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Effect of host-plant resistance on economic injury levels for the sorghum midge, *Contarinia sorghicola*

(*Keywords* plant resistance, economic injury level, sorghum midge, *Contarinia sorghicola*)

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Abstract. Sorghum midge, *Contarinia sorghicola* Coq (Cecidomyiidae Diptera), is the most important pest of grain sorghum worldwide The effect of midge-resistant cultivars on economic injury levels (EILs) for sorghum midge was studied on two midge-resistant (ICSV 197 and ICSV 745) and four commercial cultivars (CSH 1, CSH 5, ICSV 1 and ICSV 112) There was a linear relationship between midge density and percentage loss of grain in the midge-susceptible cultivars CSH 1, CSH 5, and ICSV 112 However, there was only a marginal increase in midge damage with an increase in midge density in the midge-resistant cultivars ICSV 197 and ICSV 745 while ICSV 1 showed a moderate increase in midge damage Insect density–damage relationships were better correlated when the cultivars were infested four times with a range of midge densities (5–40 midges/panicle) than with single infestations Regression coefficient (*b*-value) and coefficient of determination (R^2%) increased with number of infestations and insect density in the midge-susceptible cultivars EILs based on four infestations (across infestation levels) were 0 1–0 2 midges/panicle for the commercial cultivars ICSV 1, ICSV 112, and CSH 1, and 25 and 33 midges for the midge-resistant cultivars ICSV 197 and ICSV 745, respectively EILs at 40 midges/panicle (across number of infestations) were. 0·2 midges/panicle for CSH 1, ICSV 1, and ICSV 112 compared with 6·7 midges for ICSV 745, and 100 midges for ICSV 197 Economic injury levels for sorghum midge therefore differ with plant resistance, insect densities, and the number of days for which the panicles are exposed to the midge flies Panicles infested with a range of insect densities, and for three to four days give a reliable estimate of EILs for sorghum midge. It is important to determine EILs for resistant and susceptible cultivars for appropriate pest management decisions.

1. Introduction

Sorghum midge, *Contarinia sorghicola* Coq. (Diptera: Cecidomyiidae), is a major pest of grain sorghum (Harris, 1976). Management of sorghum midge includes cultural practices, host-plant resistance, natural enemies, and chemical control. Chemical control is costly, and numerous applications are required if infestation is prolonged because of staggered flowering. The prospects for successful implementation of cultural control by synchronized plantings have their limitations since all the farmers in a region may not be able to plant the same cultivar at the same time. Uneven distribution of rainfull leads to staggered plantings which may increase midge populations. In such situations, there may be a complete loss of grain in late-sown crops.

Host-plant resistance is a viable component in integrated pest management and this tactic has a wide applicability and function. Midge-resistant varieties are one of the most effective means of controlling this insect (Johnson *et al.*, 1973; Sharma *et al.*, 1992; Sharma, 1993). Economic injury levels (EILs) may or may not change with different cultivars depending upon the criterion used for establishing the EILs (e.g. insect numbers, % damage, etc.), and the mechanisms of resistance to the insect (non-preference, antibiosis or tolerance) (Sharma, 1993). Since thresholds for midge are based on the non-damaging adult populations, the EILs would be expected to change with the level of host-plant resistance

The present studies examined the change in EILs for sorghum midge on newly-developed midge-resistant cultivars, and determine insect density–damage relationships for different infestation levels, number of infestations across seasons, and cultivars for rationalizing insecticide usage in integrated pest management in sorghum.

2. Materials and methods

The experiments were carried out between 1985 and 1989 at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India, and the ICRISAT sub-station at the University of Agricultural Sciences, Dharwad, Karnataka, India.

2.1. Crop

At ICRISAT Center, the crop was planted on ridges 75 cm apart. Seedlings were thinned to a spacing of 10 cm between the plants 15 days after emergence. Carbofuran 3G (1·2 kg a.i./ha) was applied at the time of sowing to protect the seedlings against sorghum shoot fly (*Atherigona soccata* Rond.) and spotted stem borer (*Chilo partellus* Swin.). Cypermethrin (Cymbush 3ED) (R) was also sprayed 15 days after seedling emergence to control the sorghum shoot fly. No insecticide was applied during the reproductive phase of the crop. The crop was raised under rainfed conditions during the rainy season (July–October), and under irrigated conditions during the post-rainy season (October–March). At Dharwad, the crop was sown with carbofuran 3G on flat beds, with rows spaced 50 cm apart, and the seedlings thinned to a distance of

Table 1. Economic injury levels for sorghum midge across different number of infestations and infestation levels (ICRISAT Center, 1985–1988)

