CP215

Insect Sci Applic Vol 6 No 3, pp 453-460 1985
Printed in Great Britain

0191-9040 85 $3.00 + 0.00
Pergamon Press Ltd

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THE ROLE OF HOST-PLANT RESISTANCE IN PEST MANAGEMENT IN SORGHUM IN INDIA*

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(*Received 9 November 1984, revised 7 March 1985*)

Abstract—The paper stresses the fact that an integrated pest management system is not a new concept leading to a more stable agroecosystem, but was practiced by the farmers for centuries, host-plant resistance is one of its major components. The system was destabilized by the introduction of new sorghum varieties and hybrids not resistant against the major sorghum insect pests like shootfly *Atherigona soccata* (Rondani), stem borer, *Chilo partellus* (Swinhoe), midge, *Contarinia sorghicola* (Coquillet), and headbugs, *Calocoris angustatus* (Lethiery). In order to balance the agroecosystem again, an integrated insect pest management system for sorghum has to be developed based on traditional pest management practices These are host-plant resistance, cultural control and biological control. Insecticides should be used only if absolutely necessary. For a better understanding of such a control approach, a summary of the biology and population dynamics of the major insects is given, together with a brief account on the levels and mechanisms of host-plant resistance so far known Based on this information, the rainfall pattern, plant duration to maturity, time of planting, natural enemies and insecticides, a sorghum based integrated pest management system is proposed for the monsoon and post-monsoon season in which host-plant resistance alone or in combination with the above mentioned control methods could be used.

Key Words Sorghum shootfly, stem borer, midge, headbugs, host-plant resistance, integrated pest management, India

Résumé—L'article souligne qu'un système intégré de contrôle des insectes n'est pas un nouveau concept conduisant à un agroécosystème plus stable, mais qu'il a été pratiqué pendant des siècles, par des agriculteurs, la résistance de la plante hôte est un de ses composés majeurs. Le système a été déstabilisé par l'introduction de nouvelles variétés de sorgho et des hybrides non résistant aux insectes majeurs nuisibles au sorgho tels que *Atherigona soccata* (Rondani), le *Chilo partellus* (Swinhoe), le *Contarinia sorghicola* (coquillet) et les *Calocoris angustatus* (Lethiery). Pour rééquilibrer l'agroécosystème, un système intégré de contrôle des insectus nuisibles au sorgho doit être développé, basé sur les pratiques traditionelles de contrôle des insectus suivantes: résistance de la plante hôte, contrôle cultural, contrôle biologique. Les insecticides ne doivent être utilisés que quand c'est absolument nécessaire. Pour une meilleure comprehension d'une telle approche, un résumé des dynamiques de la biologie et de la population des insectes importants est donné avec un text bref expliquant les niveaux et mecanismes connus de la résistance de la plante hôte. Sur la base de ces informations, les types de précipitations, la période avant maturité, moment de la plantation, les ennemis naturels et les insecticides, un système intégré de contrôle des insectes nuisibles au sorgho est proposé pour la mousson et la saison suivant la mousson dans lequel la résistance de la plante hôte seule ou en combinaison avec les méthodes de contrôle citées plus haut pourrait être utilisé.

Mots Cléfs: *Atherigona soccata* (Rondani), *Chilo partellus* (Swinhoe), *Contarinia sorghicola* (Coquillet), *Calocoris angustatus* (Lethiery), résistance de la plante hôte, contrôle intégré des insectes, Inde

INTRODUCTION

Sorghum bicolor (L.) Moench is the third most important cereal crop in India after rice and wheat. It is grown on alfisols (red soil) and vertisols (black soil) during the monsoon (Kharif) and on vertisols on stored moisture during the post-monsoon season (Rabi). Yields range from 500 to 800 kg/ha. Most of the sorghum is still grown in the traditional way and inputs such as fertilizers and pesticides are seldom used except where hybrids have been accepted by the farmers. The low yields of grain sorghum are due to poor soil management, low soil fertility, use of local low yielding cultivars and losses to weeds, insects and diseases. In 1967 the National Council of Applied Economic Research (NCEAR) estimated an average loss of 12.2% due to sorghum insect pests.

