Field Screening Sorghum for Resistance to Sorghum Midge (Diptera: Cecidomyiidae)

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J. Econ. Entomol. 81(1): 327–334 (1988)

ABSTRACT Various techniques to increase infestation and improve efficiency of screening sorghum for sorghum midge, *Contarinia sorghicola* (Coquillett), resistance were tested at ICRISAT Center. Adjustment of planting dates to synchronize flowering with period of peak abundance of adult midges, planting infester rows of susceptible cultivars ('CSH 1' and 'CSH 5') 20 d before test cultivars, spreading midge-damaged sorghum panicles containing diapausing midge larvae in infester rows, and using sprinkler irrigation during flowering in the postrainy season helped to increase midge abundance. Careful and selective use of contact insecticides to control head bug, *Calocoris angustatus* Lethiery, and midge parasite *Tetrastichus diplosidis* Crawther was useful in screening and selecting sorghum cultivars for midge resistance. Planting two sets of test material at fortnightly intervals helped to reduce chances that sorghum would escape midge damage. Maintaining thin plant stands also increased midge damage by preventing population dilution due to fewer numbers of panicles per unit area.

KEY WORDS Insecta, resistance screening, infester rows, sprinkler irrigation

SORGHUM MIDGE, *Contarinia sorghicola* (Coquillett), is the most destructive pest of grain sorghum in Asia, Africa, the Americas, and Australia, and it has widespread and substantial effects on sorghum grain yields (Harris 1976). Maintenance of sorghum midge population density below the economic threshold is difficult. In areas where rainfed sorghum is grown, it is not always possible to avoid midge damage through timely plantings, and insecticides are too expensive for poor farmers with limited means. In these situations, midge-resistant sorghum cultivars offer a feasible means of keeping midge damage below economic threshold levels.

Most screening of sorghums for midge resistance has been conducted under natural infestation. The results of these screening trials have been reviewed by Sharma & Davies (1981). Selecting cultivars with repeatable resistance is difficult under conditions of natural infestation because of fluctuating midge population and staggered flowering of the sorghum cultivars. Thus far, a concerted effort to determine ways to increase midge density for resistance screening under field conditions has not been made. Wiseman & McMillian (1971) suggested planting midge-susceptible sorghums (infester rows) to increase midge density. However, this procedure is not always useful in the absence of natural midge infestation in the infester rows. Midge emergence, activity, and subsequent damage are influenced by temperature and relative humidity (Summers 1975, Fisher & Teetes 1982). Interspecies competition for food from sorghum head bug, *Calocoris angustatus* Lethiery, parasitization by *Tetrastichus diplosidis* Crawther, and predation by *Orius maxidentex* Ghauri also restrict midge abundance in India. In this paper, we report the results of trials with six techniques tested to overcome these problems and increase the efficiency of screening sorghums for midge resistance under field conditions.

Materials and Methods

Six techniques were tested to increase sorghum midge abundance and improve the efficiency of selecting sorghum cultivars for resistance to sorghum midge. These techniques were as follows: 1) manipulating planting date, 2) augmenting midge density, 3) using sprinkler irrigation, 4) controlling head bug and midge parasites, 5) using split plantings of test materials, and 6) adjusting planting density.

Planting Date. A sorghum midge-resistant ('TAM 2566') and a susceptible ('CSH 1') sorghum cultivar were planted every 2 wk on 10 occasions from May to September 1980 to determine the optimum time to plant sorghum lines for resistance screening. These cultivars flower in 55 and 60 d, respectively. The cultivars were planted at the ICRISAT Center in plots of four rows, each 4 m long. A randomized complete block design with three replications was used. The optimum planting date was the one at which the resistant and susceptible cultivar flowered when midge density and subsequent damage were highest. Adult midge density was determined at the 50% anthesis stage and was based on the number of adult midges per five panicles. Midge damage (number of florets with midge larvae) was determined from a sample of 500 florets taken at

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random from five panicles 15 d after anthesis. The florets were collected by detaching three primary branches from the top, middle, and bottom portion of each panicle. Samples were taken from five randomly selected panicles of each cultivar in each replication. These primary branches were then mixed and smaller, secondary branches were detached. From this, 500 florets were examined and midge-damaged florets without grain were separated. Midge-damaged chaffy florets were pressed between the tips of blunt forceps. The spikelets infested with midge larvae produced a red ooze when pressed. The number of midge-infested florets was recorded.

