH 20k*, PJ 4K, PJ 6K, PJ 34J, PJ 14K	*Most promising*	Mote *et al.* (1981)
	PJ 4R X Shenoli 4-2-5, ND 15X Improved Soaner-10, M 35-1X PJ 4R-22, M 35-1XPJ 4-25, M 35-1X, Improved Soaner 12		Bapat and Mote (1982a)
	Sorghum purpureo-sericeum and Sorghum versicolor (wild species)	*Immune to shoot fly*	*Bapat and Mote (1982b)*
	Improved Soaner, GM 2-3-1 and IS 3922		Salunkhe *et al.* (1982)
	IS 1982, IS 2122, IS 2195, IS 4663, IS 4664, IS 5490, IS 5484, IS 5566, IS 18551	LEss susceptible	Sharma *et al.* (1983)
Chilo partellus	Line 477	*Highly promising*	Kundu and Jotwani (1977)
	E 302 (BP-53X KaferB) and E 303 (BP-53XIS-3954)		Jotwani *et al.* (1974)
	DU 19, DU 98, DU 245, DU 291, U 218, U 373, U 358, U 376	Derivatives of M-35-1XBP-53	Jotwani *et al.* (1979)
	D 168, D 172, D 259, D 358, D 367, D 369	Show stable resistance	Singh *et al.* (1980)
	E 501, E 502, E 503, E 604, E 601, E 602, E 603, E 604	Highly promising with good *agronomic characters*	Jotwani (1982)
	IS 1044, IS 2123, IS 2137, IS 2168, IS 2205, IS 2309, IS 5538, IS 5560, IS 5571, IS 5585, IS 5604, IS 5622, IS 7229, IS 18551, IS 18573, IS 18577, IS 18578, IS 18584, IS 18662	Less susceptible	Sharma *et al.* (1983)
Mythimna separata	R 16, R 24, 604, CS 3541	*Less susceptible*	*Rangarajan et al. (1974b)*
	SB 803, I 744, 296, 604 and E 302, Line 141, E 303, NJ 1953	Less susceptible	Kulkarni and Ramakrishna (1975), Kulkarni *et al.* (1978a)
Peregrinus maidis	I 753, H 109, GIB, 3 77B, BP 53	Free from attack	Agarwal *et al.* (1978)
Rhopalosiphum maidis	S 3541, Piper Sudan 428-1, TAM 428		Narayana (1975)
			Teets (1979)
Myllocerus maculosus	SPH 6, 22 E, CSV 3, 3660AX370, 36AX148	Less damaged	Kishore *et al.* (1977a)
Contarinia sorghicola	Nunaba	3% incidence	Bowden and Neve (1953)
	ODC 19	0·2 flies/head compared to 52·2 flies on CT 938	Wiseman and McMillian (1968)
	IS 413, IS 1002, IS 1004, IS 1021, IS 1064, IS 1079, IS 1087, IS 1151, IS 1457, IS 1462, IS 1472, IS 1474, IS 1501, IS 1510, IS 1542, IS 1568, IS 2160, IS 2205, IS 3472, IS 3950, IS 4307, IS 4308, IS 4316, IS 4411, IS 4429, IS 4477, IS 4511, IS 4528, IS 4544, IS 4569, IS 4653, IS 4757, IS 4761, IS 4782, IS 4808, IS 4832, IS 4859, IS 4868, IS 4870, IS 4876, IS 4955, IS 5230, IS 5384, IS 5389, IS 5452, IS 5475, IS 5656, IS 5940,	<20% incidence	*Pradhan (1971)*

Table 3. Sources of resistance identified against important insect pests of sorghum