Nearly 150 insect species have been reported as pests on sorghum (Reddy and Davies, 1979; Jotwani *et al.*, 1980), of which 31 species are of potential economic importance. However, the shootfly, *Atherigona soccata*; stem borer, *Chilo partellus*; midge, *Contarinia sorghicola*; and headbug, *Calocoris angustatus* are considered to be the major pests in India (Sharma, 1984a,b). This paper comments on the historical background to pest problems in sorghum and goes on to discuss the research knowledge accu-

*Approved as CP Paper No. 215 by the International Crops Research Institute for the Semi-Arid Tropics, ICRISAT, Patancheru PO, Andhra Pradesh 502 324 India mulated for various insect pests which is finally utilized to formulate a possible integrated pest management programme for sorghum.

CURRENT PEST CONTROL PRACTICES USED BY FARMERS

Most farmers do not consider pest control necessary until the damage becomes visible and threatens the crop yields substantially. One of the reasons may be that the traditional techniques used were incorporated in a pest management system which under normal conditions kept the pests below economic thresholds. The key to this system was seeds from plants that survived insect damage etc. which were sown the following season. This selection process led to better adaptation against stress factors such as insects, drought and diseases. Farmers augmented these traits with suitable sowing dates (e.g. early sowing to avoid shootfly damage), weeding, interculture, mixed cropping and crop rotation. Mixed cropping served two purposes: (1) It reduced risk of total crop loss resulting from a single climatic or biotic stress factor; (2) maintenance of a diverse insect fauna including predators and parasites of common pests which led to stability within agroecosystem. Thus, the traditional crop husbandry practices can be seen to have created an equilibrium between the plant, the insect and the environment. The stability of this system has been disturbed by the introduction of varieties bred specially for high yield alone, but which also require high inputs of disruptive factors like insecticides and artificial fertilizers. It was not realized that the application of insecticides which is an accepted practice on research stations is not feasible on a countrywide scale in India on a crop with as low a cash value as sorghum. Therefore, a new approach is needed to match pest control efforts with production goals.

The basic components of such a programme which will meet these requirements are: (1) host-plant resistance; (2) cultural control; and (3) biological control. Insecticides should be used as a last resort and only where absolutely necessary. Adkisson and Dyck (1980) expressed this clearly by saying: "Resistant varieties can provide a foundation on which to build an integrated control system, and, in fact, may be most productive when used in adjunct with cultural, biological and chemical control methods, with some crops, particularly those having low cash value per ha. The use of resistant varieties may offer the best (and perhaps only) economical method of control of certain pests."

NATURE OF DAMAGE, BIOLOGY AND POPULATION DYNAMICS

Shootfly

The shootfly *Atherigona soccata* lays its eggs on the lower leaf surface of 5–25 day-old-sorghum seedlings. The egg hatches in about 1–2 days. The larva moves to the growing point which it cuts causing a "dead heart". The life cycle from egg to adult takes about 17–21 days. As a result of shootfly attack, the plant stand and number of harvestable heads are greatly reduced. The death of the main shoot often results in the production of tillers. Although the tillers can also be attacked under high shootfly pressure, they often serve as a recovery mechanism and produce productive heads. The adult population is very low during the dry season (April–June), is highest during August to September and declines towards the end of April (Fig. 1).

Stem borer

The female of the spotted stem borer, *Chilo partellus* lays eggs in batches on the under surface of the leaves irrespective of the plant age. A batch contains usually 30–40 eggs and each female lays an average of 10 batches under laboratory conditions. The life cycle from egg to adult lasts about 30 days. The symptoms of an early attack are shotholes and leaf scars caused by first to third instar larvae feeding. Second and third instar larvae leave the plant whorls, migrate downward to the plant base and bore into the stem. They cause the "dead heart" if they are able to feed on the growing point. As soon as internode elongation and penicle initiation take place, stem tunnelling is the predominant symptom. Fully-grown larvae survive the summer diapausing in sorghum stubbles and dead stalks. The stem borer population is usually lowest during May. The diapause population hatches between June and July and the major peak occurs during September at ICRISAT. The population levels builds up gradually until April (Fig. 1).

