Host-plant resistance to insects in sorghum and its role in integrated pest management

H C Sharma

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

Abstract Sorghum is one of the most important cereal crops in Asia Africa and Latin America It is damaged by 150 insect species of which sorghum shoot fly (*Atherigona soccata* Rond) stem borers (*Chilo partellus* Swin *Busseola fusca* Fuller *Eldana saccharina* Wlk *Sesamia* spp and *Diatraea saccharalis* Wlk) armyworms (*Mythimna separata* Wlk *Spodoptera exempta* Wlk and *S frugiperda* J E Smith) aphids (*Melanaphis sacchari* Zehnt *Schizaphis graminum* Rond and *Rhopalosiphum maidis* Fitch) mites (*Oligonychus* spp) midge (*Contarinia sorghicola* Coq) head bugs (*Calocoris angustatus* Leth *Eurystylus immaculatus* Odh and *Oebalus* spp) and head caterpillars (*Helicoverpa armigera* Hb *Eublemma* spp *Pyroderces simplex* Wsm *Cryptoblabes* spp and *Nola* spp) are the major pests world wide Considerable progress has been made in screening and breeding for resistance to shoot fly stem borers greenbug midge armyworms and head bugs Resistance to major pests is available in diverse genotypes It is possible to combine resistance to two or more insect species in some cases (e g shoot fly and stem borer stem borer and armyworms midge and aphids and head bugs and head caterpillars) However it may be quite difficult to combine resistance to some insect species (e g shoot fly versus midge and/or head bugs) Host plant resistance can be used for the management of sorghum midge greenbug mites aphids and head caterpillars However host plant resistance need to be supplemented with other methods of pest control for shoot fly stem borers armyworms and head bugs

Keywords Sorghum *Sorghum bicolor* pest management host plant resistance

Introduction

Sorghum *Sorghum bicolor* (L) Moench one of the most important cereals in the semi-arid tropics provides food feed and forage however grain yields on peasant farms are generally low owing partly to insect pest damage (Doggett 1988) Nearly 150 species of insects have been recorded as pests of sorghum (Reddy and Davies 1979 Jotwani Young and Teetes 1980) the damage economic importance and distribution of most important pests are listed in *Table 1* Avoidable yield losses have been estimated at nearly 32% in India (Borad and Mittal 1983) 9% in USA (Wiseman and Morrison 1981) and nearly 20% in Africa Central America and Mexico The financial loss is nearly A$80 × 10^6 due to midge alone in Australia (ICRISAT 1985) and Rs 100 × 10^6 due to panicle-feeding insects in India (Leuschner and Sharma 1983)

Recommendations for integrated pest management (IPM) in sorghum involve cultural practices natural enemies host plant resistance and insecticides In rainfed agriculture the sowing date cannot be manipulated to avoid pest damage so sowing pest resistant cultivars is especially useful under subsistence farming conditions of the semi-arid tropics (Davies 1981) Unfortunately newly developed cultivars often fail the challenge of heterogeneous pest populations and are rejected by farmers Products of crop improvement programmes must be viable under existing field conditions and have the potential for increased yields with improved inputs In this context host plant resistance assumes a central role in the efforts to increase the production and productivity of sorghums Insect resistant cultivars should yield more than susceptible cultivars in the presence of pests and yield at least as much as the susceptible cultivars in the absence of pest attack However there may be a few exceptions where the pest problems are overwhelming (Doggett Starks and Eberhart 1970) low yielding insect resistant varieties may be accepted by the farmers Pest management in sorghum has been discussed earlier by Jotwani *et al* (1980) Gahukar and Jotwani (1980) Teetes (1979 1980 1985) Leuschner Taneja and Sharma (1985) and Sharma (1985a) In this paper the latest information on host-plant resistance to insects in sorghum is reviewed to formulate a strategy for the use of resistant cultivars in integrated pest management in different agroecosystems

Host-plant resistance to insects

Shoot fly (*Atherigona soccata* Rond)

Studies in the All India Coordinated Sorghum Improvement Project (AICSIP) at ICRISAT and in

0261–2194/93/01/0011–24

Table 1 Important arthropod pests of sorghum[a]

			Pest status[b]								
			Asia			Africa			America		Australia
Common name	Scientific name	Nature of damage	South	South East	West	West	East	South	North and Central	South	
White grubs	a *Holotrichia* spp b *Anomala* spp c *Phyllophaga crinita* (Burm)	Feed on roots	*ab	*ab	*ab	*ab	*ab				
Wireworms		Feed on germinating seeds and seedlings	*	*							
Shoot fly	*Atherigona soccata* Rond	Feeds on growing point and produces a deadheart	***	**							
Stem borers	a *Chilo partellus* Swin b *Busseola fusca* Fuller c *Eldana saccharina* Wlk d *Diatraea* spp e *Sesamia* spp	Larvae feed on leaves, produce a deadheart and tunnel into the stem	***ae		*ae	**bce	***abce	**abc			
Corn leaf aphid	*Rhopalosiphum maidis* Fitch	Sucks sap from whorl leaves and panicle	*	**	*	*	*	*			
Sugarcane aphid	*Melanaphis sacchari* Zehnt	Sucks sap from lower leaves	**	**	*		**				
Green bug	*Schizaphis graminum* Rond	Sucks sap from lower leaves		*			*	*			
Armyworms	a *Mythimna separata* Wlk b *Spodoptera exempta* Walk c *Spodoptera frugiperda* J E Smith	Larvae feed on on leaves	**a	**a	*a	*ab	**b	*b			
Grasshoppers and locusts	a *Oedaleus senegalensis* Krauss b *Hieroglyphus* spp c *Colemania sphenarioides* Bal d *Schistocerca gregaria* Forsk e *Locusta migratoria* L f *L migratoria migratorioides* R &F	Feed on leaves and sometimes on grain	*bcde	*b	*bde	***adef	**def	*def			
Mites	a *Oligonychus indicus* Hirst b *O pratensis* Banks	Sucks sap from leaves Sucks sap from leaves	*a	*a		*b	*b				
Shoot bug	*Peregrinus maidis* Ashm	Sucks sap from leaves	*	*	*	*	*	*			
Spittle bug	*Poophilus costalis* Walk	Sucks sap from leaves	*			*	*				

Table 1 (continued)

			Pest status[2]								
			Asia			Africa			America		Australia
Common name	Scientific name	Nature of damage	South	South East	West	West	East	South	North and Central	South	
Sorghum midge	*Contarinia sorghicola* Coq	Larvae feed on developing grain	***	*	**	***	**	**	***	***	***
Head bugs	a *Calocoris angustatus* Leth b *Eurystylus immaculatus* Odh c *Taylorilygus vosseleri* Popp d *Campylomma* spp e *Agonoscelis* spp f *Oebalus* spp	Sucks sap from developing grain	*** ade		*de	***bcde	*cde	*cd	**f	*f	
Beetles	a *Psalydolytta* spp b *Cylindrothorax* spp c *Mylabris* spp d *Pachnoda* spp e *Rhinyptia* spp	Feed on inflorescence	*abce			**abcde	**abcde	*cd			
Head caterpillars	a *Helicoverpa armigera* Hb b *Cryptoblabes* spp c *Eublemma* spp d *Pyroderces simplex* Wsm e *Celama* spp f *Nola* spp	Larvae feed on developing grain	*abcdef	*a	*a	**abcde	*ace	*ac	**bcf	*abcf	*ab

[1] This list of major insect pests of sorghum, their relative importance and distribution is based on Reddy and Davies (1979), Gahukar and Jotwani (1980), Teetes (1979, 1980), Sharma (1985a), Sharma and Davies (1988), Teetes *et al* (1983) and ICRISAT (1985). [2] * insect present and damage occasionally serious; ** low to moderate levels of damage over seasons, occasionally serious; *** serious damage

West, Eastern and Southern Africa (*Table 2*) (Singh *et al*., 1968; Starks, Eberhart and Doggett, 1970; Pradhan 1971; Jotwani, 1978; Taneja and Leuschner, 1985a; Singh and Rana, 1986) have shown that most sources of resistance to shoot fly originate from the post-rainy season sorghums grown in India under stored soil moisture. Cultivars M 31-1 (IS 1054), IS 2123, IS 2146, IS 4664, IS 2205, IS 5604 and IS 18551 have been widely tested, and possess moderate levels of resistance. Some of the improved lines such as ICSV 700, ICSV 705 and ICSV 717 developed at ICRISAT have a yield potential better than the landraces (Agrawal and Abraham, 1985).

Non-preference for oviposition is considered as a primary mechanism for shoot fly resistance in sorghum by Krishnananda, Jayaraj and Subramanian (1970), Pradhan (1971), Soto (1974), Sharma *et al* (1977), Singh and Narayana (1978), Singh and Jotwani (1980a), Sharma and Rana (1983), Raina *et al* (1984) and Unnithan and Reddy (1985), but under no-choice conditions the resistant and susceptible varieties are equally damaged (Soto, 1974; Taneja and Leuschner, 1985a). Under glasshouse conditions, none of the varieties are highly resistant (Jotwani and Srivastava, 1970), and non-preference is substantially reduced with a high shoot fly density (Singh and Jotwani, 1980a). Antibiosis to shoot fly has been reported by Jotwani and Srivastava (1970), Blum (1972) and Soto (1974). Survival and development were adversely affected when shoot flies were reared on resistant varieties (Narayana, 1975b; Raina *et al*, 1981; Unnithan and Reddy, 1985) compared with susceptible genotypes (Singh and Narayana, 1978). Growth and development were retarded and the larval and pupal periods were extended by 8-15 days on resistant varieties (Singh and Jotwani, 1980b). Survival and fecundity were also better on highly susceptible varieties (Singh and Narayana, 1978). After the main shoot is killed by shoot fly, some sorghum cultivars can produce side tillers that can produce a reasonable yield if the plant is not subsequently attacked (Blum, 1972; Doggett, 1972). Survival of tillers and their development depends upon primary resistance (Sharma *et al*., 1977).

Some characters of sorghum seedlings are associated with shoot fly resistance. The wild species of sorghum that are immune to shoot fly have a high trichome density on the lower surface of the leaves (Bapat and Mote, 1982b). Although the direct influence of trichomes on behaviour of the shoot fly needs to be established, the importance of trichomes on the under-

Table 2 Sources of resistance to sorghum shoot fly *Atherigona soccata*

Genotype(s)	Remarks	Reference
IS 5566, IS 5285, IS 5623 and IS 5613	Low oviposition	Krishnanand *et al.* (1970)
IS 4522, IS 5210, IS 1061 and IS 1034	Resistance attributed to oviposition non preference and natural mortality	Jotwani and Srivastava (1970)
IS 1054 (M 35-1)	Low susceptibility	Rao, Singh and Srinivasulu (1977)
IS 2123, IS 5470 and IS 1054	Non preference was a major mechanism of resistance. Larval survival and adult emergence differed on different varieties	Soto (1974)
Soaner	Also less susceptible to stem borer	Ghode (1971)
IS 1054, IS 2269, IS 2123 and IS 5604	Oviposition was greater on susceptible varieties. Susceptible varieties were also suitable for larval growth. Flies reared on the susceptible varieties had the greatest fecundity	Singh and Narayana (1978)
Jhalawar and Vallabhnagar	< 10% deadhearts	Kundu and Sharma (1975)
M 31-2B, MAI-B and XZM 2B	Resistant	Lakshminarayana and Subba Rao (1978)
IS 1054, IS 5469 and IS 5490	Highly stable	Singh *et al.* (1978)
PJ 3K, PJ 20K, PJ 4K, PJ 6K, PJ 34K, PJ 19K and PJ 21K	Resistant	Mote, Shirole and Bapat (1981)
PJ 4R × Shenoli 4-2-5, ND 15 × Improved Soaner 10, M 35-1 × PJ 4R 22, M 35-1 × PJ 4R 25 and M 35-1 × Improved Soaner 1	Derivatives of these crosses were better than their resistant parents	Bapat and Mote (1982a)
Sorghum purpureo sericeum and *S. versicolor*	Immune to shoot fly	Bapat and Mote (1982b) and Mote (1984)
M 35-1 and BP 53 (IS 1055)	Tiller development depends on primary resistance	Kundu, Kishore and Jotwani (1977)
IS 2146, IS 4664, IS 5469 and IS 5490	Resistance due to non preference is quantitative and governed by the additive genes	Sharma *et al.* (1977)
IS 1054, IS 5469 and IS 5490	Non preference was reduced under situations of heavy infestation; susceptible hybrid CSH 1 had greater amounts of sugars, moisture and chlorophyll. Larval and pupal periods were 8–15 days longer on the resistant lines, survival and fecundity were adversely affected, and long and narrow leaves, faster seedling growth and hardness of leaf sheath were associated with resistance	Singh and Jotwani (1980a, b, c, d)
IS 2123, IS 5604, IS 5490 and IS 8315	Resistance controlled by additive and non additive gene effects. Heritability was 23–25%. Biparental mating is suggested for recovery resistance. Estimates of genetic gains are low. Under low infestation, the heritability estimates were higher	Borikar and Chopde (1980, 1981, 1982) and Borikar, Chandurwar and Chopde (1982a, b)
IS 4663, IS 4776, IS 5333, IS 8315 and PC 9	Amino acid content is greater in resistant lines. Susceptibility to shoot fly is positively correlated with P and negatively with total phenols	Khurana and Verma (1982, 1983, 1985)
Improved Soaner, GM 2-3-1 and IS 3922	Highly resistant	Salunkhe *et al.* (1982)
IS Nos 923, 1034, 1057, 1071, 1082, 1096, 1104, 2122, 2123, 2146, 2195, 2309, 2265, 2269, 2291, 2309, 2312, 2394, 3962, 4224, 4646, 4663, 4664, 5072, 5210, 5469, 5470, 5480, 5484, 5511, 5538, 5566, 5604, 5613, 5636, 5648, 18366, 18368, 18369, 18471 and 18551	Trichomed and glossy (except IS 1034, IS 1057, IS 4224, IS 5072 and IS 5511). IS 1054, IS 1071, IS 2394, IS 5484 and IS 18364 were most stable. IS 2123, IS 2195, IS 4664 and IS 18551 showed low damage and moderate stability	Taneja and Leuschner (1985a)
365A3, 367A1 and 366B4	Resistant	Mote, Kadam and Bapat (1983)
IS 5642, IS 5490, IS 5469 and IS 4664	Low oviposition	Sharma and Rana (1983)
IS 2146, IS 3962 and IS 5613	Non preference for oviposition	Raina *et al.* (1984)

Table 2 (continued)