Insect	Cultivar	Remarks	Reference
	IS 5977, IS 6146, IS 6163, IS 6170, IS 6179, IS 6195, IS 6206, IS 6367		
	IS 2579C, IS 2816C, IS 3574C, IS 12612C, IS 12666C	<4·5 damage rating	Johanson *et al.* (1973)
	SGIRL-MRI	<5 damage rating	Wisoman *et al.* (1973C)
	A 25, Grenador INTA mf; Linea 64/21 mf (RS2583); Linea 63/54 mf (Rs 2324), Line 3017 (SA 8774 2 2 109 Wh), 11157 (Arkansas)	<5 damage rating	Wiseman *et al.* (1974)
	IS 2660, IS 2663	Closed glume character	Bergquist *et al.* (1974)
	Hurein INTA	Tolerant to midge	Parodi *et al.* (1974)
	AF 28	Resistant	Rossetto *et al.* (1975)
	1809 cm, 2321 cm, 2331 cm	Showed least damage	Wiseman *et al.* (1975)
	DJ 6514	27·87% incidence	Shyamsundar *et al.* (1975)
	BC 92792, EC 92794 and S GIRL-MR-1	<10% Incidence	Raodeo and Karanjkar (1975)
	E 248A, 1209 cm, 1217 cm, 1731 cm, 1749 cm	Less susceptible	Wiseman *et al.* (1976)
	ATX 398, TAM 2566, IS 2501C, IS 2508C, ATX 378 X TAM 2566, S GIRL-MR 1	<2·66 damage rating	Faris *et al.* (1976)
	IS 3472, IS 4411, IS 4870, IS 5940, IS 5977, IS 6170	<1 midgefly emerged/head	Gowda and Thontadarya (1976b)
	AF 28, AF 117, SC 239-14, SC 175-9, SC 175-14, SC 574-6		Rossetto (1977)
	DT 6514; S GIRL MR-1, 573-3/F3, 575-2/F3	Promising	Venugopal *et al.* (1977d)
	SPV 4, SPV 80, SPV 97, SPV 102		Avadhani *et al.* (1977)
	CO 4, CO 11, CO 18, K4K	<10% incidence	Murty and Subramaniam (1978)
	DJ 6514		Kulkarni *et al.* (1978b)
	EC 92792, IS 1151, IS 1501, IS 2205, IS 3272, IS 3472, IS 4076, IS 4114, IS 4416, IS 4808, IS 4955, IS 5977, IS 6170, IS 6174, IS 6179, ODC 92793, S GIRL MR 1	<3 damage rating	Jotwani (1978)
	IS 2626C, IS 3071C, IS 2757C IS 12608C, IS 12664	<4·5 damage rating	Wuensche *et al.* (1978), Page (1979)
	AF 28	Most stable line	Faris *et al.* (1979)
	IS 2579C, IS 3071, IS 7142, IS 8263, IS 8337, IS 12593, IS 12676	Highly resistant	Johanson *et al.* (1979)
	AF 28, DJ 6514, TAM 2566, IS 271, IS 2761, IS 3461, IS 7005, IS 7687, IS 8284, IS 8571, IS 8711, IS 8713, IS 8721, IS 8724, IS 9807, IS 10712, IS 11117, IS 12213, IS 12666C, IS 14864, IS 14871, IS 14876, IS 15107, IS 19474	Received a damage rating of <3 compared with 5 in CSH 1	Sharma *et al.* (1983)
Calocoris angustatus	Chencholam	Support low populations of head bug	Balasubramanian *et al.* (1979)
	IS 2761, Belkoiga, Myapelag, No-Name 3	Less damaged under headcage	Sharma *et al.* (1983)
Heliothis armigera	Chencholam	Less damaged	Balasubramanian *et al.* (1979)
	RS 160	Less damaged	Wilson (1976)

The level of resistance reported against different insect pests is quite often based on one seasons observation, and needs to be confirmed.

The sources of resistance reported earlier and those identified from the fresh germplasm collections have been extensively tested at the ICRISAT Center. Those showing repeatable resistance have been included in this table (Sharma *et al.*, 1983).

For detailed information, the AICSIP and ICRISAT reports may be consulted.