Midge

The sorghum midge, *Contarinia sorghicola* lays eggs in the florets. The larvae suck the contents of the developing ovaries which results in the production of chaffy florets. The adults live for <24 hr. A female lays 60–100 eggs. The life cycle from egg to adult lasts about 15 days. It survives the summer as a diapausing larvae. Adults emerge during July and August. Most activity occurs during September and October with a second, but smaller peak in February and March (Fig. 1). High humidity is the main requirement for population build-up.

Headbugs

Females of the headbug, *Calocoris angustatus* lay eggs in the florets from the time the head emerge through to flowering. Both nymphs and adults suck the liquid content from developing grain. This leads to shrivelled and discoloured grains with poor food quality and germination. Such grain is not marketable or fetches a low price depending on the amount of damage. The life cycle from egg to adult is completed in 15–20 days. Adults probably survive on wild hosts or irrigated fodder sorghum during the dry seasons. The main population peaks correspond with those of the midge flies (Fig. 1). High humidity is again essential for population build-up.

Headbugs and midge have become the most important insect pests on sorghum because of the introduction of short duration cultivars that mature during a period of high humidity and moderate temperatures. The traditional late maturing cultivars are also subjected to more pest pressure because of the build-up of populations on the early maturing hybrids and varieties.

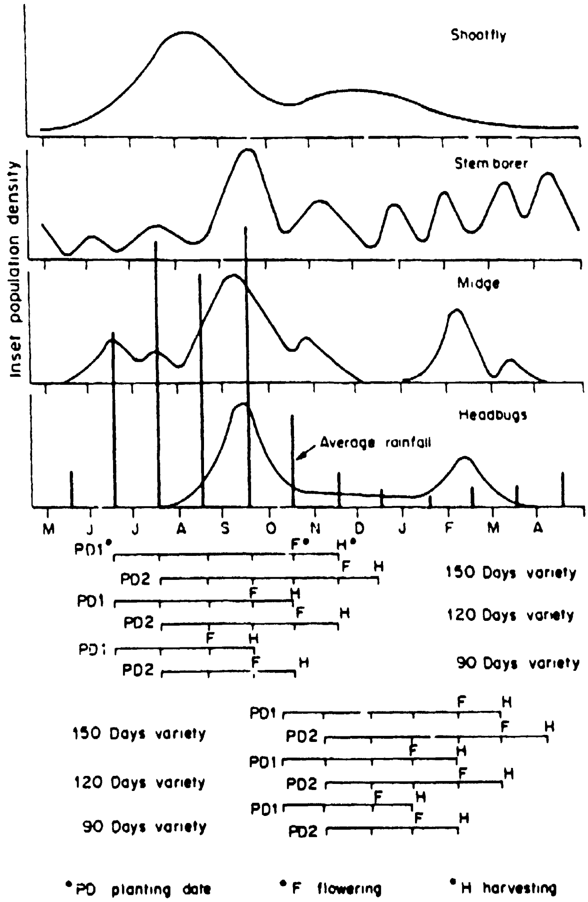

Fig 1 Population development of the four major sorghum insect pest species in relation to three sorghum varieties with different maturity cycles and two planting times during rainy and post-rainy season at ICRISAT

HOST PLANT RESISTANCE

In order to make predictions of what can be expected in terms of control through resistance, a brief summary is given of the levels and mechanisms of resistance to the four major insect pests that have been observed up to date.

Shootfly

The major mechanisms of shootfly resistance so far known are oviposition antixenosis (Soto, 1974) and antibiosis (Raina *et al.*, 1981). The oviposition non-preference factor is mainly observed under multi-choice conditions in the field and has a tendency to be less effective when there is no choice (Soto, 1972). Similar observations were made at ICRISAT (Table 1). Antibiosis is evident under moderate shootfly pressure and normal growing conditions of the plant. Unfortunately, the expression of antibiosis appears to be related to seedling vigour. Seedlings stressed by drought, low fertility or low temperature lose their resistance potential To overcome this problem, Dogget (1972) pointed out that synchronized tillering after the main shoot is killed is potentially a form of recovery resistance, because the tillers in some genotypes express higher levels of resistance than the main shoots.