Location	Year	No. of infestations	No. of flies/ panicle	Cultivar	Regression coefficient (*b*)	Coefficient of determination (R^2 %)	EIL (No. of midges/ panicle)	
							C:B	N
Dharwad	1985	4	1–10	CSH 5	3·6*	82	0·82	1·0
				ICSV 197	0·5	34	6·34	7·8
Dharwad	1985	5	1–10	CSH 5	3·6**	99	0·82	1·0
				ICSV 197	-0·1	12	31·70	41·7
Patancheru	1985	4 + 5 combined	1–10	CSH 5	2·3**	94	1·28	1·6
				ICSV 1	1·0**	85	3·11	3·9
				ICSV 197	0·5	86	6·34	7·8
Dharwad	1985	1	4–50	CSH 5	0·8*	80	3·68	4·6
				ICSV 197	−0·01	6	31·70	21·6
Patancheru	1988	1	5–60	CSH 1	0·7**	92	4·74	5·6
				ICSV 1	0·2**	92	15·55	5·4
				ICSV 197	0·06**	72	52·83	62·5
				ICSV 745	0·12**	93	25·25	31·3

EIL = Economic injury level, C:B = EIL based on a cost:benefit ratio of 1:1, and N = EIL computed by the formula of Norton (1976).

*,**Regression coefficient significant at P = 0·05, and 0·01, respectively.

10 cm between plants 15 days after emergence. During the 1985 rainy season, the commercial hybrid CSH 5 and the midge resistant variety ICSV 197 were sown at Dharwad, and CSH 5, ICSV I and ICSV 197 at ICRISAT Center. During the 1988 rainy season CSH 1, ICSV 1, ICSV 197 and ICSV 745 were sown, and during the 1989/90 post-rainy season ICSV 197, ICSV 745, ICSV 1, ICSV 112, and CSH 1 were sown at ICRISAT Center for estimating EILs.

Each cultivar was planted in 108 m^2 plots. At flowering, the panicles were tagged at random and infested with different numbers of midge females using the headcage technique (Sharma *et al.*, 1988). Each infestation level was replicated on 20 panicles. Cultivars tested, number of midges released/panicle, and the number of infestations are given in Table 1.

2.2. *Insects*

Adult females were collected from flowering sorghum panicles in 200 ml plastic aspirators in the morning (08.30 to 10.00 h), and were immediately released on sorghum panicles inside headcages at initiation of flowering. The headcage consisted of a wire-framed cage (16 cm diameter, 20 cm long, with three vertical support wires) having a loop at the top. Extensions of the vertical wires were tied around the peduncle. The cage was covered with a blue cloth bag (30 cm long, and 16 cm diameter) having an inlet hole at the top (5 cm diameter, and 5 cm long) (Figure 1) (Sharma *et al.*, 1988). Midge infestation was repeated on subsequent days as per experimental details (Table 1). Midge females lay eggs inside the spikelets, and die within 4–8 h. The larvae feed on the developing grain. As a result, the infested spikelets become chaffy. The panicles were checked 1 week after infestation

Figure 1. Wire-framed headcage used to confine midge females with the sorghum panicles at anthesis for determining insect density–damage relationships.