Table 4. Population increase of sorghum midge on CSH 1 (susceptible), IS 12664C (moderately resistant) and DJ 6514 (resistant) (a hypothetical example based on Knipling (1964) and Sharma et al. *(1983))*

Generation	CSH 1* (no. of midge flies/ha)	IS 12664C* (no. of midge flies/ha)	DJ 6514* (no. of midge flies/ha)
First year			
P1	100†	100*	100*
F_1	600	300	100
F_2	3600	900	100
F_3	21,600	2700	100
F_4	129,600	8100	100
Diapause population (1%)‡	1554	120	4
Second year			
P2	1554	120	4
F_1	9324	360	4
F_2	55,944	1080	4
F_3	335,664	3240	4
F_4	2,113,984	9720	4
Diapause population (6%)	25,149	142	1

* Midge population increased six times on CSH 1, three times on IS 12664C, and once on DJ 6514 (Sharma *et al.*, 1983).

† The midge population at the beginning of the season is assumed to be 100 flies/ha.

‡ In each generation, 1% of the total populations is assumed to enter diapause.

P1, P2, parent population;

F_1–F_4, no. of insect generations.

Table 5. Population increase of sorghum midge on CSH 1 (susceptible) and IS 12664C (moderately resistant) plus one insecticidal spray in first generation (a hypothetical example based on Knipling (1964) and Sharma et al. *(1983))*

Generation	CSH 1* (no. of midge flies/ha)	IS 12664C* (no. of midge flies/ha)
First year		
P1	100†	100†
F_1 (+ insecticide)‡	60	30
F_2	360	90
F_3	2160	270
F_4	12,960	810
Diapause population	155	12
Second year		
P2	155	12
F_1 (+ insecticide)‡	93	4
F_2	558	12
F_3	3348	36
F_4	20,088	108
Diapause population	241	2

* The population of midge increased six times on CSH 1 and three times on IS 12664C (Sharma *et al.*, 1983).

† *The midge population at the beginning of the season is assumed to be 100 flies/ha.*

‡ The insecticide is applied on F_1 and is presumed to kill 90% of the population.

§ In each generation 1% of the total population is assumed to enter diapause.

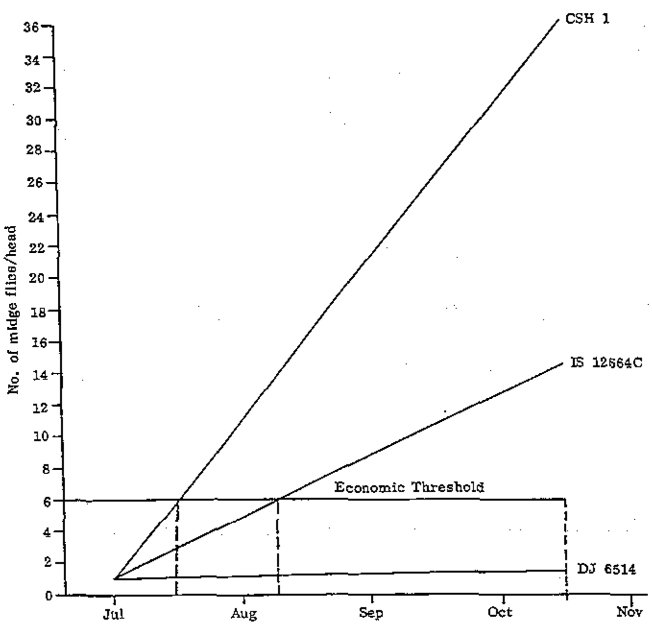

Figure 1. Trends of population increase of sorghum midge on resistant and susceptible cultivars and attainment of economic thresholds (A hypothetical example: the initial midge population is one midge/head (assumed); the midge population multiplies six times on CSH-1, three times on IS-12664C and once on DJ-6514 (Tables 4, 5).