Stem borer

Stem borer resistance has been reported by Pant *et al.* (1961), Swarup and Chaugale (1962) and Singh *et al.* (1968). Resistant genotypes have less leaf feeding, "dead heart" formation and stem tunnelling The mechanisms involved are antixenotic (Dabrowski and Nyangiri, 1982) and antibiosis (Jotwani *et al.*, 1978). Our studies at ICRISAT have shown that reduced "dead heart" formation is associated with fast seedling growth and late infestation. Early artificial infestation (14 days after germination) yielded about 60% "dead hearts" while later infestation (29 days after germination) gave only 7.4% "dead hearts" (Fig. 2). At this stage, the growing point has already moved upwards so that stem tunnelling is the only symptom. This mechanism can best be described as tolerance. Investigations at ICRISAT (unpublished) of the effect of tunnelling on CSH-1 (hybrid) showed that it did not cause detectable yield loss. This was further supported by an experiment in which different

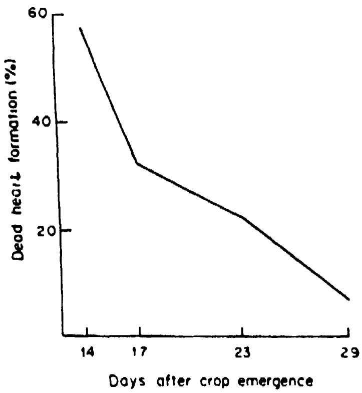

Fig 2 "Dead heart formation in susceptible sorghum hybrid CSH-1 with larval infestation at 14, 17, 23 and 29 days after seedling emergence

growth stages of the plant (CSH-1) were protected by carbofuran (Table 2) Insecticide protection in treatments one and two gave marginal yield increase while the early protection treatments three and four (protection against "dead heart" formation) increased yield substantially These results show that "dead heart" formation results in substantial yield loss

Midge

Midge resistance has been reported by Johnson *et al* (1973) and in ICRISAT (1982) Teetes and Johnson (1978) indicated that both antibiosis and antixenosis are involved High levels of antibiosis or oviposition antixenosis have been confirmed in AF 28, IS 12666C and TAM-2566 (Table 3) under no choice conditions (ICRISAT, 1982)

Headbugs

No resistance has been found so far against head bugs At ICRISAT small differences in susceptibility have been found under no-choice headcage screening However, these differences were not evident under high population pressure under field conditions

Although resistance levels have been reported for stem borer, shootfly and midge, a concentrated effort is needed to incorporate resistance into breeding stocks with better agronomic background This process is currently under way at AICSIP (All India Coordinated Sorghum Improvement Program) and ICRISAT

Table 1 Incidence of shootfly on indicated sorghum lines under choice and no-choice conditions ICRISAT Centre 1982

Sorghum lines	Choice condition: Egg laying (%)	Choice condition: Dead hearts (%)	No choice condition: Egg laying (%)	No choice condition: Dead hearts (%)
IS 1082	53 1 (47 4)*	29 2 (30 5)	85 3 (67 2)	72 7 (58 9)
IS 2122	55 4 (48 3)	40 7 (39 5)	91 3 (73 9)	82 1 (65 2)
IS 2195	63 3 (53 9)	50 5 (45 4)	76 3 (61 8)	73 9 (60 1)
IS 4663	67 0 (55 9)	49 0 (44 5)	59 3 (50 8)	54 5 (47 6)
IS 4664	41 7 (40 2)	36 4 (37 1)	55 3 (48 1)	26 3 (36 9)
IS 5470	64 4 (53 7)	50 0 (44 8)	71 7 (58 7)	52 2 (46 4)
IS 5484	48 1 (43 9)	41 8 (40 0)	72 1 (58 7)	58 7 (50 4)
IS 5566	47 7 (43 8)	40 5 (39 2)	62 8 (52 6)	55 3 (48 1)
IS 18551	57 2 (49 9)	42 7 (40 6)	51 6 (46 0)	44 0 (41 5)
PS 21171	70 1 (57 5)	46 7 (43 1)	58 6 (50 2)	51 3 (45 8)
PS 21217	48 3 (44 0)	32 7 (33 9)	54 9 (47 9)	40 4 (39 5)
PS 21318	51 1 (45 7)	43 8 (41 3)	60 8 (51 3)	48 3 (44 1)
CSH-1	93 1 (75 0)	92 3 (75 1)	100 0 (85 9)	95 3 (78 5)
SE	± (6 29)	± (5 05)	± (4 97)	± (4 27)
CV(%)	(21)	(20)	(15)	(15)