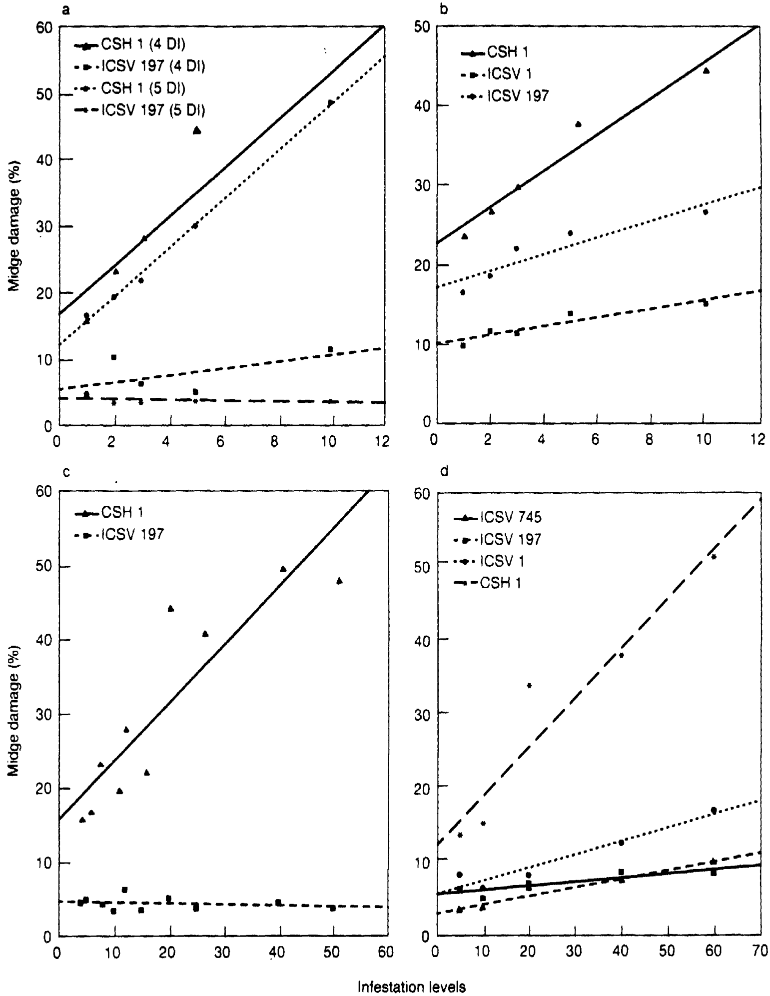


Figure 2. Insect density–yield loss relationships for sorghum midge, C. sorghicola *(a = Dharwad, 1985 rainy season; b = Patancheru, 1985 rainy season; c = Dharwad, 1985 rainy season; and d = Patancheru, 1988 rainy season).*

for the presence of other panicle-feeding insects such as head bugs and head caterpillars, and these insects were removed by tapping the panicle.

In general, there are 5–20 midges/panicle under natural conditions (Sharma *et al.*, 1988). However, in situations of heavy midge infestation, there may be up to 100 midges/panicle. In susceptible cultivars, 40 midges/panicle cause 100% damage (Sharma *et al.*, 1988). Therefore, we selected a range of insect densities representing low (1–10 midges/panicle) or high (5–40 midges/panicle) midge infestations. Also, flowering in sorghum panicles continues for 4–6 days, when the midge females lay eggs inside the spikelets at anthesis (Harris, 1976). However, in situations of cloudy weather, rain, and low temperatures, midge emergence and oviposition may be restricted to 1 or 2 days. Therefore, the sorghum panicles were infested for 1 or 4 days to get an idea of insect density–damage relationships across a range of insect densities and number of infestations.

2.3. *Observations*

The percentage of midge-damaged spikelets (grain) were recorded at maturity. Generally, the female midge lays a single egg inside each spikelet, and the larva completes its life cycle on a single grain resulting in complete chaffiness of the spikelet. Percentage midge damage therefore is equal to percentage loss in grain yield, since there is very little scope for compensation in grain yield as a result of midge damage (Hallman *et al.*, 1984a). Midge damage was recorded at maturity in a sample of 500 spikelets selected at random. The CV% is <20% in a sample of 500 spikelets, and hence this was used to estimate midge damage in the infested panicles (Sharma *et al.*, 1988).

2.4. *Statistical analysis*

Data were subjected to regression analysis to determine the relationship between insect density and/or number of infestations with percentage loss in grain. EILs were computed by two methods; (1) based on a cost:benefit ratio of 1:1, and (2) by the formula of Norton (1976) as used for estimating EILs for sorghum head bugs (Sharma and Lopez, 1989). The cost of one application of insecticide was estimated at Rs 250/ha, and the market price of sorghum grain was taken at Rs 2500/t. For a cost:benefit ratio of 1:1, the EILs were computed on the basis of mean yield potential of cultivars over locations in the All India Coordinated Sorghum Improvement Project, which was 3·15, 3·20, 3·21, 3·18, 3·01, and 39·1 t/ha for ICSV 197, ICSV 745, ICSV 1, ICSV 112, CSH 1, and CSH 5, respectively (AICSIP, 1985, 1990). Loss of grain yield due to one midge/panicle was obtained by:

$$L = \frac{Y \times b}{100}$$

where L = loss in grain yield due to one midge/panicle (t/ha)

Y = yield potential of the cultivar (t/ha)

b = regression coefficient (% grain loss due to one midge/panicle)

EILs based on a cost:benefit ratio of 1:1 were obtained by:

$$\text{EIL} = \frac{Q}{L}$$

where Q = loss of grain (t/ha) sufficient to justify insecticide application (i.e. loss of 0·1 t of sorghum grain/ha is sufficient to justify the cost of one insecticide application).

EILs by Norton's (1976) formula were computed as follows:

$$\text{EIL} = \frac{C}{P \times L \times K}$$

where C = cost of control, i.e. Rs 250/ha

P = price of grain, i.e. Rs 2500/t

L = loss of grain due to 1 midge/panicle (t/ha)

K = reduction constant, i.e. efficiency of the insecticide to control the insect (taken here as 0·80).