Genotype(s)	Remarks	Reference
PS 21171, PS 21217, PS 21318, PS 14093, PS 14103 and PS 14454	Breeding lines developed at ICRISAT. Trichomes and glossiness are associated with resistance. Simply inherited recessive traits. Resistance controlled by additive and non-additive genes	Agrawal and Abraham (1985)
IS 5490	It had greater Si content (19.97%) than CK 60B (11.67%)	Bothe and Pokharkar (1985)
CSV 6, SPV 8, SPV 13, SPV 29, SPV 70, CSH 7R, E 303 and IS 5490	Improved varieties with significantly low susceptibility in early and late sowings	Kishore, Rana and Agarwal (1985)
SPH 196 and SPH 225	Showed good recovery resistance	Mote, Kadam and Bapat (1985)
IS 2146, IS 4664, IS 5469 and IS 5490	One single recessive gene governed non-preference to oviposition and two duplicate recessive genes governed the resistance to deadheart formation	Sharma and Rana (1985)
IS 2122, IS 2123, IS 2708, IS 2291, IS 4660, IS 5092, IS 5480 and IS 18551	Non-preference and antibiosis are the mechanisms of resistance. IS 2291 showed evidence of antibiosis	Unnithan and Reddy (1985)
E 201 to E 208 and E 303	30% deadhearts compared with 54% in CSH 1	Kishore (1986)
IS 1082, IS 2146, IS 2312, IS 3962, IS 4663, IS 4646, IS 4661, IS 4666, IS 4712, IS 5214, IS 5470, IS 5490, IS 5604, IS 5613, IS 5622 and IS 5633	Rapid growth, tallness, and narrow yellow green leaves were associated with resistance	Mote *et al.* (1986)
SG 59-3, SL 60 and SL 21	Least susceptible	Sandhu, Dhaliwal and Sidhu (1986)
IS 5604, IS 5490 and IS 2146	Showed good general combining ability. Inheritance was additive and additive × additive gene action	Nimbalkar and Bapat (1987)
IS 1456, IS 7094 and IS 12611	Sweet stalk sorghums with less susceptibility to shoot fly	Jadhav, Mote and Bapat (1988)
RSV 8R and RSV 9R	Showed greater resistance than their parents M 35-1 and SPV 86	Mote and Bapat (1988)
IS 5490 and M 35-1	They had the lowest chlorophyll content and were most resistant	Mate *et al.* (1988)
IS 4660, IS 2123, IS 2269, IS 2312, IS 2146, IS 2162, IS 18551, IS 2394 and IS 841	Showed < 20% deadhearts. Trichome density mainly contributed towards genetic divergence for shoot fly resistance, followed by glossiness. IS 841 and IS 1054 formed separate clusters over the years	Omori *et al.* (1988)
IS 1054, IS 18551, IS 2123 and IS 5469	Resistance was governed by additive gene effects	Singh and Verma (1988a)
PC 6, Pioneer X 2142, X 1124, X 2293 and 3193	Showed good tolerance	Shivankar, Ram and Gupta (1989)
IS 18584, IS 2205, IS 1054, IS 3962, S 386, IS 5469, SPV 102, IS 5619, IS 18577 and IS 8320	Showed 20–40% deadhearts compared with 87% deadhearts in CSV 1. These lines are also resistant to stem borer	Patel, Sukhani and Srivastava (1989) and Patel and Sukhani (1990b)
P 24, E 303, 370 × 3660A, 36A × 1481, Khedi 2-2-40, CS 3541, E 302, and IS 1199	Showed < 20% deadhearts compared with 78% in CSH 1	Dalvi, Dalaya and Khanvilkar

surface of leaves has been reported by several workers (Blum, 1968, Maiti and Bidinger, 1979, Maiti *et al.*, 1980; Taneja and Leuschner, 1985a). Most of the lines resistant to shoot fly also exhibit the glossy leaf character during the seedling stage (Blum, 1972, Maiti and Bidinger, 1979, Taneja and Leuschner, 1985a, Omori, Agrawal and House, 1988). Glossy leaves may possibly affect the quality of light reflected from leaves and influence the orientation of shoot flies towards their host plants. Glossy leaves may also influence the host selection by means of chemicals present in the surface waxes and/or leaves. Rapid growth of seedlings may retard the first-instar larvae from reaching the growing tip. In contrast, slow growth due to poor seedling vigour, low fertility or environmental stress increases shoot fly incidence (Taneja and Leuschner, 1985a, Patel and Sukhani, 1990a). Shoot fly-resistant lines have rapid plant growth (Mote, Kadam and Bapat, 1986), greater seedling height and hardness (Singh and Jotwani, 1980d), and have longer stems and internodes, and short peduncles (Patel and Sukhani, 1990a). Cultivars with a high transpiration rate are preferred for oviposition (Mate, Phadanwis and Mehetre, 1988). Surface wetness of the central shoot leaf varies between resistant and susceptible genotypes (Nwanze, Reddy and Soman, 1990). Raina *et al* (1981) reported that leaf moisture is important for the movement of the larva to the growing point and deadheart formation. Several biochemical studies on selected genotypes have shown interesting differences between susceptible and resistant genotypes, but their role in shoot fly resistance is not clear. Ponnaiya (1951), Blum (1968) and Bothe and Pokharkar (1985) reported the appearance of silica bodies in resistant varieties from the four-leaf stage, and from the six-leaf stage in the susceptible ones. They suggested that the relatively late appearance of these silica bodies in the susceptible varieties makes them prone to shoot fly attack over a longer period. Similarly, the percentage of nitrogen, reducing sugars, total sugars, moisture and chlorophyll content of leaves was higher in susceptible than in resistant cultivars (Singh and Jotwani, 1980c, Mate *et al*, 1988, Patel and Sukhani, 1990a). Lysine is present in the leaf sheath of susceptible cultivars but was absent in three resistant cultivars tested (Singh and Jotwani, 1980c). Shoot fly-resistant lines also contained more amino acids, phosphorus and total phenols (Khurana and Verma, 1982, 1983).

Resistance to *A soccata* is inherited quantitatively, and is predominantly controlled by additive gene action (Rao *et al*, 1974, Balakotaiah *et al*, 1975, Rana *et al*, 1975, Sharma *et al*, 1977, Rana, Jotwani and Rao, 1981, Borikar and Chopde, 1981, Biradar and Borikar, 1985, Nimbalkar and Bapat 1987, Singh and Verma, 1988a), whereas Agrawal and Abraham (1985) reported predominantly non-additive resistance genes. Heritability has been estimated as 50% and 82% for F_1 and F_2 generations, respectively (Sharma *et al* 1977). In F_1 hybrids shoot fly resistance increased over the mid-parental value under low shoot fly infestation, but the reverse was true under high shoot fly infestation (Sharma and Rana, 1983). Estimates of genetic coefficients of variability, heritability and gentic advance were better when shoot fly infestation was optimized (Borikar, Chandurwar and Chopde, 1982b). Hybrid behaviour was also indicated well by parental performance (Sharma *et al*, 1977).

Stem borers (*Chilo partellus* Swin. and *Busseola fusca* (Fuller)

Resistance to stem borers has been studied in India (Pradhan, 1971, Jotwani *et al*, 1978b, 1979, Singh *et al.*, 1983; Singh and Rana, 1984, 1989, Srivastava, 1985; Taneja and Leuschner, 1985b, Agrawal and Taneja, 1989), Kenya (Alghali, 1985, Reddy, 1985), Brazil (Lara *et al*, 1979), and in southern Africa (Leuschner, 1989) (*Table 3*). IS 1055 (BP 53), IS 1044, IS 2123, IS 2195, IS 2205, IS 2146, IS 5469 and IS 18551 show moderate levels of resistance to spotted stem borer. Genotypic resistance is poorly expressed under conditions of low fertility, drought and unfavourable weather. The stage of infestation is most critical for expression of resistance, as a progressive delay in infestation reduces the production of deadhearts (Taneja and Leuschner 1985b). ICSV 705, SPV 135, CSV 8 R, SPV 104, SPV 238 and SPV 842 are improved genotypes with moderate levels of resistance to spotted stem borer and with a better yield potential than the original sources of resistance.

Ovipositional non preference by moths has been reported in several genotypes (Lal and Pant 1980, Dabrowski and Kidiavai 1983, Singh and Rana 1989). Moths did not prefer to oviposit on IS 2309, IS 5538, IS 18551, IS 18573 or IS 18580 under natural infestation (Taneja and Woodhead 1989). The main mechanism of stem borer resistance in sorghum is antibiosis (Jotwani, 1978, Pathak and Olela, 1983, Singh and Rana 1984) with high mortality in the early larval stages (Jotwani, 1978, Jotwani, Chaudhari and Singh, 1978a) and poor survival of larvae (Lal and Pant 1980) in resistant genotypes. Pupal development is also affected adversely and fecundity is reduced (Lal and Sukhani, 1982, Alghali and Saxena, 1988, Singh and Verma, 1988b, Taneja and Woodhead, 1989). In some selections with severe leaf injury and stem tunneling, yields were not reduced very much by spotted stem borer infestation (Jotwani *et al* 1978a). Similar results have been reported by Dabrowski and Kidiavai (1983) and Alghali (1987) in Kenya.

Plant height, tassel percentage, stem thickness, number of leaves, leaf length, leaf width, leaf thickness and leaf strength were negatively correlated with deadheart formation according to Khurana and Verma (1985). Genotypes with early panicle initiation (IS 12308 and IS 13100) escape deadheart formation owing to the inability of the larvae to reach the growing point. Faster internode elongation also reduces the chances of the larva damaging the growing point (Taneja and Woodhead, 1989). The resistant genotypes tend to have a narrow angle between the leaf and the stem (Woodhead and Taneja, 1987), and the lower leaves of sorghum are detached from the culm in some resistant genotypes. The epicuticular wax and ligular hairs also act as a trap for the young larvae, thus reducing their success in climbing, and rate of establishment (Bernays, Chapman and Woodhead, 1983, Chapman, Woodhead and Bernays, 1983). Larvae climbed almost twice as fast on stems of IS 1151 from which the wax had been removed, compared with stems before removal of wax (Bernays *et al*, 1983). Other factors associated with stem borer resistance in sorghum include low sugar content (Swarup and Chaugale, 1962), and greater amounts of amino acids, tannins, total phenols, neutral detergent fibre (NDF), acid detergent fibre (ADP), lignins (Khurana and Verma, 1982, 1983) and silica (Narwal, 1973).

Stem borer resistance is inherited quantitatively (Rana and Murty, 1971, Pathak and Olela, 1983) but

Table 3 Sources of resistance to stem borers (*Chilo* *Busseola* and *Diatraea*)

Genotype(s)	Remarks	Reference
Chilo Busseola		
Line 477	Highly promising	Kundu and Jotwani (1977)
E 302 (BP 53 × Kafir B) and E 303 (BP 53 × IS 3954)	Tolerant of stem borer	Jotwani Srivastava and Kundu (1974)
E 302 E 303 P 37 NCL 3 and P 151	Tolerance mechanism of resistance	Jotwani *et al* (1978b)
IS 5629	Most resistant line Resistance associated with mortality of first instar larvae	Jotwani *et al* (1978a)
DJ 19 DJ 95 DJ 245 DJ 291 E 218 E 373 E 358 and E 376	Derivatives of BP 53 × M 35 1	Jotwani *et al* (1979)
D 168 D 172 D 259 D 358 D 367 and D 369	Highly resistant and stable over four seasons	Singh *et al* (1980)
E 302 D 303 D 114 and IS 4308	Lower pupation and lighter pupal weights on the resistant lines compared with those on CSV 1 and CSH 1	Lal and Sukhani (1982)
E 501 E 502 E 503 E 504 E 601 E 602 E 603 and E 604	Promising lines with good agronomic characters	Jotwani (1982)
E 302 and E 303	E 303 was least susceptible in the rainy season and E 302 in the post rainy season	Dalvi Dalvi and Khanvilkar (1983)
E 302 E 303 IS 1044 IS 1151 IS 2162 IS 4660 IS 17739 IS 18328 IS 18349 IS 18479 and IS 18849	Non preferred for oviposition Deadhearts were lower on IS 2162 IS 2263 IS 18328 and IS 18349	Dabrowski and Kidiavai (1983)
IS Nos 1044 1082 1119 2122 2123 2146 2168 2169 2291 2309 2312 2375 2376 4273 4546 4637 4576 4757 4776 4881 4981 5075 5253 5429 5469 5470 5480 5538 5566 5571 5585 5604 5619 5622 7223 8811 9608 10711 12308 13100 13674 17742 17745 17747 17750 17948 17966 18333 18366 18551 18573 18577 18578 18579 18580 18548 18585 18662 18667 20643 21969 22039 22091 22145 22507 23411 23962 and 24027	Showed resistance over five seasons	Taneja and Leuschner (1985b)
E 303 E 501 E 502 E 601 and E 641	Moderately resistant to shoot fly and stem borer	Mote and Bapat (1983)
CSV 8R SPV 35 SPV 103 SPV 140 and SPV 192	Promising sources of resistance	Singh *et al* (1983)
SPV 31 SPV 101 SPV 110 SPV 232 SPV 257 SPV 209 SPV 291 SPV 301 and SPV 311 E 302 E 701 CSV 3 CSV 6 CSV 8R and Aispuri	Non preference for oviposition	Singh and Rana (1984)
CSV 5 × CSV 6 CSV 5 × CSV 4 and CSV 5 × IS 4664	Most promising crosses Continuous screening improved the levels of borer resistance	Kishore *et al* (1984)
E 302 SPV 135 IS 2312 IS 4664 CSV 8R and SPV 104	E 302 and SPV 135 are good combiners	Rana *et al* (1984)
E 304	Derived from IS 2954 × BP 53 It is equivalent to CSV 1 in yield	Kundu (1985)
IC 119/83 3	Its yield was not influenced by borer damage	Alghali (1985)
IS 10370 E 2 IS 10364 IS 1044 S 178 IS 3962 IS 4213 IS 12497 IS 18479 IS 18326 E 1 IS 4405 IS 10711 IS 18676 IS 5613 IS 18517 IS 18323 IS 4881 IS 1151 and IS 18427	Resistant to borer complex of C *partellus* B *fusca* E *saccharina* and S *calamistis* Hmps	Reddy (1985)
IS 2146 × Serena	Provided best chance to select for resistance	Pathak (1985)
Serena IC 119/80 2 and P 101	Produced maximum tillers due to borer infestation IC 119/80 2 showed an increase in grain yield due to borer infestation	Alghali (1987)
P 311	Resistant	Kishore (1987a)

Table 3 (continued)

Genotype(s)	Remarks	Reference
P 217, P 297, P 500, P 84, P 296, P 467, P 471 and P 498	Resistant	Kishore (1987)
IS 1044, IS 2123, IS 5469 and IS 12308	25% deadhearts at two locations compared with 78% in ICSV 1. Erect and curled leaves and a factor in wax is associated with larval establishment	Woodhead and Taneja (1987)
IS 5469 and IS 2205	Showed antibiosis	Singh and Verma (1988b)
IS 2123 and IS 5469	Good combiners for borer resistance	Singh and Verma (1988c)
IS 178, Improved Ramkel, S 136, PC 6, SPV 238	Resistant	Dhaliwal, Malhindratta and Arora (1988)
IS 2146	Less feeding	Alghali and Saxena (1988)
ICSV 700, ICSV 701, ICSV 825 to ICSV 829	High levels of resistance	Agrawal and Taneja (1989)
IS 3962, IS 18584, IS 2235, IS 1054, SPV 102, IS 5469, IS 5619, IS 18577 and P 37	Resistant	Patel and Sukhani (1989)
	Diatraea saccharalis	
AF 28 and FA 177	AF 28 is also resistant to midge and corn leaf aphid	Lara *et al* (1979)
M 66152 (NPI C 64735 × F 35 1), 88 4 Poza Rica and 787 3	Superior to the susceptible checks	Mihm (1985) and Guiragossian and Mihm (1985)

heritability is low (Singh, Jotwani and Rana 1980). General combining ability is predominant for leaf feeding, whereas specific combining ability is greater for stem tunnelling. Resistance to leaf feeding, deadheart formation, and stem tunnelling are inherited in different ways (Singh *et al* 1983, Pathak 1985). Stem and peduncle tunnelling are significantly correlated (Rana *et al* 1984). However, tunnel length has no correlation with loss in grain yield (Pathak and Olela 1983). Additive gene effects are predominant for deadheart and leaf injury (Singh and Verma 1988c). For *Ostrinia nubilalis* Hb., borer damage traits generally had strong negative correlations with grain yield (Ross *et al* 1982). Continuous screening over several generations has been suggested to improve selection for borer resistance (Kishore, Rana and Sharma 1984). E 302, SPV 135, IS 2123, IS 5469, SPV 104 and IS 4664 are good general combiners (Rana *et al* 1984, Singh and Verma 1988c).

Aphids (*Schizaphis graminum* Rond., *Melanaphis sacchari* Zehnt. and *Rhopalosiphum maidis* Fitch)

Extensive screening for resistance to *S. graminum* has been carried out in the USA. IS 809, KS 30, PI 264456, TAM 2567, SA 7536-1, Tx 2567 and DK 46 are good sources of resistance (*Table 4*). FA 266 shows nonpreference, an important component of resistance to aphids (Schuster and Starks 1973). IS 809 has both tolerance and antibiosis, whereas PI 202178 and PI 302236 exhibit all three mechanisms of resistance (Lara, Galli and Busoli 1981). Antibiosis has been reported also in PI 228928, PI 220248, IS 809, PI 302178, PI 302231, PI 226096, PI 264953, KS 30 and SA 7536 1 (Schuster and Starks 1973, Teetes, Schaefer and Johnson 1974) and tolerance has been observed in PI 264453. Tolerance is also affected by nutrient supply (Schweissing and Wilde 1979). Nonpreference and tolerance are not influenced by continuous culturing of aphids on resistant plants. Fecundity of the aphids decreases significantly with continuous rearing on resistant plants, and it is not regained immediately upon transfer to susceptible hosts (Starks and Schuster 1976). On resistant lines, aphids have a longer nymphal instar, produce fewer progeny per female, have a shorter adult life span (Teetes *et al* 1974) and imbibe less phloem sap (Campbell *et al* 1982). Differences between resistant and susceptible lines increase at higher temperatures (Schweissing and Wilde 1978, 1979). Genotypes with bloomless and sparse bloom characters are not preferred by the aphids (Weibel and Starks 1986, Weibel 1986a, b), the reproduction of which is adversely affected by these characters (Starks and Weibel 1981). Dreyer and Campbell (1984) suggested that increased methylation of the middle lamellar pectin hinders penetration by aphids.