*Figures in parentheses are arcsine transformations

Table 2 Effect of protection levels on stem borer (*Chilo partellus*) infestation and yield loss in sorghum hybrid CSH 1, ICRISAT Centre 1982 and 1983

Treatment*	Dead hearts (%) 1982	Dead hearts (%) 1983	Harvestable heads 1982	Harvestable heads 1983	Grain yield (kg/plot)† 1982	Grain yield (kg/plot)† 1983
T_1	10 5	9 5	63 7	102 7	37 0	27 2
T_2	8 2	12 4	67 0	99 3	34 1	23 8
T_3	20 3	21 8	56 7	100 0	29 3	19 7
T_4	49 0	60 1	45 7	34 5	20 5	8 9
T_5	62 2	60 1	33 7	16 5	10 7	4 6
SE	±2 98	±3 79	±2 9	±9 22	±1 26	±1 29
CV(%)	(17)	(23)	(9)	(26)	(8)	(15)

*T_1 = Carbofuran at sowing and 15 30 and 45 DAE. T_2 = Carbofuran at sowing and 15 and 30 DAE T_3 = Carbofuran at sowing, and 15 DAE T_4 = Carbofuran at sowing T_5 = Untreated DAE = days after emergence Carbofuran at sowing time applied in soil, after the crop emerged applied in whorl

†Plot size 8 rows 4 m long Observations taken from middle 4 rows only

Table 3 Midge emergence from three resistant and two susceptible sorghum genotypes at ICRISAT Centre (rainy season 1982)

	Days after infestation												
	15	16	17	18	19	20	21	22	23	24	25	26	Total
Cultivar	(no of midges emerged/head)												flies
AF-28	–	—	—	—	—	—	9	9	4	2	–	—	24
IS-12666C	—	–	16	16	12	15	9	7	5	3	1	3	87
TAM-2566	—	—	—	—	—	19	8	8	4	5	2	4	50
CSH-1	21	38	49	63	41	34	33	20	9	6	—	—	314
Swarna	–	—	59	30	43	50	52	47	22	9	4	–	316

Based on caged earheads infested with 60 midge flies/cage with three replications

HOST-PLANT RESISTANCE IN A SORGHUM PEST MANAGEMENT SYSTEM

By taking our present knowledge of the biology, population dynamics and levels and mechanisms of resistance into consideration, a simple pest management system for sorghum will be described, in which resistance as soon as resistant varieties or hybrids are available alone or in combination with other control means, can be utilized. The proposed pest management system is based on experiences and results obtained from Andra Pradesh and has to be modified for other parts of India.

Resistant varieties as a principal control method

At present only midge resistance is a potential principal control element. Unfortunately, midge resistant varieties can only be of use in areas where headbugs are of little importance. For stem borer and shootfly, only moderate levels of resistance are available. High levels of resistance would be most desirable to keep the pest below the economic threshold level. However, low levels of resistance may also be advantageous, because of the long term suppressive effect on the pest population. Sharma (1983) modelled the influence of susceptible, moderately resistant and resistant cultivar on the hypothetical population trends of the sorghum midge (Table 4). By the end of the first year the pest density in an area growing the susceptible variety would be 16 times greater than in an area growing the resistant variety. After another year the ratio would be 1:210. Clearly, the larger the area, the greater the potential impact of a moderately resistant cultivar would be. The lower levels of shootfly resistance may have a similar suppression effect on the post-monsoon season population build-up.

The main disadvantage of relying solely on host-plant resistance is the development of new insect biotypes particularly where there are high levels of resistance. Examples of biotype development that have led to severe problems are the brown planthopper, *Nilaparvata lugens* on rice in the Philippines and the chestnut gall wasp, *Dryocosmus kuriphilus* in Japan (Shimura, 1972). Biotype development is also possible with sorghum insects and the situation should be closely watched to avoid similar disasters.