Chemical control

Chemical control of pest populations should only be adopted as a last resort but it still remains the main tool in pest management. A number of insecticides have been tested and found effective against important sorghum pests (Table 6, Figure 2). BHC, lindane, carbaryl, carbofuran, malathion and endosulfan can be used effectively to control seedling pests. Dusts, granules, or sprays may be applied, depending on the insect, time and mode of application. Further investigation is required to evaluate the effectiveness of some newer insecticides such as fensulfothion, isophenophos, mephospholan and synthetic pyrethroids against seedling pests. For earhead pests, dusts or sprays of BHC, carbaryl, endosulfan, quinalphos or malathion may be applied at the half-anthesis, post-anthesis or milky stages of the earhead, depending on the pest to be controlled. Care should be taken to use insecticides that are readily biodegradeable and do not leave harmful residues on the grain. Considering the difficulties involved in conventional high volume spraying, dusts, granules and u.l.v. applications may be considered for applying insecticides.

Future strategies for pest control in sorghum

Pest control programmes should be based on economic thresholds. Economic thresholds and reliable means of monitoring pest populations or damage caused by them need to be established. Shoot fly populations can be monitored using fish meal traps (Figure 3). Populations of stem

*Table 6. Chemical control of important insect pests of sorghum**

Insect	Insecticides			References
Shoot fly, (*Atherigona soccata*)	Aldicarb BHC Carbaryl Carbofuran Diazinon	Dimethoate Disulfoton Endosulfan Fensulfothion Fenvalerate	Isophenphos Mephospholan Methyl demeton Monocrotophos Phorate Phosalone	Singh and Jotwani (1975), Hsieh (1977), Srivastava and Jotwani (1976a), Srivastava (1976), Balasubramanian *et al.* (1976), Bhimnawawar *et al.* (1976), Mote and Pokharkar (1975), Mote and Talgeri (1975), Srivastava *et al.* (1973), Vibhute *et al.* (1975), Rajasekhara *et al.* (1973), Thirumurthi *et al.* (1973a, b), Thimmaiah *et al.* (1973a), Rathore *et al.* (1972), Kulkarni *et al.* (1972), Thobbi *et al.* (1979), Sukhani and Jotwani (1980), Sadakathulla (1981a), Srivastava *et al.* (1980), Sandhu and Dhaliwal (1982), Mote (1982), Singh and Saha (1969), Baskaran (1972), Ketkar (1974), Rathore *et al* (1970), Mittal *et al.* (1973), Sandhu and Young (1974), Jotwani *et al.* (1971)
Stem borer (*Chilo partellus*)	BHC Carbaryi Carbofuran Endosulfan	Fenvalerate Lindane Malathion Manocrotophos Phenoate	Quinalphos	Vaishampayan and Veda (1978), Kishore and Jotwani (1977), Kundu and Sharma (1974), Srivastava and Jotwani (1976b), Srivastava (1976), Bhimanawar *et al.* (1976), Vibhute *et al.* (1975), Venugopal *et al.* (1977b), Kundu and Kishore (1980), Sadakathulla (1981b), Bhanot *et al.* (1982), Manoharan and Balasubramanian (1982), David *et al.* (1969), Rathore *et al.* (1970), Rangarajan *et al.* (1973), Agarwal *et al.* (1976), Baskaran (1972), Ghode and Katiyar (1971), Jotwani and Kishore (1973)
Armyworm (*Mythimna separata*)	BHC Carbaryi	Dimethoate Endosulfan	Malathion	Kishore and Jotwani (1976), Bhimanwawar *et al.* (1976), Bindra and Rathore (1965)
Sorghum-midge (*Contarinia sorghicola*)	BHC Carbaryi Carbophenathion Chlorfenvinphos Diazinon Dichlorvos Dimethoate	Disuifoton Endosulfan Ethion Lindane Fenvalerate Dimethoate	Malathion Methamidophos Methyl-demeton Methyl-parathion Monocrotophos Permathrin Phenthoate Phosalone Quinalphos Tetrachlorfonvinphos	Rossiter (1977), Carq and Taley (1977b), Venugopal *et al.* (1975, 1977c), Rac (1976), Deshmukh *et al.* (1978), Rusas (1970), Reis *et al.* (1977), Nunes *et al.* (1976), Lara *et al.* (1976), Deering and Randolph (1968), Huddlestone *et al.* (1972), Borle *et al.* (1979), Gowda and Thontadaroya (1976a), MacQuillan *et al.* (1975), Thimmaiah *et al.* (1974), Lara (1974), Kulshrestha and Singh (1967), Barrow (1974), Aburto and Castro (1979), Randolph *et al.* (1971), Sarkate and Raodeo (1978), Rocha *et al.* (1979), Roth and Pitre (1973), Stanfords *et al.* (1972), Wiseman *et al.* (1973a,b), Singh *et al.* (1979), Radke *et al.* (1978a,b), Castillo and Querevedo (1980), Sadakathulla (1981b), Mogal *et al.* (1980), Bhanot *et al.* (1982), Ward *et al.* (1972), Sadakathulla *et al.* (1978), Coutin (1970)
Headbug (*Calocoris angustatus*)	BHC Carbaryi Carbophenathion Chiorfenvinphos	Diazinon Endosulfan Fenvalerate Lindane Malathion	Quinalphos	Rangarajan *et al.* (1973), Rangarajan *et al.* (1974a), Usman (1967), Subba Rao *et al.* (1980), Sundararaju *et al.* (1977), Kulkarni and Parameshwarappa (1978), Paul and Srinivasan (1978), David *et al.* (1969)
Head caterpillars (*Heliothis armigera*) *Eublemma* spp. *Cryptoblabes* sp.	BHC Carbaryi Cypermethrin Decamethrin	Dichlorvos Dimethoate Endosulfan Fenvalerate	Monocrotophos Permethrin Phenthoate Quinalphos	Kishore and Jotwani (1976), Srivastava and Singh (1975a,b), Bhonot *et al.* (1982), Kishore and Jotwani (1971), Darekar and Talgeri (1976), Rawat *et al.* (1970), Jotwani *et al.* (1978), Borle *et al.* (1979), Kulkarni *et al.* (1980)