Four biotypes of the aphid *R. maidis* have been identified but it is a sporadic pest with no apparent effect on grain yield. TAM 425 (SC 110-9) exhibits high levels of resistance to this aphid while genotypes 2R, 5R, HB 37, R 128, R 131, R 133, PI 954177 and IS 8100C are resistant to another aphid *M. sacchari* (*Table 4*). Midge resistant lines ICSV 197 and ICSV 743 are relatively less damaged by *M. sacchari* (H. C. Sharma, unpublished). Resistance of 2R (PI 257595) is controlled by a single dominant gene (Chang 1981) but it is

Table 4 Sources of resistance to aphids and mites

Genotype(s)	Remarks	Reference
	Rhopalosiphum maidis	
CS 3541 and Piper Sudan 428 1	Resistant	Narayana (1975a)
TAM 428	Resistant	Teetes (1979)
	Melanaphis sacchari	
AF 28	Resistant	[illegible] *et al* (1979)
2R 5R and HB 37	Highly resistant Resistance in 2R is controlled by a single dominant gene	Chang (1981)
R 128 R 151 and R 155	Resistant	Chang and Fang (1981)
PI 953177 and IS 8100C	10 dead seedlings	Hagio Umehara and Ono (1985)
129 3A × Tx 405 and 2R (PI 257595) × 129 3A	Resistance was dominant	Hsieh and Pi (1988)
ICSV 197 ICSV 743 and ICSV 745	Less damaged than CSH 1 and AF 28	H C Sharma (unpublished)
	Schizaphis graminum	
PI 308976 PI 229828 PI 220248 IS 809 Shallu grain PI 302178 PI 302231 PI 2206096 PI 229828I and PI 264453	PI 229628 IS 809 Shallu grain PI 302178 and PI 226096 showed evidence of all three mechanisms of resistance	Schuster and Starks (1973)
H 39 and Kafir 60 × H 39	Bugs did not reduce yield in H 39 and heterozygous seedlings of Kafir 60 × H 39 did not require protection	Harvey and Hackerott (1974)
PI 264453 IS 809 KS 30 and SA 7536 1	Non preferred	Teetes *et al* (1974)
KS 30 × SA 7536 1 SA 7536 1 and PI 264453	Resistance in one parent is sufficient to afford adequate resistance to greenbugs	Teetes Johnson and Rosenow (1975)
DeKalb Golden Acres Warner Tekseed and Asgrow	Greenbug resistant hybrids outyielded the susceptible hybrids RS 670 and RS 702	De Pew and Witt (1979)
Heterozygous resistant hybrids involving KS 30 IS 809 and SA 7536 1 as the source of resistance	Heterozygous resistant hybrids withstand 1 5 2 times as many aphids as the susceptible hybrid	Morgan Wilde and Johnson (1980)
PI 302178 PI 302236 IS 809 EA 71 7304032 and EA 252	Highly resistant	Gallo Lara and Barbosa (1981)
EA 266 IS 809 PI 202178 and PI 302236	EA 266 showed non preference IS 809 tolerance and the PI lines all three mechanisms of resistance	Lara *et al* (1981)
Weskan (*Bm and bm bm*) Martin (*Bm* and *hh*) and Redlan (*Bm* and *hh*) (*Bm* = Bloom *bm bm* = bloomless and *hh* sparse bloom)	Non preference suggested as a mechanism of resistance in bloomless sorghum	Starks and Weibel (1981)
TAM 2567 and IS 809	Population growth was less than on SC 173	Campbell *et al* (1982)
BR 64R+ WAC 652 and 1000R	Resistant	Baletka and Castellano (1984)
Tx 2789 to Tx 2800	Resistant to biotype C Tx 2789 to Tx 2792 are male steriles in A1 cytoplasm	Peterson *et al* (1985b)
SA 7536 1 K 30 IS 809 PI 264453 PI 220248 IS 923 PI 264452 and J 242	Resistant to biotype E	Starks and Mayo (1985)
OK GP 11 to OK GP 26	Resistant bloomless and sparse bloom lines	Weibel (1986a)
AOK 8 *bm* BOK 8 *bm* AOK 11 *bm* BOK 11 *bm* A Wheatland *bm* B Wheatland *bm* A Redlan *bm* and B Redlan *bm*	Bloomless lines	Weibel (1986b)
RW D3 × Weskan 43112 (N) Redbine 60 (N) R Combine Kafir 60(N) Martin(N) Redlan derivative (N) SA 7536 1 (R) and IS 809 (R)	Bloomless lines were non preferred	Weibel and Starks (1986)

Table 4 Continued

Genotype(s)	Remarks	Reference
N 41, N 42 and N 43	Resistant to biotype E	Nordquist, Kindler and Spomer (1987)
Tx 2567	Plants stayed alive for 28 days with 10 aphids per plant compared with 21 days in BR 601	Cruz and Vendramim (1988)
DeKalb DK 46	Greenbugs were consistently lower than on SG 10 and Pioneer 8790 sorghum hybdrids	Harvey and Thompson (1988)
DeKalb DK 41 y	Greenbug resistant hybrid	Burton *et al* (1990)
IS 2388, Sarvarin, PI 264453, PI 220248, IS 53000, PI 266965, IS 923, PI 229828, J 242, PI 302136, N 50735 and N 43172	Antibiosis is the major mechanism of resistance to greenbug. PI 26695 had the highest level of antibiosis. PI 229828 had the highest level of tolerance and J 242 had the highest level of tolerance to biotype E	Dixon *et al* (1990)
PI 453951, PI 457709 and PI 457715	Antiobiosis is the major mechanism of resistance to *Sipha flava* Forbes. The resistant genotypes had 25 nymphs per plant compared with 61 on PI 264453	Webster (1990)
	Mites (*Oligonychus* spp)	
SC 599 6	Showed tolerance	Foster *et al* (1977)
CSH 5, CSH 6, CSH 9, SPH 80, CSV 5, SPV 192, SPV 220, SPV 222, SPV 224 and SPV 265	Resistant	Singh, Rana and Rao (1981)
SC 599 6	Non senescence was not directly related to mite resistance	Archer *et al* (1986)

incompletely dominant in F1 (Tan *et al* , 1985) Additive and dominance variances are significant, with the additive factor larger than the dominant factor for resistance Complementary interaction was suggested in cross 129-3A × Tx 403 (Hsieh and Pi, 1988)

Mite (*Oligonychus* spp)

The genotype SC 599-6 is tolerant of mites (Foster *et al* , 1977) Mite damage has been reported to be less on late-flowering lines (Perring *et al* , 1982), and more on senescing lines (Foster *et al* , 1977), but non-senescence is not directly linked with resistance to mites (Archer, Bynum and Peterson, 1986)

Shoot bug and chinch bug (*Peregrinus maidis* Ash and *Blissus leucopterus* Say)

Lines 1753, H 109, GIB 377B, BP 53, IS 8884, IS 8887, IS 8891 and IS 8918 are less damaged by the shoot bug (Agarwal, Verma and Bharaj, 1978, H C Sharma, unpublished) BCK 60-1155, 1155, SC 303, SC 261 and Atlas are resistant to chinch bug Sorghum hybrids possessing kafer germplasm exhibit moderate levels of resistance whereas those based on milo cytoplasm are relatively susceptible (Teetes, 1980) Leaves tightly wrapped around the stem have been suggested to be associated with shoot bug resistance in sorghum (Agarwal *et al* , 1978) The fecundity of chinch bugs feeding on BCK 60 1155, 1155 Early Sumac and SC 303 is reduced (Wilde and Morgan, 1978, Mize and Wilde, 1986a b)

Armyworms (*Mythimna separata* Wlk and *Spodoptera frugiperda* J E Smith)

Armyworms are sporadic pests, and result in extensive damage on most cereals during outbreaks (Sharma and Davies, 1983) In such situations plant resistance is unlikely to be helpful However, some resistance may be useful to restrict a population build up Lines E 302 and E 709 (resistant to borers) have been reported to be less damaged by *M separata* SC 109 12, 1821 CM, TAM 2566 and NK Savana 5 are resistant to *Spodoptera frugiperda* (*Table* 5) Antibiosis has been reported as a mechanism of resistance to *S frugiperda* (Lordello, Lara and Parra, 1980) Tannin content of grain does not seem to influence the development of fall armyworm larvae (Wiseman *et al* , 1984), whereas chemical factors in glumes have a greater effect on larval development (Wiseman *et al* , 1986)

Sorghum midge (*Contarinia sorghicola*)

Substantial progress has been made in identification and utilization of resistance to sorghum midge in India (Jotwani, 1978, Sharma, 1985b, Agrawal, Sharma and Leuschner, 1987, Singh, 1987, Sharma *et al* , 1992b), the USA (Johnson, Rosenow and Teetes, 1973, Teetes,

Table 5 Sources of resistance to leaf-feeding insects

Genotype(s)	Remarks	Reference
	Myllocerus maculosus Desb	
SPH 6, 22F, CSV 3, 3600 × 370 and 36A × 148	Less damaged	Kishore, Jotwani and Sharma (1977)
	Mythimna separata	
R 16, R 24, 604 and CS 3541	Less susceptible	Rangarajan *et al.* (1974)
SB 803, 1744, 296 and 604	Less susceptible	Kulkarni and Ramakrishna (1978)
E 302, Fine 141, E 303 and NJ 1953	Less susceptible	Kulkarni, Parameshwarappa and Kajjari (1978a)
SB 905 and SB 412	Least damaged. SB 2145 is highly susceptible	Giraddi and Kulkarni (1986)
IS 9692, IS 61, IS 6984, CSH 5 and CSH 9	Suffered a damage rating of < 2 compared with 8 in IS 2761	H C Sharma (unpublished)
	Spodoptera frugiperda	
IS 4757, SC 109 12 E 15 and EA 761	Most resistant	Lordello *et al.* (1980)
1821 cm	Moderately resistant. SGIRL MR 1 highly susceptible	Wiseman and Gourley (1982) Wiseman (1985)
Savanna 5 and TAM 2566	Greatest differences were observed when milk stage grains were incorporated in the artificial diet	Wiseman *et al.* (1981)
TAM 428, 88 4 Poza Rica, 787 3 and 896 1	Tolerant to armyworm and borer	Guiragossian and Mihm (1985)
NK Savanna 5	Panicle at flowering, milk and hard dough stages affected larval mass in meridic diets compared with Funk HS 218	Wiseman *et al.* (1986)
PI 452554, PI 455018, PI 456111, PI 452571, PI 452962, PI 452987, PI 452771, PI 453120, PI 457620, PI 453356 and PI 454733	Damage rating < 6 compared with 9 in Hucrin Inta	Wiseman and Lovell (1988)

1980, Peterson *et al.*, 1985a), Australia (Page, 1979; Franzmann and Page, 1984; Passlow, Franzmann and Allsopp, 1985) and Latin America (Rossetto, Goncalves and Diniz, 1975; Reyes, 1985; Rossetto, 1985). Sorghum midge resistance is also being utilized in breeding programmes in Africa, Argentina and El Salvador.

IS 2579C, IS 12666C, TAM 2566, AF 28, DJ 6514, IS 10712, Tift MR 88, IS 7005 and IS 8721 are diverse sources of resistance (*Table 6*). ICSV 197, ICSV 745, ICSV 88013 and ICSV 88032 have high levels of midge resistance, and their yield potential is comparable to commercial cultivars. Sorghum midge resistance is being transferred to hybrid parents with improved agronomic backgrounds, and experimental hybrids are being tested. The use of host-plant resistance in the management of sorghum midge is therefore most promising as the levels of resistance are quite high. These new cultivars will provide greater flexibility in sowing times to get maximum yields, and proper utilization of available rainfall without risking midge damage.

Non-preference as a mechanism of resistance to sorghum midge was reported by Wiseman and McMillian (1968) and Sharma, Vidyasagar and Leuschner (1988b). TAM 2566, IS 12666C and SGIRL-MR 1 were not preferred by the midges, and suffered less damage (5–11% florets with midge larvae) under natural conditions, but SGIRL-MR-1 was susceptible under no-choice conditions (Sharma *et al.*, 1988b). Fewer midge flies emerged from panicles of resistant cultivars than from susceptible ones (Jotwani, 1978; Page, 1979; Sharma and Leuschner, 1986; Sharma, Leuschner and Vidyasagar, 1990a; Sharma, Vidyasagar and Leuschner, 1990b). Resistant cultivars (DJ 6514, AF 28, TAM 2566 and IS 15107) had fewer eggs (<50 eggs per 100 florets) in the spikelets compared with the susceptible check CSH 1 (122 eggs per 100 spikelets). The life cycle of sorghum midge is prolonged by 5–8 days when reared on resistant genotypes such as IS 10712, IS 19474, IS 19512 and TAM 2566.

Factors such as the degree of apposition of glumes (Geering, 1953), chestogamous glumes (Bodwen and Neve, 1953), closed spikelets (Rossetto, Nagai and Overman, 1984) and panicle compactness (Murty and Subramaniam, 1978) have been reported to be associated with resistance to sorghum midge. Susceptibility to sorghum midge is positively and significantly correlated with the length of glumes, lemma, palea, anther and

Table 6 Sources of resistance to sorghum midge *Contarinia sorghicola*

Genotype(s)	Remarks	Reference
Nunaba	3 incidence	Bowden and Neve (1953)
ODC 19	0 2 flies per panicle compared with 52 2 flies on CI 938	Wiseman and McMillian (1968)
IS 2579C IS 2816C IS 3574C IS 12612C and IS 12666C	Damage rating < 4 5	Johnson *et al* (1973)
SGIRL MR 1	Damage rating < 5	Wiseman McMillian and Widstrom (1973)
A 25 Grenador INTA mf Linea 64121 mf (RS 25 83) Linea 63/54 mf (RS 2324) Linea 3017 (SA 8774 2 2 109 WH) and 11157 (Arkansas)	Damage rating < 5	Wiseman McMillian and Widstrom (1974)
IS 2660 and IS 2663	Closed glume character	Bergquist Rotar and Mitchell (1974)
Hurein INTA	Tolerant of midge	Parodi Gamba and Scantamburlo (1974)
AF 28	Resistant to midge	Rossetto *et al* (1975)
1809 cm 2321 cm and 2331 cm	Showed least damage	Wiseman McMillian and Widstrom (1975)
DJ 6514	27 9% incidence	Shyamsunder *et al* (1975)
EC 92792 EC 92794 and SGIRL MR 1	< 10% incidence	Raodeo and Karanjkar (1975)
IS 3472 IS 4411 IS 4870 IS 5977 and IS 6170	< 1 midge per panicle	Gowda and Thontadarya (1976)
AF 28	3 midges emerged from AF 28 compared with 137 252 from the susceptible hybrid R 1090	Lara Rossetto and Igue (1977)
Co 4 Co 11 Co 18 and K 4	10% incidence	Murty and Subramaniam (1978)
DJ 6514	Resistant	Kulkarni Parameshwarappa and Kajjari (1978b)
AF 28 IS 1257C and IS 2508C	AF 28 was most stable	Faris Lara and Veiga (1979)
IS 12608C and IS 12664C	Significantly superior to Alpha and KS 19	Page (1979)
I A 73	Highly resistant	Busoli and Osuna (1982)
AF 28	At least two pairs of major recessive genes determine its resistance	Rossetto and Igue (1983)
SGIRL MR 1	Behaved in a different manner to other parents Small glume character was a useful genetic marker	Boozaya Angoon *et al* (1984)
ATx 2754 × Tx 2767	Mean yield loss per female in this hybrid was 0 19 g compared with 0 92 g for susceptible hybrids	Franzmann and Page (1984)
IS 8100C and IS 2549C	Resistant	Hagio *et al* (1984)
ATx 2755 × RTX 2767 and ATx 2761 × RTx 2767	Resistant hybrids lost 0 32 g of grain per midge compared with 1 5 g grain per midge in the susceptible hybrid ATx 2752 × RTx 430	Hallman Teetes and Johnson (1984)
ATx 2755 × RTx 2767 and ATx 2761 × RTx 2767	Midge infested resistant hybrids produced 50-60% less progeny per female	Melton and Teetes (1984)
AF 28	Recorded 17 times less eggs than Sart	Rossetto *et al* (1984)
SGIRL MR 1 and PI 383856	Resistance of SGIRL MR 1 was recessive and greatly reduced when used as a female parent and that of PI 383856 is recessive	Widstrom *et al* (1984)
Tx 2801 to Tx 2815	Resistant to midge Tx 2801 to Tx 2803 are male steriles in A1 cytoplasm	Peterson *et al* (1985a)
ATx 2755 × RTx 2767	Less midges were trapped on it than on ATx 2752 × RTx 430	Waquil Teetes and Peterson (1985)

Table 6 (continued)

Genotype(s)	Remarks	Reference
PVK 80, PVK 55, AF 28 and DJ 6514	Suffered 20% damage compared with 75% in SPV 234. Antibiosis was one of the mechanisms of resistance	Natarajan and Chelliah (1986)
ATx 2755 × Tx 2367	Diazinon application resulted in higher yield in the resistant hybrid	Teetes, Becerra and Peterson (1986)
ATx 2755 × Tx 2767	Oviposition efficiency was 4 times less on the resistant than on the susceptible hybrid ATx 2752 × Tx 430. Few larvae reached last larval instar/pupal stages	Waquil, Teetes and Peterson (1986a, b)
ICSV 197	Highly resistant to midge with yield potential comparable to commercial cultivars	Agrawal *et al.* (1987)
DJ 6514 and IAM 2566	Best general combiners for midge resistance	Agrawal *et al.* (1988)
IS 3017C, NK 66, IS 8100C and IS 2549C	Resistant	Hagio and Ono (1988)
ATx 2755 × Tx 2767, Funk HW 5692 and Funk HW 6048	Showed low susceptibility to midge	Segura Carmona *et al.* (1989)
DJ 6514, IAM 2566 and IS 12666C	Showed repeatable levels of resistance under no-choice headcage testing	Sharma, Vidyasagar and Leuschner (1988a, b)
SGIRL MR 3 and SGIRL MR 4	Resistant to midge	Wiseman, Duncan and Widstrom (1988)
Tift MR 88	Derived from BC 1 population of Redbine 60 × PI 383856	Hanna *et al.* (1989)
IS 18372C, IS 8237C, IS 8112C, IS 2740C, IS 3390C, IS 7132C, IS 2685C, IS 957C, IS 7193C, IS 2144C and IS 12572C	Selected for resistance both by visual scores and percentage yield loss	Peterson *et al.* (1989)
IS 8232C, IS 8237C, IS 8112C, IS 2740C, IS 3390C, IS 7132C, IS 2685C, IS 957C, IS 7193C, IS 2144C and IS 12572C	Resistant to midge	Sharma (1985b)

style. The rate of grain development between the third and seventh days after anthesis is negatively associated with midge damage (Sharma *et al.* 1990a). Short and tight glumes possibly hinder oviposition and limit the space between glumes and ovary for the development of midge larvae. Santos and Carmo (1974) have suggested that the tannin content of grain may be one of the factors imparting resistance to sorghum midge, but there are distinct exceptions, e.g. DJ 6514 (Sharma *et al.* 1990a).