Host-plant resistance cultural control

Kharif season (*Table 5*). In India there are two principal growing seasons for sorghum, the Kharif (monsoon season) and the Rabi season (post-monsoon season). The early sown Kharif sorghum crop is faced with low initial shootfly and stem borer populations that have survived the hot and dry season. The obvious recommendation is to plant as soon as the rains start, to avoid the higher insect populations that develop later (Fig. 1). Un-

Table 4. Population increase of sorghum midge on a susceptible (CSH-1), moderately resistant (IS-12664C) and resistant (DJ-6514) cultivar

		Number of midge flies/ha		
Generation		CSH-1*	IS-12664C*	DJ-6514*
First year	P_1	100†	100*	100*
	F_1	600	300	100
	F_2	3600	900	100
	F_3	21,600	2700	100
	F_4	129,600	8100	100
Diapause population (1%)‡		1554	120	4
Second year	P_2	1554	120	4
	F_1	9324	360	4
	F_2	55,944	1080	4
	F_3	335,664	3240	4
	F_4	2,113,984	9720	4
Diapause population (6%)		25,149	142	1

*Midge population multiplies by six times on CSH-1, and IS-12664C and DJ-6514 are two and six times less susceptible than CSH-1, under no choice conditions respectively (Sharma *et al.*, 1983).
†The midge population at the beginning of the season is assumed to be 100 flies/ha.
‡In each generation, 1% of the total populations is assumed to enter diapause.

Table 5 Insect control scheme for Kharif season sorghum (120 days to maturity)

	Control measures			
	Shootfly	Stem borer	Midge	Headbugs
Planting: Mid June	No control	No control	High level of resistance	Chemical control
Flowering: September			Moderate resistance + chemical control	
Planting: Early July	Moderate resistance + chemical control	Moderate resistance	As above	As above
Flowering: Late September –October				

General recommendations: removal of sorghum stalks and earheads from the previous season, ploughing of the fields before planting and after harvest, and uniform planting over large areas reduces pest damage

fortunately, the monsoon season does not always provide adequate soil moisture until the middle of July. In this situation, risk taking farmers sow early and others, who want to be on the safe side, plant later. Under such a staggered sowing situation, shootfly can build up to damaging levels on the late sown crops. Stem borers are usually of little importance during June and July. The farmers use sorghum stalks for fodder during the dry season, thereby reducing the diapausing population. This crop hygiene practice should be encouraged. In addition, the relatively longer period required for the completion of one stem borer generation (30 days) may result in a slower build-up of the stem borer population. Therefore, if early sowing is possible, shootfly and stem borer will not cause major losses. When planting is late and staggered, moderate levels of shootfly and stem borer resistance will be of great help in suppressing population build-up. Chemical protection against shootfly may be needed and is discussed later.

The traditional Indian land races of Kharif sorghum mature in 140–150 days. Flowering in these cultivars inevitably takes place under declining rainfall conditions irrespective of planting date, thereby avoiding the optimum conditions for headbugs and midge (Fig. 1). The new high yielding varieties and hybrids, developed recently in India, mature in 110–120 days (to avoid end season drought stress) and have no, or very low resistance to the major insect pests. If sown early, their flowering coincides with the best ecological conditions for the build-up of midge and headbugs (Fig. 1). It is possible to plant late to avoid headbug and midge problems with such sorghums, but then the shootfly becomes a major problem and the available levels of resistance cannot cope with the population pressure. Therefore, midge and headbug resistance is most needed in early maturing cultivars. Another option is to develop even shorter duration genotypes (90 days; Fig. 1) which would provide only a short period for the midge and headbug populations to build up, especially if they were sown at the same time over large areas. Unfortunately, grain weathering and grain moulds would cause major problems, because the grain would mature during the peak of the rainy season.

Uniform and early sowings should help to avoid the shootfly and stem borer problem but, for sorghums with durations of 120 days, resistance to midge and headbugs will be essential in high risk areas. Under late and staggered sowings, the low levels of resistance found against shootfly and stem borer will have to be combined with high levels of resistance against midge and headbugs.

Rabi season (*Table 6*). The traditional land races of rabi sorghum and modern varieties and hybrids are of shorter duration (120 days). They utilize stored soil moisture adequately and flower, depending on the planting time, by the end of January or February under relatively low temperature conditions (mean 20°C). Planting takes place in September and October when shootfly and stem borer are present in fairly high densities. The adjustment of planting times to avoid these insect pests is therefore not possible.