3. Results

3.1. *Insect density–yield loss relationships for midge-resistant and susceptible cultivars across seasons and infestation levels*

There was a linear relationship between midge density (number of midges released/panicle) and damage (percentage of spikelets without grain) in CSH 5 and ICSV 1 both across infestation days (one or four to five infestations) and across different midge densities (1–10 or 4–60 midges/panicle) (Figure 2, Table 1). However, the regression coefficient (b-value) was lower for the midge-resistant genotypes, ICSV 197 and ICSV 745 than the commercial cultivars, CSH 5, CSH 1 and ICSV 1. Regression coefficients were greater when the panicles were infested four to five times with 1–10 midges compared with panicles infested with 4–60 midges only once. Thus, single infestations resulted in a poor relationship between midge density and damage. Coefficients of determination (R^2%) were poor for ICSV 197 compared with CSH 5 (except in 1985 and 1988 seasons) because of its inherent resistance to sorghum midge.

EILs were higher on the midge-resistant cultivars ICSV 197 and ICSV 745 (6·34 to 31·7 midges/panicle) compared with the commercial cultivars, CSH 1 and CSH 5 (0·82 to 1·6 midges/panicle when the panicles were infested four to five times with 1–10 midges). Estimates for EILs were two to seven times higher on the susceptible cultivars when infested with 5–60 midges for 1 day than when infested with 1–10 midges four to five times.

3.2. *Insect density–damage relationships for five sorghum cultivars at different infestation levels and number of infestations*

3.2.1. *Infestation levels.* Regression coefficients were low for the midge-resistant cultivars ICSV 197 (b = 0·01 to 1·09) and ICSV 745 (b = 0·26 to 1·42) compared with the commercial cultivars (b = 1·38 to 11·75 for ICSV 1, 1·09 to 15·50 for ICSV 112, and 5·25 to 15·38 for CSH 1) (Table 2, Figure 3). The regression coefficient increased with an increase in infestation levels (except for ICSV 197 and ICSV 745 at 20 and 40 midges/panicle). Regression coefficients were significant at 20 and 40 midges/panicle for the midge-susceptible cultivars (except for ICSV 112 at

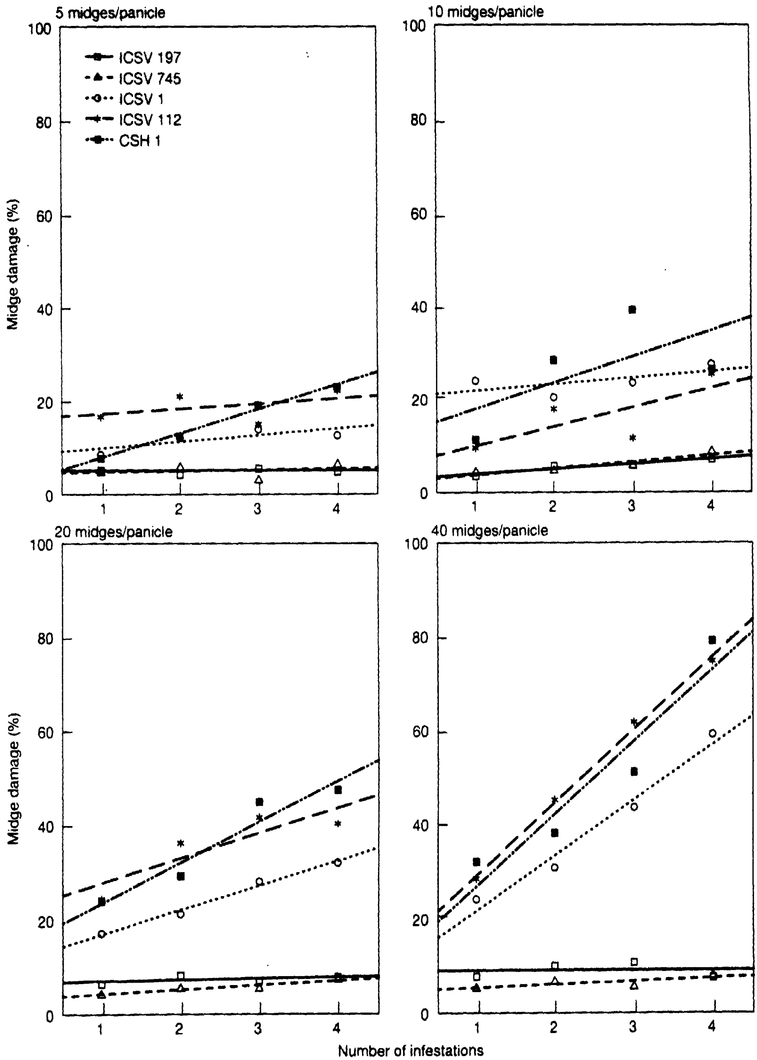


Figure 3. Insect density–yield loss relationships for sorghum midge, C. sorghicola, across number of infestations (ICRISAT Center, 1988/89 post-rainy season).