Resistance to *C. sorghicola* is inherited quantitatively and is controlled by additive genes and some cytoplasmic effects (Widstrom, Wiseman and McMillian 1984; Agrawal, Abraham and House 1988). Susceptibility to midge is completely or incompletely dominant in some parents. At least two pairs of recessive genes determine the resistance of AF 28 and genes with minor effects are also present (Rossetto and Igue 1983). Midge resistance of Tift MR 88 has been reported to be under recessive gene control (Hanna *et al.*, 1989). SGIRL-MR-1 and PI 383856 behave in different ways and resistance of SGIRL-MR-1 is lost when used as a female parent (Widstrom *et al.* 1984). The genotypes DJ 6514 and IAM 2566 are good general combiners. Both general and specific combining ability of the parents is important (Patil and Thombre 1985) as the mean performance of parents and general combining ability effects are highly correlated (Agrawal *et al.* 1988).

Head bugs (*Calocoris angustatus* Leth. and *Eurystylus immaculatus* Odh.)

A major effort concerning identification of resistance to head bugs has been made in India (Sharma 1985c; Sharma and Lopez 1990, 1991, 1992a, b) and in West Africa (Sharma, Doumbia and Diorisho 1992a; Sharma *et al.* 1993). IS 17610, IS 17645, IS 21443 and IS 17618 have moderate levels of resistance to *C. angustatus* (Table 7). CSM 388, S 29, IS 14332, Malisor 84-7 and Sakoika are good sources of resistance to *E. immaculatus*. Most of the sources of resistance have either coloured grain/high tannin content or are *guinense* sorghums from West Africa. Malisor 84-7, a line derived from *guinense* sorghums, has a moderate yield potential and is medium dwarf in height, with a good grain quality. It can be cultivated in areas endemic to bugs in West Africa and also used in a resistance breeding programme.

IS 2761, IS 17610, IS 17618 and IS 17645 were not preferred by the bugs in laboratory tests (Sharma and Lopez, 1990). Under cage conditions, nine eggs per 100 spikelets were recorded in IS 17610 compared with 129 eggs per 100 spikelets in CSH 5 (Sharma and Lopez,

Table 7 Sources of resistance to sorghum head bugs

Genotype(s)	Remarks	Reference
	Calocoris angustatus	
Chencholam	Supported low populations	Balasubramanian *et al* (1979)
IS 2761, IS 9692, IS 9639, IS 6984, IS 17610, IS 17618 and IS 17645	Supported lower head bug numbers and or suffered a grain damage rating of 3 compared with 4 in the susceptible cultivar CSH 5	Sharma (1985c)
IS 17610, IS 17618 and IS 17645	Support lower head bug numbers and suffered low grain damage across seasons and infestation levels	Sharma and Lopez (1990, 1991, 1992a, b)
IS 17610, IS 17618, IS 17645, IS 21443, IS 21444, IS 19940, IS 25069, IS 19949, IS 19950, IS 19957, IS 20068, IS 25760 and IS 27329	Suffered a damage rating of 3 across seasons and under headcage conditions compared with a damage rating of >4 in the susceptible cultivar CSH 5	Sharma and Lopez (1992b)
	Eurystylus immaculatus	
IS 14332, Malisor 84-7, CSM 388, S 29, Sakoika and Kamboinse local	Resistant to *Eurystylus immaculatus* under natural and headcage conditions	Sharma *et al* (1992a, 1993)

1990). Cultivar non-preference is also a component of resistance to *Eurystylus*. IS 14332, CSM 388, Malisor 84-7, 83F6-16 and 83F6-111 had less than five females per panicle compared with 11 females per panicle in E 35-1 under free-choice conditions in the field. The non-preference of CSM 388 has also been confirmed in laboratory cage tests (Sharma *et al*, 1993). Post-embryonic development of *C. angustatus* is prolonged by 1–2 days on IS 17610, IS 17618 and IS 17645. Survival and establishment of first-instar nymphs is relatively lower on IS 17645 than on the susceptible checks, CSH 1 and CSH 5 (Sharma, 1985c, Sharma and Lopez, 1990). Growth rate and efficiency of conversion of ingested food into body matter are lower on IS 6984 and IS 2761 than on CSH 5 (Sharma, 1985c).

Balasubramanian *et al* (1979) reported that cultivars with loose panicles are less susceptible to head bugs. Grain damage and bug population increase are positively associated with panicle compactness (Sharma, 1985c, Sharma *et al*, 1993). However, under heavy levels of head bug density, severe grain damage of genotypes with loose panicles could be due to other factors. Cultivars less susceptible to *C. angustatus* tend to have long, hard and less hairy glumes (Sharma, 1985c). Days to glume opening (>20 days from anthesis), longer glumes (>5 mm), >50% of the grain surface covered by the glumes, hard corneous grain, and possibly quicker grain ripening, all contribute towards resistance to *E. immaculatus* (Sharma *et al*, 1993).

Head caterpillars (*Helicoverpa armigera* Hb.)

Resistance to head caterpillars has not been studied specifically, although some lines suffering less damage have been reported. Chencholam, SPV 130, SPV 69, SPV 9, RS 160 and K Tall are resistant to head caterpillars (Wilson, 1976, Balasubramanian *et al*, 1979, Natarajan and Babu, 1988). Genotypes with loose panicles suffer little damage by head caterpillars, possibly because of easy access to parasitoids and predators (Balasubramanian *et al* 1979). The ability to combine factors for resistance to head caterpillars has been studied by Patel *et al* (1986).

Effect of insect-resistant cultivars on population dynamics and economic thresholds

Adequate levels of resistance are present against only a few sorghum pests — sorghum midge and aphids. However, varieties with low to moderate levels of resistance against shoot fly, stem borers, head bugs and armyworms can be very useful for pest suppression over a period of time. The adverse effects of resistant genotypes on pest populations are continuous, cumulative and without costs to the farmers, whereas pesticides require money and their effect on pest populations declines over time, so they may require reapplication. Reduction in pest density through plant resistance also can assist control with natural enemies and reduces the number of pesticide treatments that may be needed. A reduction of the rate at which the pest populations increase will delay the attainment by the insect of an economic threshold level (ETL). This is especially true if the resistance mechanisms increase the mortality of immature stages and prolong the developmental period of survivors. The delay may also prevent the insect population reaching an ETL until after the most susceptible stage of the crop, thus eliminating the need for any insecticide use. Overall, the use of host-plant resistance in IPM conserves natural enemies, preserves environmental quality, and slows down the rate of development of insecticide-resistant insect populations.

Effect of host-plant resistance on economic thresholds (ETL)

The effect of insect-resistant cultivars on threshold levels will depend on the nature of resistance and the criterion on which the threshold is based. If the ETL is based on damage (e.g. percentage of deadhearts for shoot fly and stem borer, number of leaves damaged by aphids or percentage leaf area consumed by armyworms) and the major component of resistance is tolerance, non-preference and antibiosis (as in shoot fly, stem borers, greenbug, aphids, armyworms etc.), then economic damage will be suffered by a susceptible cultivar in July, a moderately resistant cultivar in August and a resistant cultivar by the end of the season (*Figure 1 a,c*). Where insect damage is limited to a particular stage and over a short period (e.g. deadheart formation due to shoot fly and stem borer), the dates when a cultivar can be sown will depend on its level of resistance. Thus a susceptible cultivar such as CSH 1 cannot be sown after June.

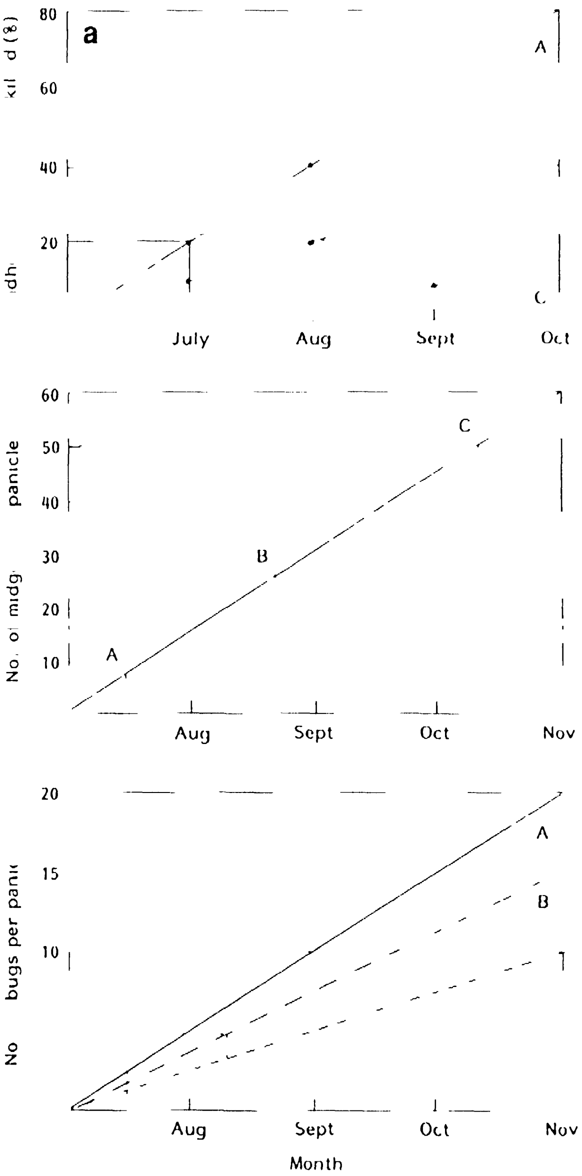

Figure 1. Effect of host plant resistance on economic threshold level (ETL) when the ETL is based on (a) damage, (b) non damaging adult stage and (c) damaging adults on genotypes with non-preference and antibiosis. A, B, and C are susceptible, moderately resistant and resistant genotypes, respectively.

If the ETL is based on adults that do not damage the crop, such as midge adults on panicles or the number of moths caught in pheromone or light traps, the ETL will be higher with an increase in the level of insect resistance. The ETL of sorghum midge may be five adults per panicle for a susceptible cultivar, 25 adults per panicle for a moderately resistant cultivar, and >50 adults per panicle for a highly resistant cultivar (*Figure 1b*). Under field conditions if the insect density increases linearly between August and November, the susceptible cultivar must flower by September, the moderately resistant one by October and the highly resistant one at any time, to keep the midge damage below ETL. Thus based on ETL for a genotype, a suitable cultivar can be selected for sowing early or late in the season. If the ETL is based on adults that cause damage (e.g. head bugs), and the mechanism of resistance is non preference and antibiosis (decreasing the rate of population increase), then sowing a resistant variety will increase the ETL (*Figure 1c*) and also delay when it is attained.

Effect of plant resistance on insect density/yield loss relationship

The usefulness of resistant cultivars can be assessed from relationships between insect density and yield loss on resistant and susceptible cultivars. Plant resistance to shoot fly depends on non-preference, but this mechanism does not operate under no choice conditions or under situations of high pest density. For all cultivars, >20% deadhearts result in a significant decrease in grain yield (*Figure 2*). The ultimate aim should therefore be to develop cultivars that would suffer <20% deadhearts, irrespective of pest densities or sowing dates. Currently available cultivars suffer 50% damage when susceptible cultivars suffer 100% damage.

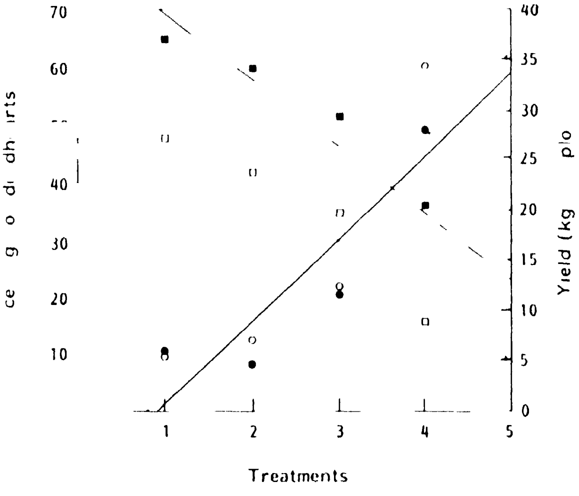

Figure 2. Effect of different levels of protection (treatments 1–4) on shoot fly deadhearts and grain yield in the susceptible cultivar CSH 1 during 1983–84. ●——●, Percentage deadhearts, 1983; ■——■, yield, 1983; ○- -○, percentage deadhearts, 1984; □- -□ yield, 1984 (S L Taneja, personal communication).