Table 6 Insect control scheme for Rabi season sorghum (120 days to maturity)

	Control measures			
	Shootfly	Stem borer	Midge	Headbugs
Planting: Mid September	Moderate resistance + chemical control	Moderate resistance + chemical control	None	None
Flowering: January				
Planting: October	Same as above	Same as above	Moderate to high levels or resistance	Chemical control
Flowering: February				

General recommendations: same as in Table 5.

Temperatures and stored moisture decrease progressively from October onwards. Slower crop establishment is therefore experienced at late planting. As mentioned earlier shootfly and stem borer problems increase in such situations. Therefore, early planting in September is desirable, and at least, moderate to high levels of shootfly and stem borer resistance are required for rabi sorghums, combined, if necessary, with insecticide protection. Sorghum planted in mid-September flowers by mid-January when midge and headbugs are of less importance, because of comparatively low air temperatures (13°C minimum, 25°C maximum). Late October plantings may only flower by the end of February where temperatures are higher (15°C minimum, 33°C maximum) and r.h. ranges from 35 to 80%. Under these conditions midge and headbugs can reach damaging levels. Although we do not yet know the economic damage threshold levels, more than moderate resistance may be needed.

Rabi season sorghums should have higher levels of shootfly and stem borer resistance since adjustment of planting time cannot work at this time of the year. In case of late plantings, midge and headbug resistance would be beneficial. In addition good crop management, removal of debris and uniform sowing over large areas could supplement the pest reduction achieved by the levels of resistance presently available against shootfly, stem borer and midge.

Host-plant resistance in combination with insecticides

Since insect resistance in modern sorghum varieties and hybrids has not yet reached the state of practical use (except for midge), the combination of moderate resistance levels and insecticide application has not been fully tested. Jotwani *et al.* (1978) reported that there was only a marginal increase in yield when stem borer resistant cultivars were protected by dropping endosulfan granules into the plant whorl 25 and 35 days after sowing. This may also be an indication that stem tunnelling, which was prevented adds only marginally to yield loss. For shootfly under late sown conditions during Kharif and during Rabi when the shootfly and stem borer population is high, even moderately resistant varieties have to be protected (Tables 5 and 6). Seed treatment with carbofuran to reduce "dead heart" formation is the recommended practice in Maharashtra (Srivastava and Jotwani, 1981).

Although midge resistance levels have been demonstrated to be fairly high, we do not know how resistant genotypes will behave under different ecological conditions. Genotypes with low levels of resistance, but otherwise favourable characteristics will have to be protected with pesticides when subjected to high pest populations (Tables 5 and 6).

As discussed above, an important characteristic of sorghum varieties with only partial resistance is their ability to slow down population build-ups. This feature will prolong the time required by the pests to reach the economic threshold level. Consequently the number of sprays can be reduced accordingly. In sorghum, we are still far from knowing what long term impact our resistance levels will have on the build-up of populations. More research is also needed on the determination of economic threshold levels.

Resistant cultivars and biological control

Resistant varieties are highly compatible with biological control since they usually do not interfere with the natural enemies of pest species.

A number of predators and parasites have been reported feeding on shootfly, headbugs, stem borer and midge, especially the last two. The impact of their hosts is not well known. Certain stem borer resistance mechanisms may increase the efficiency of some natural enemies. First instar larvae of borers are disorientated by chemicals in the surface waxes of sorghum stems (Woodhead *et al.*, 1983). This may prolong their exposure to natural enemies. There could be a similar effect when second and third instars move from the whorl to bore into the base of the stem. An increase in time required to bore into harder stems may expose the larvae for longer periods to parasites and predators.

In a mixed cropping situation the combined benefit of resistance and biological control may be even greater, because of the possibility that there will be a greater diversity of biological control agents in the vicinity.

CONCLUSION

Host-plant resistance has a key role to play in the implementation of an IPM system in sorghum. The present levels of resistance could be utilized provided a strong breeding effort is made to incorporate resistance into breeding stocks with better agronomical background. Lower levels of shootfly and stem borer resistance can be supplemented with cultural and chemical control measures. For midge it remains to be seen whether chemical control is necessary, for observed levels of resistance are fairly high. As long as no resistant sources are found against headbugs, chemical control may be essential.

The relative advantages of short and long duration varieties and hybrids should be explored in relation to insect and disease attack.

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