* Based on the published reports between 1965 and 1982.

Insects \ Insecticides	Aldicarb	BHC	Carbaryl	Carbofuran	Carbophenathion	Chlorfenvinphos	Cypermethrin	Decamethrin	Diazinon	Dichlorvos	Dimethoate	Disulfoton	Endosulfan	Ethion	Fensulfothion	Fenvalerate	Isophenphos	Lindane	Malathion	Mephospholan	Methamidophos	Methyl-demeton	Methyl-parathion	Monocrotophos	Permethrin	Phenthoate	Phorate	Phosalone	Quinalphos	Tetrachlorfenvinphos
Shoot fly	■	■	■	■					■		■	■	■		■	■	■			■		■		■			■	■		
Stem borer		■	■	■									■			■		■	■					■		■			■	
Army-worm		■	■								■		■						■											
Sorghum midge		■	■		■	■			■	■	■	■	■	■		■		■	■		■	■	■	■	■	■		■	■	■
Head bug		■	■		■	■			■				■			■		■	■										■	
Head cater-pillars		■	■				■	■		■	■		■			■								■	■	■			■	

Figure 2. Chemical control of important insect pests of sorghum. ■, *indicates the effectiveness of the insecticide.*

borers and *Heliothis* can be monitored using light and pheromone traps (Figure 4). At present, populations of midge and headbugs (Figure 5) can only be monitored through field surveys. Based on the population dynamics of these pests, sowing dates can be adjusted or insecticides applied to keep the pests in check. Such exercises should be carried out by agricultural universities, research institutes and extension agencies in a particular geographical region, and should be pursued on the lines of operational integrated pest control projects on such crops as cotton and rice. The necessary information can be conveyed to the farmers by radio, television, newspapers or extension agencies.