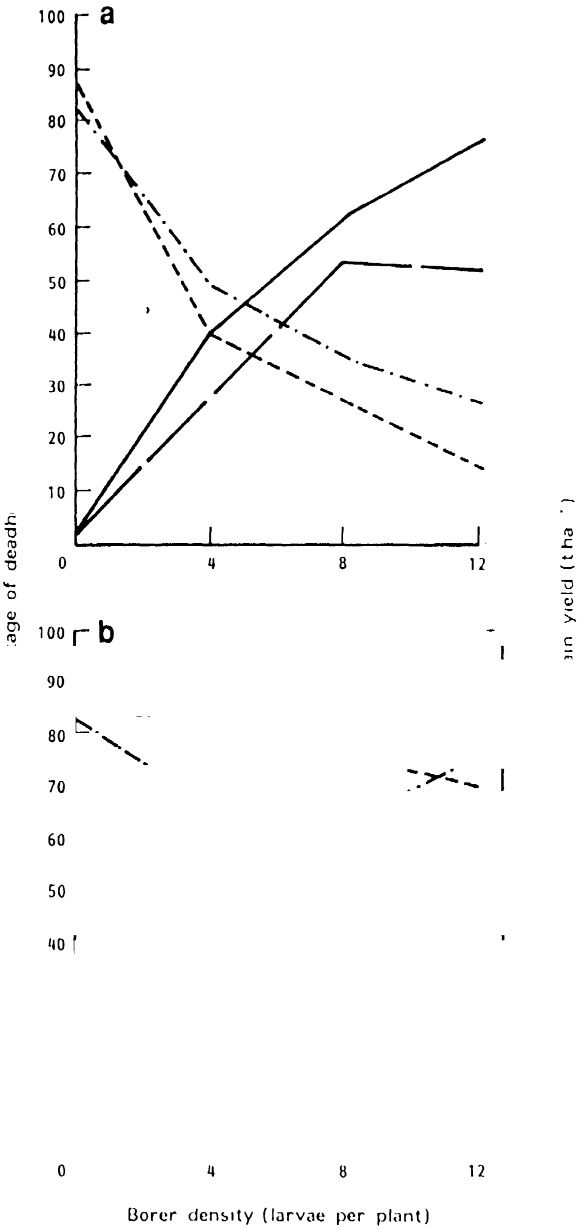

Figure 3 Effect of number of larvae per plant on deadheart formation and grain yield (a) 20 and (b) 40 days after emergence (Taneja and Nwanze, 1989) —·—·—, Yield of resistant cultivar, – – –, yield of susceptible cultivar, ———, percentage of deadhearts on susceptible cultivar, — — —, percentage of deadhearts on resistant cultivar

With *C partellus*, the situation is almost similar to that of shoot fly, except that the pest can complete 3-4 generations on a single crop compared with only one shoot fly generation. Thus, even low levels of resistance can have a greater cumulative effect in reducing pest populations. The extent of damage (deadheart formation) is greatly influenced by the timing of infestation (*Figure 3*) Greater damage and yield loss can occur 20 days after crop emergence compared with 40 days after crop emergence Under a heavy infestation (12 larvae per plant), a resistant cultivar yields more than a susceptible cultivar whereas the reverse can occur without borer infestation

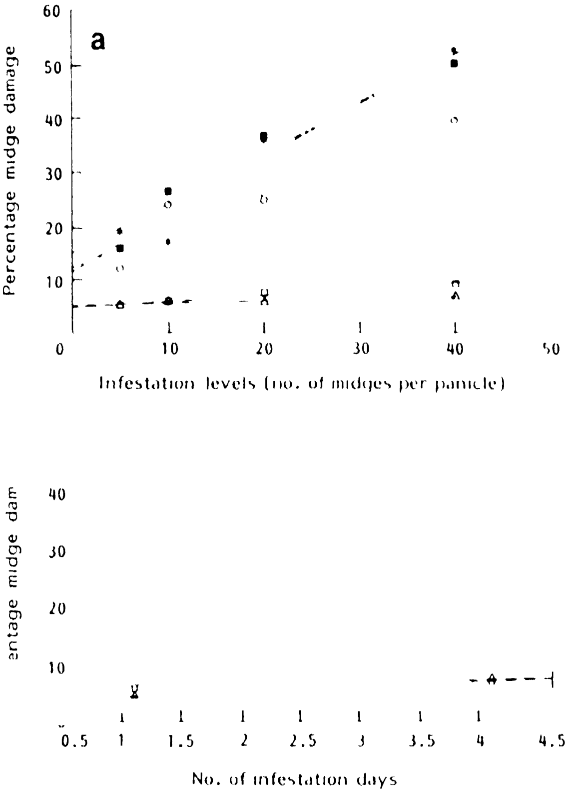

Figure 4 Effect of (a) insect density (no of midges per panicle) and (b) number of infestation days on midge damage in five sorghum genotypes resistant cultivars ICSV 197 (I) and ICSV 745 (/), susceptible cultivars ICSV 1 (( ), ICSV 112 (•) and CSH 1 (■) (H C Sharma, unpublished)

In relation to level of midge infestation or number of infestation days, the extent of loss (percentage midge damage) remains < 10% in the resistant cultivars ICSV 197 and ICSV 745 compared with a linear increase in damage in the susceptible cultivars CSH 1, ICSV 1 and ICSV 112 (*Figure 4*) At five midges per panicle, the susceptible cultivars lose 10-20% grain yield compared with <4% in the resistant cultivars Thus, midge-resistant cultivars can be sown irrespective of pest densities without suffering a significant loss in grain yield

Bug numbers remain substantially lower across stages of panicle development on a resistant cultivar (IS 21443) compared with a susceptible cultivar (CSH 11) (*Figure 5*) At the dough stage, there were 824 bugs per five panicles in CSH 11 sprayed four times with demeton-O-methyl compared with eight bugs per five panicles in the resistant cultivar IS 21443 Yield potential of the susceptible hybrid is much greater than that of the resistant cultivars, but a very low level of head bug damage can render the grain unfit for human consumption (Sharma and Lopez, 1989) Loss in grain yield in CSH 11 due to head bugs is 3 t ha^{-1} compared with 0.74 t ha^{-1} for IS 21443. Currently available sources of resistance to bugs reduce the rate of increase in bug populations, resulting in less loss of grain yield and quality

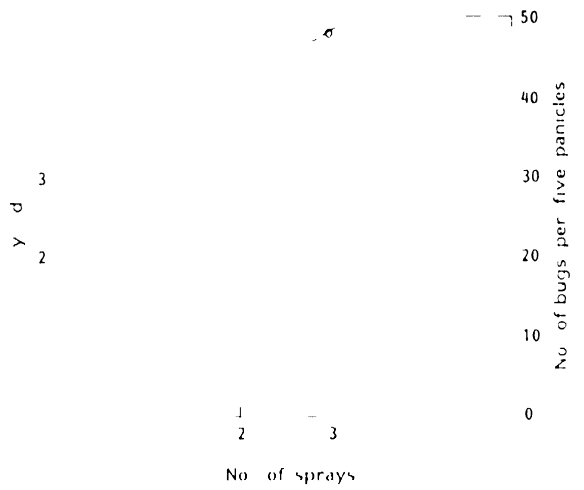

Figure 5 Effect of different levels of protection (no of sprays) on head bug numbers (closed symbols) and grain yield (open symbols) in a resistant (IS 21443) and a susceptible cultivar (CSH 11 ———) (H C Sharma unpublished)

Host-plant resistance as a component of IPM in sorghum in different agroecosystems

The most acceptable form of IPM involves the use of insect-resistant varieties in conjunction with crop husbandry practices and natural enemies, with insecticides applied only if really necessary. Both natural enemies and insecticides can be used in an IPM system provided that the target pests for each are separated in space (e g root feeding pests such as white grubs versus foliage feeders such as armyworms, aphids, etc) or time (at different stages of crop growth). As improved cultivars do not have adequate host plant resistance against bugs, chemical control with carbaryl (0 1%) or demeton O methyl (0 025%) is a better option based on economic thresholds (five bugs per ten panicles at half anthesis) (Sharma and Leuschner 1987, Sharma and Lopez 1989). In this situation natural enemies can be combined with moderate levels of plant resistance to control shoot fly and stem borers. Where chemical control is neither feasible nor economical, resistance to key pests has to be sufficiently high to avoid pesticide use and conserve the natural enemies.

The role of host-plant resistance for pest management in different agroecosystems is discussed below.

South Asia

During the rainy season, timely sowing of the same cultivar over a large area can minimize shoot fly and midge damage. This will help decrease the insect density per plant, and also avoid the multiplication of the pest that occurs on sequentially sown crops. Where other insects such as stem borers, armyworms and head bugs are also important, a need-based insecticide may be applied to minimize damage. *Trichogramma* spp and *Apanteles flavipes* Cam are important parasitoids for the control of stem borers. *A ruficrus* Hal can be used for the biological control of *M separata*. Timely sowing of midge resistant varieties can avoid shoot fly damage, and head bugs may be controlled with insecticides if necessary. Midge resistant varieties such as ICSV 197, ICSV 88032 and ICSV 88013 with loose panicles are also less damaged by the head caterpillars. Stem borer is a problem in Pakistan, Iran and Syria while midge can be devastating in Yemen. Genotypes with resistance to these pests may be developed to fit into specific needs of these regions but generally more studies are needed to determine the relative importance of pest species and to develop the IPM systems accordingly.

Cultivars with moderate levels of resistance to shoot fly such as M 35 1, IS 2205, CSH 8R and CSH 13R can be sown during the first fortnight of October when shoot fly incidence begins to decline during the post-rainy season in India. Midge and head bugs are not major pests during the post rainy season, however, as most of the genotypes with adaptation to the post rainy season are highly susceptible to these pests, an insecticide application may be necessary. *Trichogramma* and *A flavipes* can be used as important natural enemies against borers.

South East Asia

Most sorghum grown in this region is for feed and sown after the main crop of paddy. Shoot fly and armyworms are the major pests of sorghum in this area with aphids in colder areas. Midge has been reported to be a problem in the Philippines, Japan, China and Thailand. Genotypes with specific resistance to shoot fly are needed for most areas but other pests such as armyworms may have to be controlled by using natural enemies or insecticides. Dwarf cultivars with resistance to shoot fly and midge are most desirable. Resistance to aphids is required in China, Taiwan and Japan.

Americas

Cultivars with adequate levels of resistance to aphids have been developed, and efforts are being made to develop midge-resistant hybrids. Other pests are sporadic in nature and may be managed through other components of pest management. The parasite *Lysiphlebus testaceipes* Cress can be used for the management of aphids in conjunction with resistant varieties (Starks, Muniappan and Eikenbary 1972, Starks, Wood and Burton 1974).

Australia

Midge-resistant varieties and hybrids are needed for control of this major pest. Other pests, which are sporadic in nature, may be controlled through other components of IPM.

Eastern Africa

In Burundi, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania and Uganda the severity of stem borers, midge, shoot fly and aphids differs. Armyworms and locusts are sporadic pests, while head bugs may become serious on late-flowering crops. In equatorial areas, two successive crops of sorghum are grown during the long- and short-season rains; in addition, the sowings are staggered in relation to rainfall pattern. This creates conditions that are highly conducive to increased populations of shoot fly and midge. Local landraces are tall, photoperiod sensitive, coloured (less damaged by birds) and have specific adaptations for pests, diseases and drought, depending upon altitude, latitude and rainfall pattern. To increase sorghum productivity, short-duration (for drought-prone areas) and medium-duration cultivars are required. Resistance (or at least some tolerance) to stem borers and shoot fly is essential in most areas, especially the drier lowland and mid hill areas where most sorghum is grown. Farmers have a marked preference for red sorghums to minimize bird damage but, where large areas are sown, white sorghums can be cultivated to increase crop productivity and improve nutrition. Resistance to aphids is also essential in some of these areas. Resistance to midge will be most desirable for regions in which the sowings are staggered or where the genotypes with different maturities are grown, e.g. the lowlands of Ethiopia (Gambella region), the midlands of Kenya (Busia region) and Tanzania. As resistance to shoot flies and midge is not available in the same backgrounds, genotypes with specific resistances to these pests may be sown over large areas to avoid population build-up. Mixed cropping of sorghum with cowpeas, together with biological control, can also be used to minimize the damage by stem borers. Chemical control is largely non-existent in these areas, but in epidemic situations such as major armyworm infestations, chemical control may be necessary. With a change in the cropping patterns and the cultivars grown, the situation with head bugs (*Taylorilygus*) may have to be watched carefully.

West Africa

In sub-Saharan Africa (Mauritania, Senegal, Mali, Niger, Nigeria, Cameroon, Burkina Faso, Togo, Ivory Coast, Ghana, etc.), the major pests of sorghum are head bugs, midge, stem borers and shoot fly. Farmers usually grow tall photoperiod-sensitive *guinense* landraces, which flower at the end of the rainy season during the last week of September. In some areas, *durra* and *durra-bicolor* sorghums are also grown. There is a wide variation in rainfall (400-1500 mm) in the sorghum-growing areas, accordingly, landraces with specific adaptation to different agroclimatic regions are grown by the farmers. Efforts to replace the local landraces have largely been unsuccessful because of problems of adaptation and food quality. The latter is highly influenced by head bug damage, which also predisposes the grain to a greater incidence of grain mould. Resistance to head bugs and/or midge is essential in most areas; resistance to stem borers is necessary in drier zones. Timely and uniform sowing of the same cultivar in a region can help to minimize the losses due to shoot fly and midge. Local landraces have long glumes, which cover the grain for a period of 20-25 days compared with 6-8 days in the improved cultivars. These genotypes usually have very hard and corneous grain, which reduces the effective feeding period by the head bugs. In addition, these genotypes flower at the end of the rainy season when the relative humidity begins to decline and the climatic conditions are not conducive to the development and survival of head bugs.

Medium maturity genotypes with glume, grain and panicle characteristics imparting resistance to head bugs need to be developed for this region. Furthermore, improvements within *fara fara* in Nigeria and *guinense* sorghums in other regions would be highly desirable. Efforts are being made to achieve this objective in ICRISAT's sorghum improvement programme in West Africa. CSM 388 (a high yielding landrace of *guinea* sorghums) and Malisor 84-7 (a medium maturity line derived from *guinea* sorghums) may be useful for areas endemic to head bugs. Midge resistant lines may be useful in areas where midge populations build up because of staggered sowings. As head bugs are external feeders, chemical control is fairly effective, and a single application of a readily available insecticide is enough to minimize head bug damage. Intercropping sorghum with cowpeas (which is the most important legume crop of the region) can also be used to reduce the damage by stem borers.

Southern Africa

Stem borers, shoot fly, armoured cricket and aphids are some of the important pests of sorghum in southern Africa. Head bugs have begun to appear on newly developed genotypes in Botswana. Both local landraces and improved genotypes are grown by farmers in the region. Cultivars with resistance to borers and aphids may be applicable to the integrated pest management systems. Timely and uniform sowing can reduce the incidence of shoot fly and midge, and adequate fertilizer application can help to reduce damage by borers. Head bugs may have to be watched carefully on newly developed cultivars. Birds are by far the most important pests in this region. Coloured grain sorghums with a high tannin content, which are also useful in the brewing industry, may be developed for these areas.

Notes and acknowledgements

The author is grateful to Dr G. A. Matthews, UK, for his encouragement to prepare this manuscript, to Drs J. M. J. de Wet, K. F. Nwanze, A. M. Zein El-Abdin

and R V Satyanarayana Rao for their comments to Mr P Vidyasagar for his help in preparing the figures Dr S L Taneja for providing some data on shoot fly and stem borer and Mr T Krishna Murthy for typing the manuscript

Approved as **JA No 1269 by ICRISAT**

References

Agarwal, R K , Verma, R S and Bharaj, G S (1978) Screening sorghum lines for resistance against shoot bug *Peregrinus maidis* (Ashmead) (Homoptera Delphacidae) *JNKVV Res J* **12** 116

Agrawal, B L and Abraham, C V (1985) Breeding sorghum for resistance to shoot fly and midge In *Proc Int Sorghum Entomol Workshop 15 21 July 1984 Texas A&M Univ College Stn TX USA* pp 371 383 International Crops Research Institute for the Semi Arid Tropics (ICRISAT) Patancheru Andhra Pradesh India

Agrawal, B L and Taneja, S L (1989) Breeding for resistance to stem borer (*Chilo partellus* Swinhoe) in sorghum In *Int Workshop Sorghum Stem Borers 17 20 Nov 1987 ICRISAT Center* pp 159 168 ICRISAT Patancheru Andhra Pradesh India

Agrawal, B L , Abraham, C V and House, L R (1988) Inheritance of resistance to midge *Contarinia sorghicola* Coq in sorghum *Sorghum bicolor* (L) Moench *Insect Sci Appl* **9** 43 45

Agrawal, B L , Sharma, H C and Leuschner, K (1987) Registration of ICSV 197 midge resistant sorghum cultivar *Crop Sci* **27** 1312 1313

Alghali, A M (1985) Insect host plant relationships the spotted stalk borer *Chilo partellus* (Swinhoe) (Lepidoptera Pyralidae) and its principal host sorghum *Insect Sci Appl* **6** 315 322

Alghali, A M (1987) Effect of time of *Chilo partellus* Swinhoe (Lepidoptera Pyralidae) infestation on yield loss and compensatory ability in sorghum cultivars *Trop Agric (Trinidad)* **64** 144 148

Alghali, A M and Saxena K N (1988) Larval movement feeding and development of *Chilo partellus* Swinhoe (Lepidoptera Pyralidae) on two sorghum cultivars *Insect Sci Appl* **9** 7 11

Archer, T L , Bynum, E D and Peterson, G C (1986) Importance of plant senescence on grain sorghum resistance to the Banks grass mite (Acari Tetranychidae) *J Econ Entomol* **79** 15 17

Balakotaiah, K , Rana, B S , Tripathi, D P and Rao, N G P (1975) Genetic analysis of some exotic × Indian crosses in sorghum X Inheritance of resistance to sorghum shoot fly *Indian J Genet* **35** 344 349

Balasubramanian, G , Sivaprakasam, K , Kulandaivelu, R and Robinson, J G (1979) Impact of sorghum earheads on the incidence of earheadbug caterpillar webber and mould *Indian J Agric Res* **13** 106 108

Baletka, A D and Castellano, S R (1984) Levels of greenbug (*Schizaphis graminum* (Rond)) resistance in cultivars of commercial grain sorghum *Sorghum Newslett* **27** 81