Table 2. Insect density–damage relationships for sorghum midge at different infestation levels in five sorghum cultivars (ICRISAT Center, 1989/90 post-rainy season)

Cultivar		Regression coefficient (*b*)				Coefficient of determination (R^2 %)			
		5	10	20	40	5	10	20	40
ICSV 197	R	0·01	1·09*	0·24	0·04	—	84	—	—
ICSV 745	R	0·26	1·42*	0·94*	0·48	—	78	82	3
ICSV 1	MS	1·41	1·38	5·18**	11·75**	43	6	98	96
ICSV 112	S	1·09	4·14	5·40	15·50**	—	34	67	99
CSH 1	S	5·25	5·60	8·60*	15·38*	99	10	89	86

R = Resistant, MS = moderately-susceptible, and S = susceptible.
— = Residual greater than *Y*-variate
*,** = Regression coefficient significant at $P = 0{\cdot}05$, and 0·01, respectively.

Table 3. Insect density–damage relationships for sorghum midge at four infestations in five sorghum cultivars (ICRISAT Center, 1989/90 post-rainy season)

Cultivar		Regression coefficient (*b*)				Coefficient of determination (R^2 %)			
		1	2	3	4	1	2	3	4
ICSV 197	R	1·02	1·97**	1·61	0·88	29	98	68	60
ICSV 745	R	0·14	0·41	0·67	0·12	–	–	29	—
ICSV 1	MS	3·97	5·65*	9·34**	14·35*	24	89	93	88
ICSV 112	S	5·05	9·06*	16·96*	17·24*	40	74	79	79
CSH 1	S	8·53**	7·81*	10·14*	18·88*	94	84	85	85

R = Resistant, MS = moderately-susceptible, and S = susceptible.
— = Residual greater than *Y*-variate.
*,** = Regression coefficient significant at $P = 0{\cdot}05$, and 0·01, respectively

20 midges/panicle). R^2 values were 86–99% at 20 and 40 midges/panicle for the commercial cultivars.

3.2.2. *Number of infestations.* Regression coefficients were greater for the commercial cultivars CSH 1, ICSV 112, and ICSV 1 than for ICSV 197 and ICSV 745, and increased with an increase in the number of infestations (except for ICSV 197 and ICSV 745 for four infestations) (Figure 4, Table 3). Regression coefficients were significant for panicles infested two to four times in the commercial cultivars; CSH 1, ICSV 1, and ICSV 112. For the midge-resistant cultivars, the regression coefficients were non-significant (except for ICSV 197 for two infestations). R^2 values were 74–93% for panicles infested two to four times in CSH 1, ICSV 1, and ICSV 112.

3.2.3. *Economic injury levels.* Estimates for EILs decreased with an increase in the number of infestations in the susceptible cultivars. In ICSV 197 and ICSV 745, the EILs were higher at four infestations than at one to three infestations (Table 4). EILs were 0·1 to 0·2 midges/panicle for the commercial cultivars, ICSV 1, ICSV 112, and CSH 1 compared with 33·3 midges for ICSV 197 and 25·0 midges for ICSV 745 when the panicles were infested four times. EILs decreased with an increase in midge density on ICSV 1, ICSV 112, and CSH 1. At 40 midges/panicle, the EILs for the commercial cultivars were 0·2 midges/panicle compared with 6·7 midges for ICSV 745, and 100 midges for ICSV 197. EILs were lowest for the midge-resistant cultivars at 10 midges/panicle and at two infestations. For the commercial cultivars, four infestations and 40 midges/panicle resulted in lowest estimates for EILs.

3.3. *Insect density–damage relationships across infestation levels and number of infestations*

Regression coefficients were higher for number of infestations than for infestation levels. Regression coefficients for ICSV 197 and ICSV 745 were lower than those for ICSV 1, ICSV 112 and CSH 1 both for the number of infestations and the infestation levels (Table 5, Figure 5). R^2 values were $<50\%$ (except for infestation levels for ICSV 112), indicating that averaging the data either across infestation levels or number of infestations does not explain the relationship between insect density and grain damage for computing EILs. Insect density–damage relationships across cultivars improved with an increase in insect numbers/panicle (Figure 5(b)).

EILs were lower for number of infestations than for infestation levels (Table 5). EILs varied from 0·3 to 0·6 midges/panicle for ICSV 1, ICSV 112, and CSH 1 compared with 4·0 midges/panicle for ICSV 745, and 9·1 midges/panicle for ICSV 197 across number of infestations. Across infestation levels, the EILs were 2·8–4·5