Cultural pest control operations such as date of sowing, seeding rates, fertilizer application, field sanitation, weeding and cropping systems should form an essential

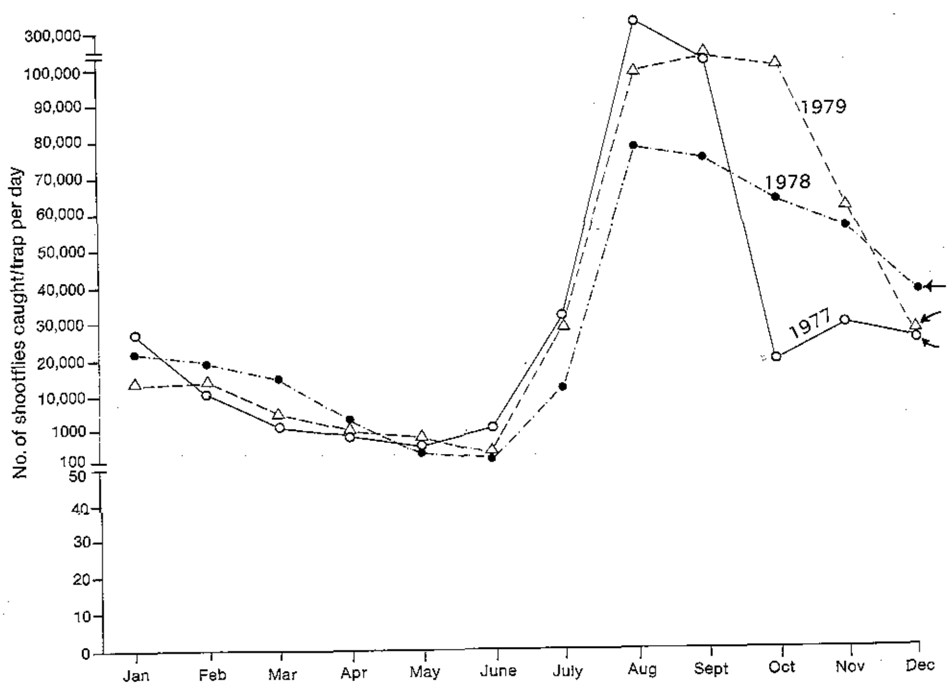

Figure 3. Catches of shootflies in fishmeal traps at ICRISAT Center (1977–79) (Sharma and Davies, 1982).

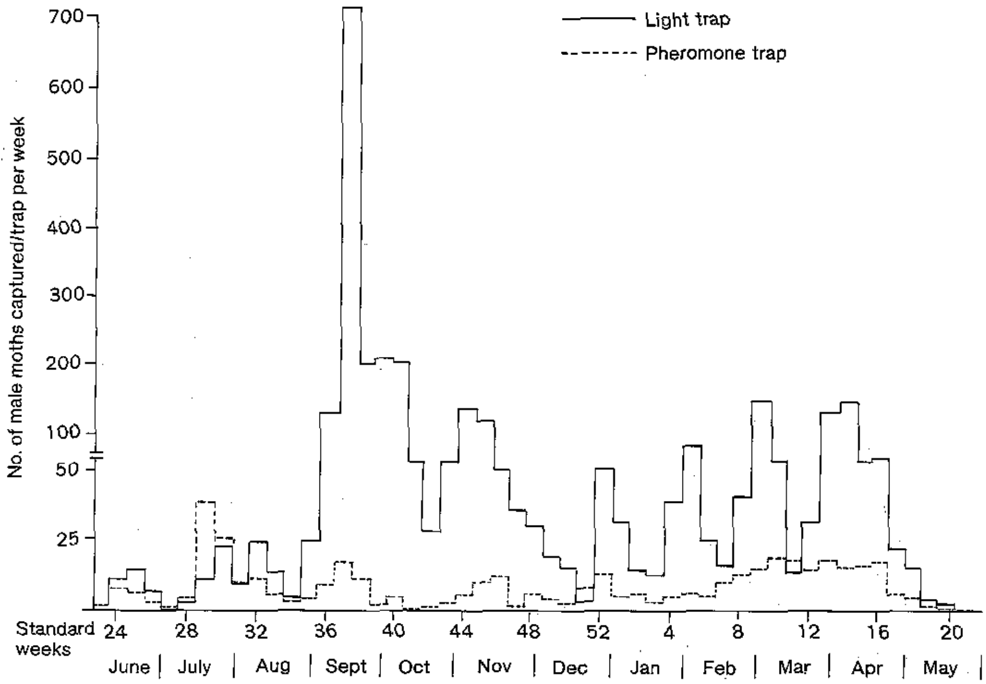

Figure 4. Chilo *catches in light and pheromone traps at ICRISAT Center, 1980–81 (ICRISAT, 1982).*