Bapat, D R and Mote, U N (1982a) Upgrading the resistance levels of derivatives from Indian × Indian crosses of sorghum against shootfly *J Maharashtra Agric Univ* **7** 170–173

Bapat, D R and Mote, U N (1982b) Sources of shoot fly resistance in sorghum *J Maharashtra Agric Univ* **7** 238 240

Bergquist, R R , Rotar, P and Mitchell, W C (1974) Midge and anthracnose head blight resistance in sorghum *Trop Agric (Trinidad)* **51** 431–435

Bernays, E A , Chapman, R F and Woodhead, S (1983) Behaviour of newly hatched larvae of *Chilo partellus* (Swinhoe) (Lepidoptera Pyralidae) associated with their establishment in the host plant sorghum *Bull Entomol Res* **73** 75–83

Biradar, S G and Borikar, S T (1985) Genetic analysis of shoot fly resistance in relation to growth stages in sorghum *Z PflZucht* **95** 173–178

Blum, A (1968) Anatomical phenomena in seedlings of sorghum varieties resistant to the sorghum shoot fly (*Atherigona varia soccata*) *Crop Sci* **8** 388–390

Blum, A (1972) Breeding for resistance in crop plants with special reference to sorghum In *Sorghum in the Seventies* (Ed by N G P Rao and L R House) pp 390 410 Oxford and IBH Publishing Co New Delhi India

Borad, P K and Mittal V P (1983) Assessment of losses caused by pest complex to sorghum hybrid CSH 5 In *Crop Losses due to Insect Pests* (Ed by B H Krishnamurthy Rao and K S R K Murthy) pp 271 278 Entomological Society of India Rajendranagar Hyderabad Andhra Pradesh India

Boozaya-Angoon D Starks K J Weibel D E and Teetes G L (1984) Inheritance of resistance in sorghum *Sorghum bicolor* to the sorghum midge *Contarinia sorghicola* (Diptera Cecidomyiidae) *Environ Entomol* **13** 1531 1534

Borikar S T and Chopde P (1980) Inheritance of shoot fly resistance under three levels of infestation *Maydica* **25** 175 183

Borikar S T and Chopde P R (1981) Inheritance of shoot fly resistance in sorghum *J Maharashtra Agric Univ* **6** 47 48

Borikar, S T and Chopde P (198) Genetics of resistance to sorghum shoot fly *Z PflZucht* **88** 220 224

Borikar, S T Chandurwar R D and Chopde P R (1982a) Note on genetic variability for traits related with primary and recovery resistance to shootfly in sorghum *Indian J Agric Sci* **52** 867 869

Borikar, S T , Chandurwar, R D and Chopde P R (1982b) Genetic variability for shoot fly resistance in sorghum *J Maharashtra Agric Univ* **7** 223 225

Bothe N N and Pokharkar R N (1985) Role of silica content in sorghum for reaction to shoot fly *J Maharashtra Agric Univ* **10** 338 339

Bowden, J and Neve R A (1953) Sorghum midge and resistant varieties in Gold Coast *Nature Lond* **172** 551

Burton R L Burd J D Jones O R and Wicks G A (1990) Crop protection strategies for managing greenbug *J Econ Entomol* **83** 2476 2479

Busoli A C and Osuna J A (1982) Resistance of genotypes of sorghum (*Sorghum bicolor* (L) Moench) to *Contarinia sorghicola* (Coquillet 1908) (Diptera Cecidomyiidae) under field conditions *Anais Soc Entomol Brasil* **11** 169 180

Campbell, B C McLean, D L Kinsey M G Jones K C and Dreyer, D L (1982) Probing behaviour of the greenbug (*Schizaphis graminum* biotype C) on resistant and susceptible varieties of sorghum *Entomologia exp appl* **31** 140 146

Chang, C P and Fang, M N (1984) Studies on the resistance of sorghum varieties to the sorghum aphid *Melanaphis sacchari* (Zehntner) *Chin J Entomol* **4** 97 105

Chang, N T (1981) Resistance of some grain sorghum cultivars to sorghum aphid injury *Plant Prot Bull Taiwan* **23** 35 41

Chapman, R F Woodhead, S and Bernays E A (1983) Survival and dispersal of young larvae of *Chilo partellus* (Swinhoe) (Lepidoptera Pyralidae) in two cultivars of sorghum *Bull Entomol Res* **73** 65 74

Cruz, I and Vendramin, J D (1988) Effects of different levels of infestation by the green bug *Schizaphis graminum* (Rondani 1852) on susceptible and resistant sorghum *Pesq Agropec Brasil* **23** 111 118

Dabrowski, Z T and Kidiavai, E L (1983) Resistance of some sorghum lines to spotted stalk borer *Chilo partellus* under Western Kenya conditions *Insect Sci Appl* **4** 119 126

Dalvi, C S , Dalaya, V P and Khanvilkar, V G (1983) Screening of some sorghum varieties for resistance to stem borer *Chilo partellus* (Swinhoe) *Indian J Entomol* **45** 266 271

Dalvi, C S , Dalaya, V P and Khanvilkar, V G (1990) Screening of some sorghum varieties for resistance to shoot fly *Atherigona soccata* Rondani *Indian J Entomol* **52** 279 289

Davies, J C (1981) Pest losses and control of damage on sorghum in developing countries the realities and myths In *Sorghum in the Eighties Proc Int Symp Sorghum 2 7 Nov 1981* pp 215 223 ICRISAT Patancheru Andhra Pradesh India

De Pew, L J and Witt, M D (1979) Evaluations of greenbug resistant sorghum hybrids *J Econ Entomol* **72** 177 179

Dhaliwal, J S, Mahindratta, P D and Arora, B S (1988) Reaction of some promising sorghum fodder varieties to insect pests *J Res Punjab Agric Univ* **25** 280–286

Dixon, A G O, Brand Cox, D J, Reese, J C and Harvey, T L (1990) Mechanisms of resistance and their interactions in twelve sources of resistance to biotype E of greenbugs (Homoptera Aphididae) in sorghum *J Econ Entomol* **83** 234–240

Doggett, H (1972) Breeding for resistance to sorghum shoot fly in Uganda In *Control of Sorghum Shoot Fly* (Ed by M G Jotwani and W R Young) pp 192–201 Oxford and IBH New Delhi India

Doggett, H (1988) *Sorghum* Longman London 688 pp

Doggett, H Starks, K J and Eberhart, S A (1970) Breeding for resistance to the sorghum shoot fly *Crop Sci* **10** 528–531

Dreyer, D L and Campbell, B C (1984) Association of the degree of methylation of intercellular pectin with plant resistance to aphids and with induction of aphid biotypes *Experientia* **40** 224–226

Faris, M A, Lira, M de A and Veiga, A F de S L (1979) Stability of sorghum midge resistance *Crop Sci* **19** 577–580

Foster, D G, Teetes, G L, Johnson, J W and Ward, C R (1977) Resistance in sorghums to the banks grass mite *J Econ Entomol* **70** 259–262

Franzmann, B A and Page, F D (1984) Relationship between sorghum midge (*Contarinia sorghicola*) (Coquillett) numbers and damage in a selection of sorghum genotypes *Sorghum Newslett* **27** 81

Gahukar, R T and Jotwani, M G (1980) Present status of field pests of sorghum and millets in India *Trop Pest Mgmt* **26** 138–151

Galli, A J B, Lara, F M and Barbosa, J C (1981) Resistance of genotypes of sorghum to *Schizaphis graminum* (Rondani 1852) (Homoptera Aphididae) *Anais Soc Entomol Brasil* **10** 61–71

Geering, Q A (1953) The sorghum midge *Contarinia sorghicola* in East Africa *Bull Entomol Res* **44** 363–366

Ghode, R N (1971) Study of natural resistance of popular varieties to tissue borers *Sorghum Newslett* **14** 54–56

Giraddi, R S and Kulkarni, K A (1986) Sorghum varietal reaction to the armyworm *Mythimna separata* (Walker) under field conditions *Mysore J Agric Sci* **20** 201–203

Gowda, B T V and Thontadarava, T S (1976) Varietal response of sorghum to the midge *Contarinia sorghicola* (Coquillet) (Diptera Cecidomyiidae) *Curr Sci* **4** 177–179

Guiragossian, V and Mihm, J A (1985) Improving host plant resistance to fall armyworm and sugarcane borer in sorghum In *Proc Int Sorghum Entomol Workshop 15–21 July 1984 Texas A&M Univ College Stn TX USA* pp 201–204 ICRISAT Patancheru Andhra Pradesh India

Hagio, T and Ono, S (1988) Screening for varietal resistance to sorghum midge (*Contarinia sorghicola* Coquillett) in sorghum (*Sorghum bicolor* Moench) [*Bull Chugoku Expl Stn] Chugoku Nogyo Shikenjo Kenkyu Hokoku* **2** 1–11

Hagio, T, Umehara, M and Ono, S (1985) Varietal reaction of sorghum to sugarcane aphid (*Melanaphis sacchari* Zehntner) in the seedling stage *Sorghum Newslett* **28** 51–52

Hagio, T, Hoshino, T, Ono, S and Umehara, M (1984) Varietal reactions of grain sorghum to sorghum midge *Sorghum Newslett* **27** 90

Hallman, G J, Teetes, G L and Johnson, J W (1984) Relationship of sorghum midge (Diptera Cecidomyiidae) density to damage in resistant and susceptible sorghum hybrids *J Econ Entomol* **77** 83–87

Hanna, W W, Wiseman, B R, Duncan, R R and Schertz, K F (1989) Registration of Tift MR 88 midge resistant sorghum germplasm *Crop Sci* **29** 246–248

Harvey, T L and Hackerott, H L (1974) Effects of greenbugs on resistant and susceptible sorghum seedlings in the field *J Econ Entomol* **67** 377–380

Harvey, T L and Thompson, C A (1988) Effects of sorghum density and resistance on infestation of greenbug *Schizaphis graminum* (Homoptera Aphididae) *J Kansas Entomol Soc* **61** 68–71

Hsieh, J S and Pi, C P (1988) Diallel analysis of resistance to aphid in sorghum *J Agric Ass China* **142** [illegible] 84

ICRISAT (International Crops Research Institute for the Semi Arid Tropics) (1985) *Proc Int Sorghum Entomol Workshop 15–21 July 1984 Texas A&M Univ College Stn TX USA* ICRISAT Patancheru Andhra Pradesh India

Jadhav, S S, Mote, U N and Bapat, D R (1988) Performance of sweet stalked sorghum genotypes to shoot fly reaction *J Maharashtra Agric Univ* **13** 252–254

Johnson, J W, Rosenow, D T and Teetes, G L (1973) Resistance to the sorghum midge in converted sorghum cultivars *Crop Sci* **13** 754–755

Jotwani, M G (1978) *Investigations on Insect Pests of Sorghum and Millets with Special Reference to Host Plant Resistance Final Technical Report (19[illegible]) Res Bull Div Entomol* Indian Agricultural Research Institute New Delhi India 114 pp

Jotwani, M G (1982) Factors reducing sorghum yields insect pests In *Sorghum in the Eighties Proc Int Symp Sorghum* [illegible] *Nov 1981* pp 251–255 ICRISAT Patancheru Andhra Pradesh India

Jotwani, M G and Srivastava, K P (1970) Studies on sorghum lines resistant against shoot fly *Atherigona varia soccata* Rond *Indian J Entomol* **32** 1–3

Jotwani, M G, Chaudhari, S and Singh, S P (1978a) Mechanism of resistance to *Chilo partellus* (Swinhoe) in sorghum *Indian J Entomol* **40** 273–276

Jotwani, M G, Srivastava, K P and Kundu, G G (1971) Two highly promising stem borer resistant lines of sorghum *Entomologist's Newslett* **4** 51–52

Jotwani, M G, Young, W R and Teetes, G L (1980) *Elements of integrated control of sorghum pests FAO Plant Prod Prot Paper* FAO Rome Italy 159 pp

Jotwani, M G, Srivastava, K P, Kundu, G G, Kishore, P and Sukhani, T R (1978b) Management of the stem borer *Chilo partellus* (Swinhoe) infesting sorghum through resistant varieties and chemical control *J Entomol Res* **2** 203–208

Jotwani, M G, Kundu, G G, Kishore, P, Srivastava, K P, Sukhani, T R and Singh, S P (1979) Evaluation of some high yielding sorghum derivatives for resistance to stem borer *Chilo partellus* (Swinhoe) *Indian J Entomol* **41** 1–4

Khurana, A D and Verma, A N (1982) Amino acid contents in sorghum plants resistant/susceptible to stem borer and shoot fly *Indian J Entomol* **44** 184–188

Khurana, A D and Verma, A N (1983) Some biochemical plant characters in relation to susceptibility of sorghum to stem borer and shoot fly *Indian J Entomol* **45** 29–37

Khurana, A D and Verma, A N (1985) Some physical plant characters in relation to stem borer and shoot fly resistance in sorghum *Indian J Entomol* **47** 14–19

Kishore, P (1986) Breeding for resistance to shoot fly and stem borer in sorghum *Insect Sci Appl* **7** 117–121

Kishore, P (1987a) P 311 A new sorghum variety resistant to the stem borer *Chilo partellus* (Swinhoe) *J Entomol Res* **11** 115–118

Kishore, P (1987b) New sources of resistance to stem borer *Chilo partellus* (Swinhoe) in sorghum *J Entomol Res* **11** 155–157

Kishore, P, Jotwani, M G and Sharma, G C (1977) Screening of sorghum lines for relative susceptibility to the cotton grey weevil *Myllocerus maculosus* Debrochers (Curculionidae Coleoptera) *Indian J Entomol* **39** 379–381

Kishore, P, Rana, B S and Agarwal, K N (1985) Selection for shootfly *Atherigona soccata* Rondani resistance in high yielding varieties of sorghum *J Entomol Res* **9** 188–194

Kishore, P, Rana, B S and Sharma, G C (1984) Selection for stem borer *Chilo partellus* (Swinhoe) resistance in segregating generations of sorghum *J Entomol Res* **8** 20–24

Krishnananda, M, Jayaraj, S and Subramaniam, T R (1970) Resistance in sorghum to stem fly *Atherigona varia soccata* R *Madras Agric J* **57** 674–679

Kulkarni, K A and Ramakrishna, V C (1975) Studies on the susceptibility of sorghum lines and hybrids to the armyworms (*Pseudaletia separata* Walker) *Sorghum Newslett* **18**, 33

Kulkarni, K. A., Parameshwarappa, R. and Kajjari, N. B. (1978a) Screening of high yielding sorghum varieties to armyworm (*Mythimna separata* Walker) *Mysore J Agric Sci* **12** 572 574

Kulkarni, K. A., Parameshwarappa, R. and Kajjari, N. B. (1978b) Screening of sorghum entries to midge ((*Contarinia sorghicola* Coquillett) *Mysore J Agric Sci* **12** 577 578

Kundu, G. G. (1985) E 304 a high yielding sorghum derivative resistant to stem borer *Chilo partellus* Swinhoe *Bull Entomol* **26** 25 27

Kundu, G. G. and Jotwani, M. G. (1977) 477 – a highly promising stem borer line of sorghum *Entomologist's Newslett* 7 7

Kundu, G. G. and Sharma, J. K. (1975) Field screening of some local germplasms of sorghum from Rajasthan for resistance against shoot fly *Atherigona varia soccata* Rondani *Sorghum Newslett* **18** 58 59

Kundu, G. G., Kishore, P. and Jotwani, M. G. (1977) Field evaluation of some sorghum selections for resistance to shoot fly and stem borer *Entomon* **2** 153 155

Lakshminarayana, K. and Subba Rao, D. V. (1978) Screening of sorghum varieties for resistance to shoot fly *Sorghum Newslett* **18** 22–23

Lal, G. and Pant, J. C. (1980) Ovipositional behaviour of *Chilo partellus* (Swinhoe) on different resistant and susceptible varieties of maize and sorghum *Indian J Entomol* **42**, 772 775

Lal, G. and Sukhani, T. R. (1982) Antibiotic effects of some resistant lines of sorghum on post larval development of *Chilo partellus* (Swinhoe) *Indian J Agric Sci* **52** 127–129

Lara, F. M., Galli, A. J. B. and Busoli, A. C. (1981) Types of resistance in *Sorghum bicolor* (L) Moench to *Schizaphis graminum* (Rondani, 1852) (Homoptera Aphididae) *Cientifica* **9** 273 280

Lara, F. M., Rossetto, C. J. and Igue, T. (1977) Resistance of AF 28 sorghum variety to *Contarinia sorghicola* *Entomologia exp appl* **21** 238 242