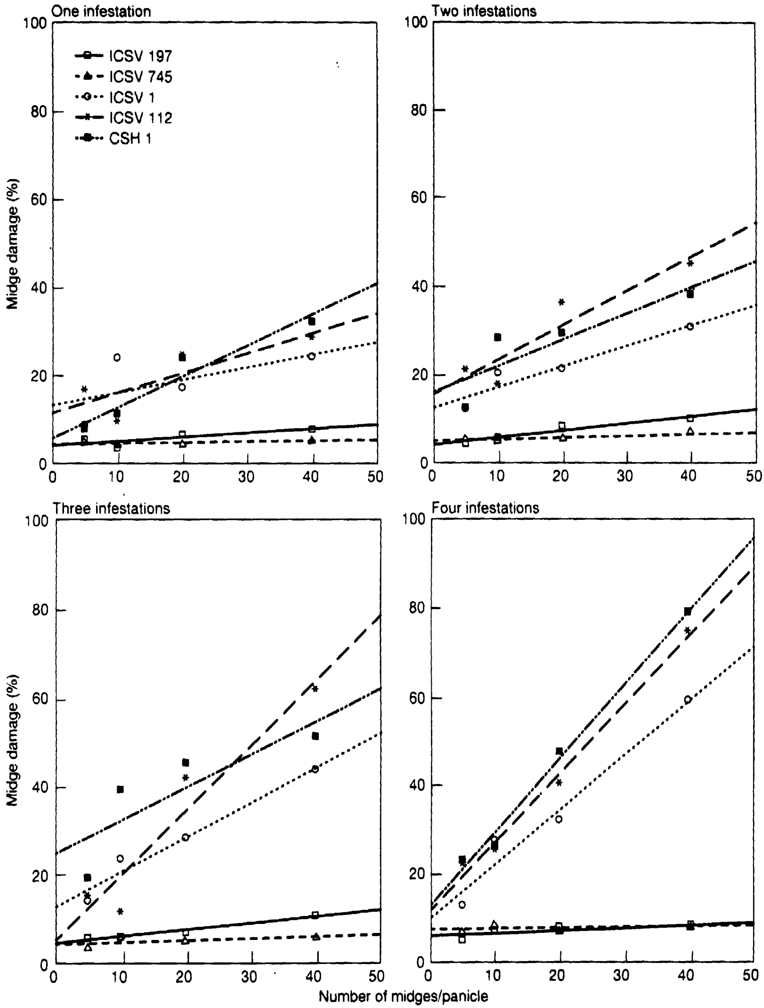


Figure 4. Insect density–yield loss relationships for sorghum midge, C. sorghicola, *across infestation levels (ICRISAT Center, 1988/89 post-rainy season).*

midges/panicle for susceptible cultivars compared with 25–50 midges for ICSV 745 and ICSV 197. The estimates for EILs were much higher than those obtained with damage–density relationships for number of infestations and infestation levels.

4. Discussion

Midge density–damage relationships were linear for the midge-susceptible cultivars CSH 1, CSH 5, ICSV 1 and ICSV 112 across seasons and/or number of infestations.

Table 4. Economic injury levels (number of midges/panicle) for sorghum midge across four infestation days and four insect densities in five sorghum cultivars (ICRISAT Center, 1989/90 post-rainy season)

	EILs at different number of infestations				EILs at different infestation levels (No. of midges/panicle)			
Cultivar	1	2	3	4	5	10	20	40
ICSV 197	3·1	1·6	2·0	33·3	333·3	2·9	12·5	100·0
ICSV 745	20·0	7·7	4·8	25·0	12·2	2·2	3·3	6·7
ICSV 1	0·8	0·6	0·3	0·2	2·2	2·3	0·6	0·2
ICSV 112	0·6	0·4	0·2	0·2	2·9	0·8	0·6	0·2
CSH 1	0·3	0·3	0·3	0·1	0·5	0·5	0·3	0·2

Table 5. Insect density–damage relationships for sorghum midge on five sorghum cultivars across number of infestations and at different insect densities (ICRISAT Center, 1989/90 post-rainy season)

					EILs (No of midges/panicle)			
	No. of infestations		Infestation levels (IL)		No. of infestations		Infestation levels	
Cultivar	b	R^2(%)	b	R^2(%)	C:B	N	C:B	N
ICSV 197	0·34	1	0·12**	33	9·1	11·1	25·0	33·3
ICSV 745	0·78*	19	0·03	3	4·0	5·0	50·0	125·0
ICSV 1	4·93**	16	0·69**	47	0·6	0·8	4·5	5·6
ICSV 112	6·00**	13	1·03**	58	0·5	0·7	3·5	3·8
CSH 1	8·67**	28	0·92**	48	0·3	0·5	2·8	3·8