component of the pest-management systems. Extension agencies can play a major role in making farmers aware of the benefits of cultural practices for pest control.

The use of pest-resistant cultivars should form the backbone of future pest management systems. Efforts to develop, release and popularize varieties that are resistant to key pests should be intensified. Several cultivars resistant to midge, shoot fly, and stem borer have been reported (Table 3), and may be recommended for cultivation in endemic areas. Efforts should be made to incorporate resistance into cultivars with good agronomic backgrounds and to strengthen the level of resistance through gene pyramiding. Resistance to headbugs has still not been found. Major emphasis should be placed on such

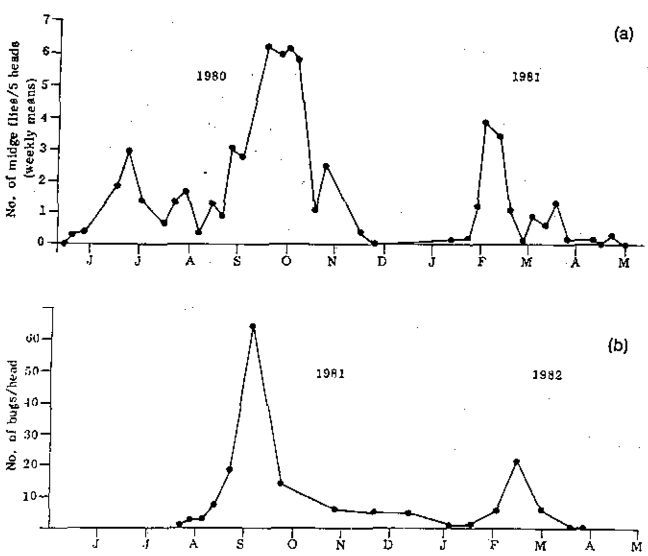

Figure 5. Population dynamics of (a) sorghum midge, Contarinia sorghicola, *at ICRISAT Center, 1980–81 (ICRISAT, 1984) and (b) sorghum head bug,* Calocoris angustatus, *at ICRISAT Center, 1981–82 (ICRISAT, 1984).*

management practices as sowing date, and the use of cultivars that flower during periods of low bug activity. Loose panicled cultivars need to be developed for areas where headbugs and head caterpillars are major pests. Cultivars resistant to more than one pest need to be developed through 'heterolines' or by combining resistance to different pests through population breeding techniques.

Insecticide effectiveness and selectivity should form the basis of chemical control. Insecticide residues on grain should be determined so that safety intervals can be fixed. Greater emphasis should be placed on the mode of insecticide application. Granules, dusts and u.l.v. applications can easily be substituted for conventional spraying, thus avoiding the difficulties involved in conventional high-volume spraying.

Cropping systems and cultivars that encourage natural enemies should be identified and fitted into pest control schedules.

The possibility of using attractants, repellants and antifeedants in pest management systems should be explored. Insecticides of plant origin such as those obtained from *Azadirachta indica, Acorus calamus, Catharanthus roseus, Bluemea eriantha* etc., should be exploited for pest control.

Remote-sensing satellites could be employed to determine host density, location, and extent of damage. Remote sensing can help to detect damage early and determine the effectiveness of control measures. It offers an efficient and cheaper method for pest surveys.

Conclusions

Insect pest resistant varieties and cultural practices should form the backbone for pest control programs in sorghum agro-ecosystems. Insecticides may be used when necessary based upon economic thresholds.

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