Lara, F. M., Barbara, F. G. C., Busoli, A. C. and Barbosa, J. C. (1979) Behaviour of sorghum genotypes in relation to attack by *Diatraea saccharalis* (Fabricius 1790) *Anais Soc Entomol Brasil* **8** 125 130

Leuschner, K. (1989) A review of sorghum stem borer screening procedures In *Int Workshop Sorghum Stem Borers 17–20 Nov 1987* pp 129–135 ICRISAT Patancheru Andhra Pradesh India

Leuschner, K. and Sharma, H. C. (1983) Assessment of losses caused by sorghum panicle pests In *Proc Crop Losses Due to Insect Pests* (Ed by B H Krishnamurthy Rao and K S R K Murthy) pp 201–212, Entomological Society of India Rajendranagar Hyderabad, Andhra Pradesh, India

Leuschner, K., Taneja, S. L. and Sharma, H. C. (1985) The role of host-plant resistance in pest management in sorghum in India *Insect Sci Appl* **6** 453–460

Lordello, A. L. L., Lara, F. M. and Parra, J. R. P. (1980) Food preference among sorghums in *Spodoptera frugiperda* (J E Smith 1797) (Lepidoptera Noctuidae) under laboratory conditions *Anais Soc Entomol Brasil* **9**, 219–241

Maiti, R. K. and Bidinger, F. R. (1979) A simple approach to identification of shoot fly tolerance in sorghum *Indian J Plant Prot* **7**, 135–140

Maiti, R. K., Bidinger, F. R., Seshu Reddy, K. V., Gibson, P. and Davies, J. C. (1980) *Nature and Occurrence of Trichomes in Sorghum Lines with Resistance to Sorghum Shoot Fly Joint Progress Report 3 of Sorghum Physiology and Sorghum Entomology*, ICRISAT Patancheru, Andhra Pradesh, India (limited distribution)

Mate, S. N., Phadanwis, B. A. and Mehetre, S. S. (1988) Studies on growth and physiological factors in relation to shoot fly attack on sorghum *Indian J Agric Res* **22**, 81–84

Melton, K. D. and Teetes, G. L. (1984) Effect of resistant sorghum hybrids on sorghum midge (Diptera Cecidomyiidae) biology *J Econ Entomol* **77**, 626–631

Mihm, J. A. (1985) Methods of artificial infestation with *Diatraea* species and evaluation of stem borer resistance in sorghum In *Proc Int Sorghum Entomol Workshop 15 21 July 1984 Texas A&M Univ College Stn TX USA* pp 169 173 ICRISAT Patancheru Andhra Pradesh India

Mize, T. W. and Wilde, G. (1986a) Reproduction of the Chinch bug (Heteroptera Lygaeidae) on new resistance sources in grain sorghum *J Econ Entomol* **79** 664 667

Mize, T. W. and Wilde, G. (1986b) New grain sorghum sources of antibiosis to the Chinch bug (Heteroptera Lygaeidae) *J Econ Entomol* **79** 176 180

Morgan, J., Wilde, G. and Johnson, D. (1980) Greenbug resistance in commercial sorghum hybrids in the seedling stage *J Econ Entomol* **73**, 510 514

Mote, U. N. (1984) Sorghum species resistant to shoot fly *Indian J Entomol* **46** 241 243

Mote, U. N. and Bapat, D. R. (1983) Evaluation of some sorghum genotypes for multiple resistance to shoot fly and stem borer *J Maharashtra Agric Univ* **8** 151 153

Mote, U. N. and Bapat, D. R. (1988) Evaluation of some high yielding sorghum derivatives for resistance to shoot fly *J Maharashtra Agric Univ* **13** 230 237

Mote, U. N., Kadam, J. R. and Bapat, D. R (1983) Screening of new male sterile lines for shoot fly reaction *Sorghum Newslett* **26** 29

Mote, U. N., Kadam, J. R. and Bapat, D R. (1985) Recovery resistance to shoot fly in some sorghum hybrids *J Maharashtra Agric Univ* **10** 190 193

Mote, U. N., Kadam, J. R. and Bapat, D. R. (1986) Antibiosis mechanism of resistance to sorghum shoot fly *J Maharashtra Agric Univ* **11** 43 46

Mote, U. N., Shirole, S. M. and Bapat, D. R. (1981) Screening of local kharif varieties of sorghum for resistance to shoot fly *J Maharashtra Agric Univ* **6** 165 166

Murty, A. D. and Subramaniam, T. R. (1978) Varietal susceptibility of sorghum to the midge (*Contarinia sorghicola* Coq) *Madras Agric J* **65** 180 182

Narayana, D. (1975a) Screening for aphids and sooty molds in sorghum *Sorghum Newslett* **18** 21

Narayana, D. (1975b) Characters contributing to sorghum shoot fly resistance *Sorghum Newslett* **18** 21 22

Narwal, R. P. (1973) Silica bodies and resistance to infection in jowar (*Sorghum vulgare* Pers) *Agra Univ J Res (Sci)* **22** 17 20

Natarajan, K. and Chelliah, S. (1986) Studies on the mechanism of resistance in sorghum accessions to the grain midge *Contarinia sorghicola* Coquillett *Insect Sci Appl* **7** 751 755

Natarajan, N. and Babu, P. C. S. (1988) Seasonal occurrence of *Heliothis armigera* Hb infesting sorghum panicles *Trop Pest Mgmt* **34** 338 342

Nimbalkar, V. S. and Bapat, D. R. (1987) Genetic analysis of shoot fly resistance under high level of shoot fly infestation in sorghum *J Maharashtra Agric Univ* **12** 331 334

Nordquist, P. T., Kindler, S. D. and Spomer, S. M. (1987) Registration of three greenbug biotype E resistant sorghum germplasms *Crop Sci* **27** 154

Nwanze, K. F., Reddy, Y. V. R. and Soman, P. (1990) The role of leaf surface wetness in the larval behaviour of the sorghum shoot fly *Atherigona soccata* *Entomologia exp appl* **56** 187 195

Omori, T., Agrawal, B. L. and House, L. R. (1988) Genetic diversity for resistance to shoot fly *Atherigona soccata* Rond in sorghum *Sorghum bicolor* (L) Moench and its relationship with heterosis *Insect Sci Appl* **9** 483 488

Page, F. D. (1979) Resistance to sorghum midge ((*Contarinia sorghicola* Coquillet) in grain sorghum *Aust J Exp Agric Anim Husb* **19**, 97–101

Parodi, R. A., Gamba, R. D. and Scantamburlo, J. L. (1974) 'Huerin INTA grain sorghum variety tolerant to the sorghum midge' ((*Contarinia sorghicola* Coq) *Sorghum Newslett* **17** 1

Passlow, T., Franzmann, B. A. and Allsopp, P. G. (1985) Sorghum insect problems in Australia In *Proc Int Sorghum Entomol*

Workshop 15–21 July 1984 Texas A&M Univ College Stn TX USA pp 65–72 ICRISAT, Patancheru Andhra Pradesh India

Patel, G. M. and Sukhani, T. R. (1989) Studies on varietal resistance to sorghum stem borer *Chilo partellus* (Swinhoe) *Indian J Entomol* **51** 384–392

Patel, G. M. and Sukhani, T. R. (1990a) Biophysical plant characters associated with shoot fly resistance *Indian J Entomol* **52** 14–17

Patel, G. M. and Sukhani, T. R. (1990b) Screening of sorghum genotypes for resistance to shoot fly *Atherigona soccata* Rondani *Indian J Entomol* **52** 1–8

Patel, G. M., Sukhani, T. R. and Srivastava, K. P (1989) Studies on multiple resistance in sorghum to shoot fly and stem borers *Indian J Entomol* **51**, 261–264

Patel, R. H., Desai, K. B., Desai, M. S. and Kukadia, M. U. (1986) Combining ability for resistance to earhead worms in sorghum *Gujarat Agric Univ Res J* **11** 79–81

Pathak, R. S. (1985) Genetic variation of stem borer resistance and tolerance in three sorghum crosses *Insect Sci Appl* **6** 359–364

Pathak, R. S. and Olela, J. C. (1983) Genetics of host plant resistance in food crops with special reference to sorghum stem borers *Insect Sci Appl* **4** 127–134

Patil, R. C. and Thombre, M. V. (1985) Inheritance of shoot fly and earhead midge fly resistance in sorghum *Curr Res Reptr Mahatma Phule Agric Univ* **1** 44–48

Perring, T. M., Archer, T. L., Johnson, J. W. and Phillips, J. M. (1982) Evaluation of several grain sorghum characteristics for resistance to Banks grass mite *J Econ Entomol* **75** 257–260

Peterson, G. C., Johnson, J. W., Teetes, G. L. and Rosenow, D. T. (1985a) Registration of midge resistant sorghum germplasm *Crop Sci* **25**, 372

Peterson, G. C., Johnson, J. W., Teetes, G. L. and Rosenow, D. T. (1985b) Registration of greenbug biotype C resistant sorghum germplasm *Crop Sci* **25**, 373

Peterson, G. C., Ali, A. E. B., Teetes, G. L., Jones, J. W. and Schaefer, K. (1989) Grain sorghum resistance to sorghum midge by yield loss vs visual scores *Crop Sci* **29**, 1136–1140

Ponnaiya, B. W. X. (1951) Studies on the genus Sorghum II The cause of resistance in sorghum to the insect pest *Atherigona indica* M *Madras Univ J* (*B*) **21**, 203–217

Pradhan, S. (1971) *Investigations on Insect Pests of Sorghum and Millets Final Technical Report (1965–70)* Indian Agricultural Research Institute, Division of Entomology New Delhi India 157 pp

Raina, A. K., Thindwa, H. Z., Othieno, S. M. and Corkhill, R. T. (1981) Resistance in sorghum to the sorghum shoot fly larval development and adult longevity and fecundity on selected cultivars *Insect Sci Appl* **2**, 99–103

Raina, A. K., Thindwa, H. Z., Othieno, S. M. and Douglass, L. W. (1984) Resistance in sorghum to shoot fly (Diptera Muscidae) oviposition on selected cultivars *J Econ Entomol* **77** 648–651

Rana, B. S. and Murty, B. R. (1971) Genetic analysis of resistance to stem borer in sorghum *Indian J Genet* **35**, 350–355

Rana, B. S., Jotwani, M. G. and Rao, N. G. P. (1981) Inheritance of host plant resistance to shoot fly in sorghum *Insect Sci Appl* **2** 105–109

Rana, B. S., Tripathi, D. P., Balakotaiah, K., Damoder, R. and Rao, N. G. P. (1975) Genetic analysis of some exotic × Indian crosses in sorghum IX Selection for shoot fly resistance *Indian J Genet Plant Breed* **35**, 350–355

Rana, B. S., Singh, B. U., Rao, V. J. M., Reddy, B. B. and Rao, N. G. P. (1984) Inheritance of stem borer resistance in sorghum *Indian J Genet Plant Breed* **44**, 7–14

Rangarajan, A., Mahadevan, N. R., Kandaswamy, G. and Iyemperumal, S. (1974) Some observations on the susceptibility of sorghum types and hybrids to the cut worm, *Pseudaletia unipuncta* Haw *Sorghum Newslett* **17**, 48

Rao, N., Singdi, S. S. and Srinivasulu, G. (1972) Breeding for shoot fly resistance in sorghum *Sorghum Newslett* **13**, 32–38

Rao, N. G. P., Rana, B. S., Balakotaiah, K., Tripathi, D. P. and Fayed, M. F. S (1974) Genetic analysis of some exotic × Indian crosses in sorghum VIII F_1 analysis of ovipositional non preference underlying resistance to sorghum shoot fly *Indian J Genet Plant Breed* **34** 122–127

Raodeo, A. K. and Karanjkar, R. R (1975) Screening of sorghum lines for relative damage by the sorghum midge *Contarinia sorghicola* (Coq) *Sorghum Newslett* **18** 48–49

Reddy, K. V. S. (1985) Relative susceptibility and resistance of some sorghum lines to stem borers in Western Kenya *Insect Sci Appl* **6** 401–404

Reddy, K. V. S. and Davies, J. C. (1979) *Pests of Sorghum and Pearl Millet and their Parasites and Predators Recorded at ICRISAT Center India up to August 1979 Cereal Entomology Progress Report* 2 ICRISAT Patancheru Andhra Pradesh India (limited distribution)

Reyes, R. (1985) Sorghum insect pest problems in Central America In *Proc Int Sorghum Entomol Workshop 15–21 July 1984 Texas A&M Univ College Stn TX USA* pp 89–95 ICRISAT Patancheru Andhra Pradesh India

Ross, W. M., Kindler, S. D., Kofoid, K. D., Hookstra, G. H., Guthrie, W. D. and Atkins, R. E. (1982) European cornborer resistance in half sib families from a sorghum random mating population *Crop Sci* **22** 973–978

Rossetto, C. J (1985) Sorghum midge host plant resistance mechanisms In *Proc Int Sorghum Entomol Workshop 15–21 July 1984 Texas A&M Univ College Stn TX USA* pp 293–299 ICRISAT Patancheru Andhra Pradesh India

Rossetto, C. J. and Igue, T (1983) Inheritance of the resistance to *Contarinia sorghicola* Coquillet of the sorghum variety AF 28 *Bragantia* **42** 211–219

Rossetto, C. J., Goncalves, W. and Diniz, J. L. M. (1975) Resistance of variety AF 28 to the sorghum midge *Contarinia sorghicola* in the absence of other varieties *Anais Soc Entomol Brasil* **4** 16–20

Rossetto, C. J., Nagai, V. and Overman, J (1984) Mechanism of resistance in sorghum variety AF 28 to *Contarinia sorghicola* (Diptera Cecidomyiidae) *J Econ Entomol* **77** 1439–1440

Salunkhe, G. N., Gandhale, D. N., Murti, T. K. and Naik, L. M. (1982) Field screening of sorghum lines for resistance to shoot fly *J Maharashtra Agric Univ* **7** 270

Sandhu, G. S., Dhaliwal, G. S. and Sidhu, B. S. (1986) Resistance of forage sorghum to shoot fly (*Atherigona soccata* Rond) *Indian J Agric Sci* **56** 753–756

Santos, J. H. R. and Carmo, C. M. (1974) Evaluation of resistance to *Contarinia sorghicola* by sorghum lines from Cameroon Africa collection in Ceara Brazil *Sorghum Newslett* **17**, 10–11

Schuster, D. J. and Starks, K. J. (1973) Greenbugs components of host plant resistance in sorghum *J Econ Entomol* **66** 1131–1134

Schweissing, F. C. and Wilde, G. (1978) Temperature influence on greenbug resistance of crops in the seedling stage *Environ Entomol* **7** 831–834

Schweissing, F. C. and Wilde, G. (1979) Temperature and plant nutrient effects on resistance of seedling sorghum to the greenbug *J Econ Entomol* **72**, 20–23

Segarra-Carmona, A. E., Sotomayer-Rios, A., Torres-Cardona, S. and Quiles-Belen, A. (1989) Field evaluation of the susceptibility of eight sorghum hybrids to the sorghum midge, *Contarinia sorghicola* (Coquillet) (Diptera Cecidomyiidae) *J Agric Univ Puerto Rico* **73**, 155–157

Sharma, G. C. and Rana, B. S. (1983) Resistance to the sorghum shoot fly *Atherigona soccata* (Rond) and selection for antibiosis *J Entomol Res* 7, 133–138

Sharma, G. C. and Rana, B. S. (1985) Genetics of ovipositional non-preference and deadheart formation governing shoot fly resistance in sorghum *J Entomol Res* **9**, 104–105

Sharma, G. C., Jotwani, M. G., Rana, B. S. and Rao, N. G. P. (1977) Resistance to the sorghum shoot fly, *Atherigona soccata* (Rondani) and its genetic analysis *J Entomol Res* **1**, 1–12

Sharma, H. C. (1985a) Strategies for pest control in sorghum in India *Trop Pest Mgmt* **31**, 167–185

Sharma, H. C. (1985b) Screening for sorghum midge resistance and resistance mechanisms. In *Proc. Int. Sorghum Entomol. Workshop, 15–21 July 1984, College Stn, TX, USA*, pp. 275–292, ICRISAT, Patancheru, Andhra Pradesh, India

Sharma, H. C. (1985c) Screening for host-plant resistance to mirid bugs in sorghum. In *Proc. Int. Sorghum Entomol. Workshop, 15–21 July 1984, College Stn, TX, USA*, pp. 317–335, ICRISAT, Patancheru, Andhra Pradesh, India

Sharma, H. C. and Davies, J. C. (1983) *The Oriental Armyworm,* Mythimna separata *(Wlk.). Distribution, Biology and Control. A Literature Review. Miscellaneous Report No.* 59. Centre for Overseas Pest Research, London, 24 pp.