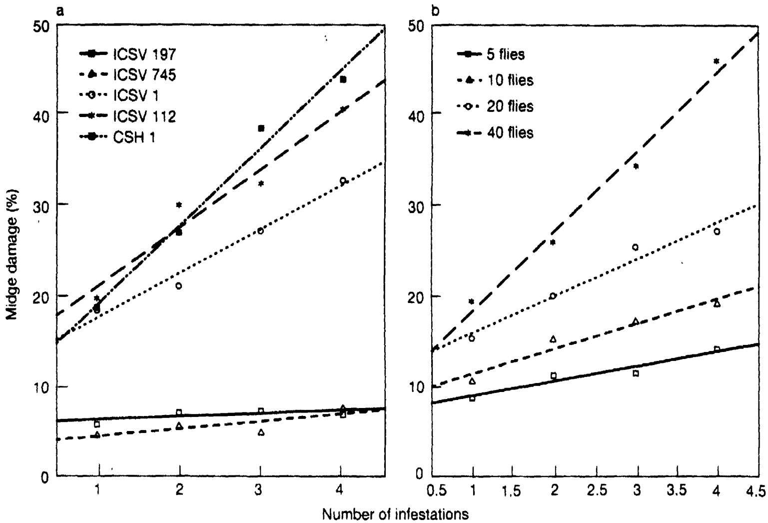
C:B = EILs based on a cost:benefit ratio of 1:1, and N = EILs based on Norton's (1976) formula
*,** = Regression coefficient significant at $P = 0·05$, and 0·01, respectively

However, increase in midge damage was low for the midge-resistant cultivars ICSV 197 and ICSV 745. A poor relationship between midge infestation and percentage loss in grain (% midge damage) was also evident in terms of low R^2 values for the midge-resistant cultivars. Low damage in the midge-resistant cultivars is largely because of low oviposition due to short and tight glumes (Sharma *et al.*, 1990).

Insect density–damage relationships were better when the panicles were infested repeatedly four to five times than when using a single infestation (Tables 1 and 3). R^2 values were >79% for the midge-susceptible cultivars with three or four infestations and with 40 midges/panicle, and these provided a fair estimate for computing EILs. EILs for the midge-resistant cultivars varied widely because of a poor relationship between midge density and percentage midge damage. EILs computed on the basis of a cost:benefit ratio of 1:1 were similar to those obtained by Norton's (1976) formula.

Economic thresholds for sorghum midge have been estimated to be 1·0 midge/panicle in Texas (USA), India, and Argentina (Hoelscher and Teetes, 1981; Limonti and Villata, 1980; Karanjakar and Chandurwar, 1978), 2–3 midges/panicle in Mississippi (Pitre *et al.*, 1975), over 6·0 midges in Australia (Passlow, 1973), and 0·6 midges in Taiwan (Hong, 1987). Hallman *et al.* (1984b) studied midge density–damage relationships for midge-resistant and midge-susceptible hybrids. They suggested a threshold level of one midge/panicle for the midge-susceptible hybrids and five midges/panicle for the midge-resistant hybrids. EILs for the midge-resistant cultivars were much greater than those reported for the midge-resistant hybrids. EILs for sorghum midge were 0·1 to 0·2 midges/panicle for the susceptible cultivars CSH 1, CSH 5, ICSV 1, and ICSV 112 compared with 25 midges/panicle for ICSV 745 and 33 midges for ICSV 197 for four infestation levels. At 40 midges/panicle, the EILs ranged from 0·2 midges/panicle for the susceptible cultivars to 6·7 midges for ICSV 745, and 100 midges for ICSV 197. EILs for midge varied with insect density, number of infestations, and host-plant resistance. Four infestations across a range of midge densities (5–40 midges/panicle) and 40 midges/panicle (across number of infestations) provided similar and reliable estimates for computing EILs for sorghum midge.

EILs vary across cultivars (Sharma and Lopez, 1989, 1993; Sharma, 1993), seasons/locations, and depend upon the prevailing market costs of the inputs and the value of the produce. They are a useful tool for decision-making in pest management. EILs for sorghum midge increase with an increase in the level of cultivar resistance to *C. sorghicola* (Sharma, 1993). Thus, it is important to determine EILs for pest-resistant cultivars to avoid wasteful usage of pesticides or other means of pest control. Determination of EILs for pest-resistant cultivars also provides information on whether the available levels of resistance are adequate to withstand prevailing pest



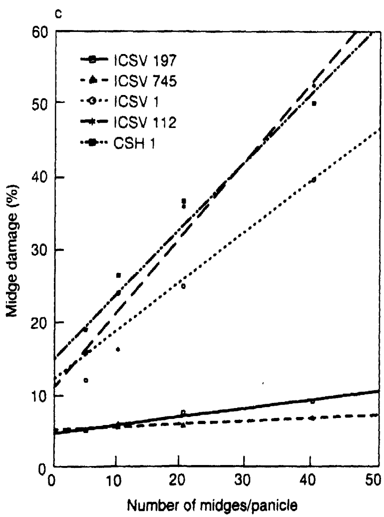


Figure 5. Insect density–yield loss relationships for sorghum midge, C. sorghicola, *across genotypes and number of infestations (ICRISAT Center, 1988/89 post-rainy season).*

populations or whether there is a need to supplement plant-resistance with other methods of pest control.