Sharma, H. C. and Davies, J. C. (1988) *Insect and Other Animal Pests of Millets.* Sorghum and Millets Information Center, ICRISAT, Patancheru, Andhra Pradesh, India

Sharma, H. C. and Leuschner, K. (1986) Mechanisms and diversity of resistance to the sorghum midge, *Contarinia sorghicola* Coq. In *Proc. 1st Aust. Sorghum Conf. 4–6 Feb. 1986, Gatton, Qd, Australia* pp. 3.8–3.19, Organising Committee of the Australian Sorghum Conference, Gatton, Queensland, Australia

Sharma, H. C. and Leuschner, K. (1987) Chemical control of sorghum head bugs (Hemiptera: Miridae). *Crop Prot.* **6**, 334–340

Sharma, H. C. and Lopez, V. F. (1989) Assessment of avoidable losses and economic injury levels for the sorghum head bug, *Calocoris angustatus* Leth. (Hemiptera: Miridae) in India. *Crop Prot.* **8**, 429–435

Sharma, H. C. and Lopez, V. F. (1990) Mechanisms of resistance in sorghum to head bug, *Calocoris angustatus. Entomologia exp. appl.* **57**, 285–294

Sharma, H. C. and Lopez, V. F. (1991) Stability of resistance to sorghum head bug, *Calocoris angustatus* Lethiery (Hemiptera: Miridae). *J. Econ. Entomol.* **84**, 1088–1094

Sharma, H. C. and Lopez, V. F. (1992a) Screening for plant resistance to sorghum head bug, *Calocoris angustatus* Leth. *Insect Sci. Appl.* **13**, 315–325

Sharma, H. C. and Lopez, V. F. (1992b) Genotypic resistance in sorghum to head bug, *Calocoris angustatus* Leth. *Euphytica* **58**, 193–200

Sharma, H. C., Doumbia, Y. O. and Diorisho, N. Y. (1992a) Screening sorghums for resistance to head bug, *Eurystylus immaculatus* Odh. in West Africa. *Insect Sci. Appl.* **13**, 417–427

Sharma, H. C., Leuschner, K. and Vidyasagar, P. (1990a) Factors influencing oviposition behaviour of the sorghum midge, *Contarinia sorghicola. Ann. Appl. Biol.* **116**, 431–439

Sharma, H. C., Vidyasagar, P. and Leuschner, K. (1988a) Field screening sorghum for resistance to sorghum midge (Cecidomyiidae: Diptera). *J. Econ. Entomol.* **81**, 327–334

Sharma, H. C., Vidyasagar, P. and Leuschner, K. (1988b) No-choice cage technique to screen for resistance to sorghum midge (Cecidomyiidae: Diptera). *J. Econ. Entomol.* **81**, 415–422

Sharma, H. C., Vidyasagar, P. and Leuschner, K. (1990b) Components of resistance to the sorghum midge, *Contarinia sorghicola. Ann. Appl. Biol.* **116**, 327–333

Sharma, H. C., Taneja, S. L., Leuschner, K. and Nwanze, K. F. (1992b) *Techniques to Screen Sorghums for Resistance to Insects. Info. Bull.* 32, ICRISAT, Patancheru, Andhra Pradesh, India, 48 pp.

Sharma, H. C., Doumbia, Y. O., Haidra, M., Scheuring, J. F., Ramaiah, K. V. and Beninati, N. F. (1993) Sources and mechanisms of resistance to sorghum head bug, *Eurystylus immaculatus* Odh. in West Africa. *Insect Sci. Appl.*, in press

Shivankar, V. J., Ram, S. and Gupta, M. P. (1989) Tolerance in some sorghum germplasm to shoot fly (*Atherigona soccata* Rondani). *Ind. J. Entomol.* **51**, 393–396

Shivankar, V. J., Ram, S. and Gupta, M. P. (1989) Tolerance in some sorghum germplasm to shoot fly (*Atherigona soccata* Rondani). *Indian J. Entomol.* **51**, 393–396

Shyamsunder, J., Parameshwarappa, R., Nagaraja, H. K. and Kajjari, N. B. (1975) A new genotype in sorghum resistant to sorghum midge (*Contarinia sorghicola*). *Sorghum Newslett.* **18**, 33

Singh, B. U. (1987) Varietal resistance in sorghum to midge, *Contarinia sorghicola* Coquillet (Diptera: Cecidomyiidae). *Insect Sci. Appl.* **8**, 129–144

Singh, B. U. and Rana, B. S. (1984) Influence of varietal resistance on oviposition and larval development of stalk borer *Chilo partellus* Swin., and its relationship to field infestation in sorghum. *Insect Sci. Appl.* **5**, 287–296

Singh, B. U. and Rana, B. S. (1986) Resistance in sorghum to the shoot fly, *Atherigona soccata* Rondani. *Insect Sci. Appl.* **7**, 577–587

Singh, B. U. and Rana, B. S. (1989) Varietal resistance in sorghum to spotted stem borer, *Chilo partellus* (Swinhoe). *Insect Sci. Appl.* **10**, 3–27

Singh, B. U., Rana, B. S. and Rao, N. G. P. (1981) Host plant resistance to mite (*Oligonychus indicus* Hirst.) and its relationship with shoot fly (*Atherigona soccata* Rond.) resistance in sorghum. *J. Entomol. Res.* **5**, 25–30

Singh, B. U., Rana, B. S., Reddy, B. B. and Rao, N. G. P. (1983) Host plant resistance to stalk-borer, *Chilo partellus* Swin., in sorghum. *Insect Sci. Appl.* **4**, 407–413

Singh, R. and Narayana, K. L. (1978) Influence of different varieties of sorghum on the biology of sorghum shoot fly. *Indian J. Agric. Sci.* **48**, 8–12

Singh, S. P. and Jotwani, M. G. (1980a) Mechanisms of resistance in sorghum to shoot fly. I. Ovipositional non-preference. *Indian J. Entomol.* **42**, 240–247

Singh, S. P. and Jotwani, M. G. (1980b) Mechanisms of resistance in sorghum to shoot fly. II. Antibiosis. *Indian J. Entomol.* **42**, 117

Singh, S. P. and Jotwani, M. G. (1980c) Mechanism of resistance to shoot fly. III. Biochemical basis of resistance. *Indian J. Entomol.* **42**, 551–556

Singh, S. P. and Jotwani, M. G. (1980d) Mechanism of resistance to shootfly. IV. Role of morphological characters of seedlings. *Indian J. Entomol.* **42**, 806–808

Singh, S. P. and Verma, A. N. (1988a) Inheritance of resistance to shoot fly, *Atherigona soccata* (Rondani) in forage sorghum. *Insect Sci. Appl.* **9**, 49–52

Singh, S. P. and Verma, A. N. (1988b) Antibiosis mechanism of resistance to stem borer, *Chilo partellus* (Swinhoe) in sorghum. *Insect Sci. Appl.* **9**, 579–582

Singh, S. P. and Verma, A. N. (1988c) Combining ability for stem borer, *Chilo partellus* (Swinhoe) resistance in sorghum. *Insect Sci. Appl.* **9**, 665–668

Singh, S. P., Jotwani, M. G. and Rana, B. S. (1980) Development and stability of sorghum varieties resistant to stem borer, *Chilo partellus* (Swinhoe). *Indian J. Entomol.* **42**, 473–481

Singh, S. P., Jotwani, M. G., Rana, B. S. and Rao, N. G. P. (1978) Stability of host plant resistance to sorghum shoot fly, *Atherigona soccata* (Rondani). *Indian J. Entomol.* **40**, 376–383

Singh, S. R., Vedmoorthy, G., Thobbi, V. V., Jotwani, M. G., Young, W. R., Balan, J. S., Srivastava, K. P., Sandhu, G. S. and Krishnananda, N. (1968) Resistance to stem borer, *Chilo zonellus* (Swinhoe) and stem fly, *Atherigona varia soccata* Rond. in the world sorghum collection in India. *Mem. Entomol. Soc. India*, No. 7

Soto, P. E. (1974) Ovipositional preference and antibiosis in relation to a sorghum shoot fly. *J. Econ. Entomol.* **67**, 265–267

Srivastava, K. P. (1985) Screening for stem borer resistance. In *Proc. Int. Sorghum Entomol. Workshop, 15–21 July 1984, Texas A&M Univ., College Stn, TX, USA* pp. 189–200, ICRISAT, Patancheru, Andhra Pradesh, India

Starks, K. J. and Mayo, Z. B., Jr (1985) Biology and control of greenbug attacking sorghum. In *Proc. Int. Sorghum Entomol. Workshop, 15–21 July 1984, Texas A&M Univ., College Stn, TX, USA*, pp. 149–158, ICRISAT, Patancheru, Andhra Pradesh, India

Starks, K. J. and Schuster, D. J. (1976) Greenbug: effects of continuous culturing on resistant sorghum. *Environ. Entomol.* **5**, 720–723

Starks, K. J. and Weibel, D. E. (1981) Resistance in bloomless and sparse-bloom sorghum to greenbugs. *Environ. Entomol.* **10**, 963–965

Starks, K. J., Eberhart, S. A. and Doggett, H. (1970) Recovery from shoot fly attack in a sorghum diallel. *Crop Sci.* **10**, 519–522

Starks, K J, Muniappan, R and Eikenbary, R D (1972) Interaction between plant resistance and parasitism against the greenbug on barley and sorghum *Ann Entomol Soc Am* **65** 650–655

Starks, K J, Wood, E A, Jr and Burton, R L (1974) Relationship of plant resistance and *Lysiphlebus testaceipes* to population levels of greenbug on grain sorghum *Environ Entomol* **3** 950–952

Swarup, V and Chaugale, D S (1962) A preliminary study on resistance to stem borer (*Chilo zonellus* (Swinhoe)) infestation on sorghum *Sorghum vulgare* Pers *Curr Sci* **31** 163 164

Tan, W Q, Li, S M, Guo, H P and Gao, R P (1985) A study of the inheritance of aphid resistance in sorghum *Shanxi Agric Sci* **8** 12 14

Taneja, S L and Leuschner, K (1985a) Resistance screening and mechanisms of resistance in sorghum to shoot fly In *Proc Int Sorghum Entomol Workshop 15 21 July 1984 College Stn TX USA* pp 115 129 ICRISAT Patancheru Andhra Pradesh India

Taneja, S L and Leuschner K (1985b) Methods of rearing infestation and evaluation of *Chilo partellus* resistance In *Proc Int Sorghum Entomol Workshop 15 21 July 1984 College Stn TX USA* pp 175 188 ICRISAT Patancheru Andhra Pradesh India

Taneja, S L and Nwanze K F (1989) Assessment of yield loss of sorghum and pearl millet due to stem borers In *Int Workshop on Sorghum Stem Borers 17 20 Nov 1987* ICRISAT Center India pp 95 104 ICRISAT Patancheru Andhra Pradesh India

Taneja, S L and Woodhead, S (1989) Mechanisms of stem borer resistance in sorghum In *Int Workshop on Sorghum Stem Borers 17 20 Nov 1987* ICRISAT Center India pp 137 144 ICRISAT Patancheru Andhra Pradesh India

Teetes, G L (1979) Overview of pest management and host plant resistance in US sorghum In *Biology and Breeding for Resistance to Arthropods and Pathogens in Agricultural Plants* (Ed by K M Harris) pp 181 223 Texas A&M University College Station Texas

Teetes, G L (1980) Breeding sorghums resistant to insects In *Breeding Plants Resistant to Insects* (Ed by F G Maxwell and P R Jennings) pp 457–485 John Wiley and Sons New York

Teetes, G L (1985) Insect resistant sorghums in pest management *Insect Sci Appl* **6** 443–451

Teetes, G L, Becerra, M I and Peterson, G C (1986) Sorghum midge (Diptera Cecidomyiidae) management with resistant sorghum and insecticide *J Econ Entomol* **79** 1091 1095

Teetes, G L, Johnson, J W and Rosenow, D T (1975) Response of improved resistant sorghum hybrids to natural and artificial greenbug populations *J Econ Entomol* **68** 546 548

Teetes, G L, Schaefer, C A and Johnson, J W (1974) Resistance in sorghum to the greenbug laboratory determination of mechanisms of resistance *J Econ Entomol* **67** 393 396

Teetes, G L, Reddy, K V S, Leuschner, K and House L R (1983) *Sorghum Insect Identification Handbook Info Bull 12* ICRISAT Patancheru Andhra Pradesh India

Unnithan, G C and Reddy, K V S (1985) Oviposition and infestation of the sorghum shoot fly *Atherigona soccata* Rondani on certain sorghum cultivars in relation to their relative resistance and susceptibility *Insect Sci Appl* **6** 409 412

Waquil, J M, Teetes, G L and Peterson, G C (1985) Adult sorghum midge (Diptera Cecidomyiidae) nonpreference for a resistant sorghum hybrid *J Econ Entomol* **79** 455–458

Waquil, J M, Teetes, G L and Peterson, G C (1986a) Sorghum midge (Diptera Cecidomyiidae) adult oviposition behaviour on resistant and susceptible sorghum hybrids *J Econ Entomol* **79** 530–532

Waquil, J M, Teetes, G L and Peterson, G C (1986b) Comparison of immature sorghum midge (Diptera Cecidomyiidae) development on resistant and susceptible sorghums *J Econ Entomol* **79** 833 837

Webster J A (1990) Yellow sugarcane aphid (Homoptera Aphididae) detection and mechanisms of resistance in Ethiopian sorghum lines *J Econ Entomol* **83** 1053 1057

Weibel D E (1986a) Registration of eight bloomless parental lines of sorghum *Crop Sci* **26** 842

Weibel, D E (1986b) Registration of 12 bloomless and four sparse bloom lines of sorghum germplasm *Crop Sci* **26** 840 841

Weibel D E and Starks K J (1986) Greenbug nonpreference for bloomless sorghum *Crop Sci* **26** 1151 1153

Widstrom N W Wiseman B R and McMillian W W (1984) Patterns of resistance in sorghum to the sorghum midge *Crop Sci* **24** 791 793

Wilde G and Morgan J (1978) Chinch bug on sorghum chemical control economic injury levels plant resistance *J Econ Entomol* **71** 908 910

Wilson A G L (1976) Varietal responses of grain sorghum to infestation by *Heliothis armigera* *Expl Agric* **12** 25[illegible]

Wiseman B R (1985) IPM of fall armyworm and panicle caterpillars in sorghum In *Proc Int Sorghum Entomol Workshop 15 21 July 1984 Texas A&M Univ College Stn TX USA* pp 219 226 ICRISAT Patancheru Andhra Pradesh India

Wiseman B R and Gourley L (1982) Fall armyworm (Lepidoptera Noctuidae) infestation procedures and sorghum resistance evaluations *J Econ Entomol* **75** 1048 1051

Wiseman B R and Lovell G R (1988) Resistance to the fall armyworm in sorghum seedlings from Ethiopia and Yemen *J Agric Entomol* 5 17 20

Wiseman B R and McMillian W W (1968) Resistance in sorghum to sorghum midge *Contarinia sorghicola* (Coquillett) (Diptera Cecidomyiidae) *J Entomol Soc Georgia* 3 147

Wiseman B R and Morrison W P (1981) *Components for Management of Field Corn and Grain Sorghum Insects and Mites in the United States USDA ARS ARM S 18* Government Printing Office Washington DC USA 18 pp

Wiseman B R Duncan R R and Widstrom N W (1988) Registration of SGIRL MR 3 and SGIRL MR 4 midge resistant sorghum germplasms *Crop Sci* **28** 202 203

Wiseman B R McMillian W W and Widstrom N W (1973) Registration of SGIRL MR 1 sorghum germplasm *Crop Sci* **13** 398

Wiseman B R McMillian W W and Widstrom N W (1974) International sorghum midge evaluations *Sorghum Newslett* **17** 80

Wiseman, B R McMillian W W and Widstrom N W (1975) Screening for sorghum midge resistance *Sorghum Newslett* **18** 79 80

Wiseman B R Pitre H N Gourley, L and Fales S L (1984) Differential growth responses to fall armyworm larvae on developing sorghum seeds incorporated into a meridic diet *Fl Entomologist* **67** 357 367

Wiseman, B R Pitre H N Fales S L and Duncan R R (1986) Biological effects of developing sorghum panicles in a meridic diet on fall armyworm (Lepidoptera Noctuidae) development *J Econ Entomol* **79** 1637 1640

Woodhead, S and Taneja, S L (1987) The importance of the behaviour of young larvae in sorghum resistance to *Chilo partellus* *Entomologia exp appl* **45** 47 54

Received 20 September 1991
Revised 31 July 1992
Accepted 3 August 1992