5. Conclusion

EILs change with the level of resistance in sorghum cultivars to *C. sorghicola*. EILs were 0·2 midges/panicle for the midge-susceptible cultivars CSH 1, ICSV 1, and ICSV 112, and 6·7 midges/panicle for ICSV 745 and 100 midges for ICSV 197 at 40 midges/panicle. EILs were 0·1 to 0·2 midges/panicle for the susceptible cultivars, and 25 and 33 midges for the midge-resistant cultivars ICSV 745 and ICSV 197, respectively for four infestations. EILs for sorghum midge change with insect density, number of infestations, and the level of host-plant resistance. For determining EILs for sorghum midge, it is important to infest the test cultivars for three to four days with a range of insect densities (5–40 midges/panicle). EILs should be determined for different cultivars grown in a region to optimize insecticide application for integrated pest management.

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References

AICSIP (All India Coordinated Sorghum Improvement Project), 1985. *Proceedings of the All India Coordinated Sorghum Improvement Workshop, 1984* (New Delhi, India: Indian Council of Agricultural Research (ICAR)).

AICSIP (All India Coordinated Sorghum Improvement Project), 1990 *Proceedings of the All India Coordinated Sorghum Improvement Workshop, 1989* (New Delhi, India: Indian Council of Agricultural Research (ICAR)).

HALLMAN, G. J., TEETES, G. L. and JOHNSON, J. W., 1984a. Weight compensation of undamaged kernels in response to damage by sorghum midge (Diptera: Cecidomyiidae). *Journal of Economic Entomology*, **77**, 1033–1036.

HALLMAN, G. J., TEETES, G. L. and JOHNSON, J W., 1984b. Relationship of sorghum midge (Diptera: Cecidomyiidae) density to damage to resistant and susceptible sorghum hybrids. *Journal of Economic Entomology*, **77**, 83–87.

HARRIS, K. M., 1976 The sorghum midge. *Annals of Applied Biology*, **84**, 114–118.

HOELSCHER, C. E. and TEETES, G L., 1981. Insect and mite pests of sorghum: management approaches. *Texas Agriculture Extension Series Publication*, B 1220, 24 pp.

HONG, S. C., 1987 Relationship of sorghum midge density to the damage of sorghum *Chinese Journal of Entomology*, **7**, 25–29

JOHNSON, J. W., ROSENOW, D. T. and TEETES, G. L., 1973. Resistance to the sorghum midge in converted exotic sorghum cultivars. *Crop Science*, **13**, 754–755.

KARANJAKAR, R. R. and CHANDURWAR, R D., 1978. Losses to jowar cob in relation to adult midge population. *Sorghum Newsletter*, **21**, 55–56.

LIMONTI, M. R. and VILLATA, C. A., 1980 Forma de detectar la presencia de la 'mosquita del sorgho' *Contarinia sorghicola* (Coquillett) y medidas para su control. *Institut Nacional Tecnica Agropecuaria Divulgacion Tecnica*, 5, Manfredi, Argentina.

NORTON, E A., 1976. Analysis of decision making in crop protection. *Agro-Ecosystems*, **3**, 27–44.

PASSLOW, T., 1973. Insect pests of grain sorghum. *Queensland Agriculture Journal*, **99**, 626–628.

PITRE H., ROTH, J.P. and GOURLEY, L. M., 1975. The sorghum midge in Mississippi. *Mississippi Agricultural Experiment Station Bulletin*, 836, 13 pp.

SHARMA, H. C., 1993. Host plant resistance to insects in sorghum and its role in integrated pest management. *Crop Protection*, **12**, 11–34.

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 Protection*, **8**, 429–435

SHARMA, H. C and LOPEZ, V F, 1993. Economic injury levels for sorghum head bug, *Calocoris angustatus*, on resistant and susceptible genotypes. *Crop Protection* **12**, 259–266.

SHARMA, H. C., VIDYASAGAR, P. and LEUSCHNER, K., 1988 No-choice cage technique to screen for resistance to sorghum midge (Diptera: Cecidomyiidae). *Journal of Economic Entomology*, **81**, 415–422

SHARMA, H. C., VIDYASAGAR, P. and LEUSCHNER, K., 1990. Components of resistance to the sorghum midge, *Contarinia sorghicola*. *Annals of Applied Biology*, **116**, 327–333.

SHARMA, H. C, TANEJA, S. L., LEUSCHNER, K. and NWANZE, K F., 1992. Techniques to screen sorghums for resistance to insect pests *Information Bulletin* No. 32 (Patancheru, Andhra Pradesh, 502 324, India: International Crops Research Institute for the Semi-Arid Tropics), 48 pp.