Augmentation of Midge Density. Two treatments, infester rows and spreading midge-damaged sorghum panicles containing diapausing larvae, were tested alone and in combination as a means to augment naturally occurring midge density in large unreplicated plots of 0.5 ha for four seasons. Plots without infester rows and midge-infested sorghum panicles served as controls. A midge-resistant ('TAM 2566') and a midge-susceptible ('CSH 1') cultivar were planted in each treatment (0.25-ha plots). The infester rows of 1:1 mixture of 'CSH 1' and 'CSH 5' commercial hybrids, which flower in 55 and 67 d, respectively, were planted 20 d before the test material. Four infester rows were planted after every 16 rows of the test cultivars. Midge-infested sorghum panicles containing diapausing larvae were spread at the flag leaf stage of the infester rows. The panicles were kept moist for 15 d to stimulate the termination of larval dispause for pupation and adult emergence. Adults emerging from diapausing larvae served as a starter infestation in infester rows to supplement the natural infestation. Emergence of adult midges from midge-damaged sorghum panicles spread in the infester rows was checked by taking a sample of 500 midge-damaged chaffy florets and moistening them in a Petri dish. Florets were kept under high relative humidity (95–100%) in a desiccator at 30°C. The experiment was replicated three times. Emergence of adult midges was recorded on alternate days up to 29 d after the florets were moistened.

Midge abundance was evaluated as the number of florets with midge larvae and midge-damaged chaffy florets. The number of florets that contained midge larvae was determined from a sample of 2,000 florets per cultivar per plot. Florets were collected 15 d after anthesis from 25 randomly selected panicles in the center of each plot. The number of florets with midge larvae was recorded as described before. The number of midge-damaged florets that failed to produce grain because of midge damage was similarly recorded from a sample of 2,000 florets taken at random from 25 panicles from each plot at grain maturity. The significance of treatment differences was determined with a Z test (Snedecor & Cochran 1967). We assumed that midge damage follows a Poisson distribution with observed values as the mean and variance, and, therefore,

$$Z = \frac{P1 - P2}{\sqrt{P(1 - P)(1/N1 + 1/N2)}}$$

where $P1$, $P2$ = proportion of florets with midge larvae or midge-damaged chaffy florets without grain in the two treatments under comparison, and

$$P = \frac{N1P1 + N2P2}{N1 + N2}$$

$N1$ and $N2$ = sample size (i.e., 2,000 florets).

Sprinkler Irrigation. Overhead sprinkler irrigation was used to increase relative humidity in the midge screening trials during the 1980–81 postrainy season. High humidity increases midge activity, adult emergence, and subsequent damage (Fisher & Teetes 1982). Sprinkler irrigation was used in a plot (1 ha) planted to sorghum. Four midge-resistant ('AF 28', 'SGIRL-MR-1', 'IS 12573C', and 'DJ 6514') and a midge-susceptible ('CSH 1') sorghum cultivar were planted at regular intervals in the field in nine replications. An equivalent, similarly planted area without sprinkler irrigation served as a control. The experiment was arranged in a split plot design with irrigation as the main treatment and cultivars as subtreatments. Sprinkler irrigation was conducted daily between 1500 and 1600 hours from panicle emergence to grain-filling stage of the crop. The number of midge-damaged florets that failed to produce grain was determined from a sample of 1,000 florets collected from five randomly selected panicles at maturity in each replication. Samples were taken as previously described. Square root transformed values were used for analysis of variance and the treatment means were compared by least significant difference (LSD) (Snedecor & Cochran 1967).

In a subsequent trial during the 1981–82 postrainy season, 170 sorghum lines were evaluated for midge resistance in plots with and without sprinkler irrigation. The sorghum lines were evaluated for midge resistance with a no-choice cage technique by infesting panicles at top-anthesis stage with 40 midges for 2 d. Five panicles of each cultivar were infested in irrigated and unirrigated plots. Cultivars with less damage than the control and with <40% midge-damaged florets were considered resistant for the purpose of comparing the efficiency of selecting for midge resistance with and without sprinkler irrigation.

Selective Use of Insecticides to Control *C. angustatus* and *T. diplosidis*. *C. angustatus* and *T. diplosidis* are the two major biotic factors limiting midge abundance in trials of screening for midge resistance in India. Head bugs damage the sorghum panicles from emergence to hard-dough stage and compete for food with sorghum midge. Symptoms

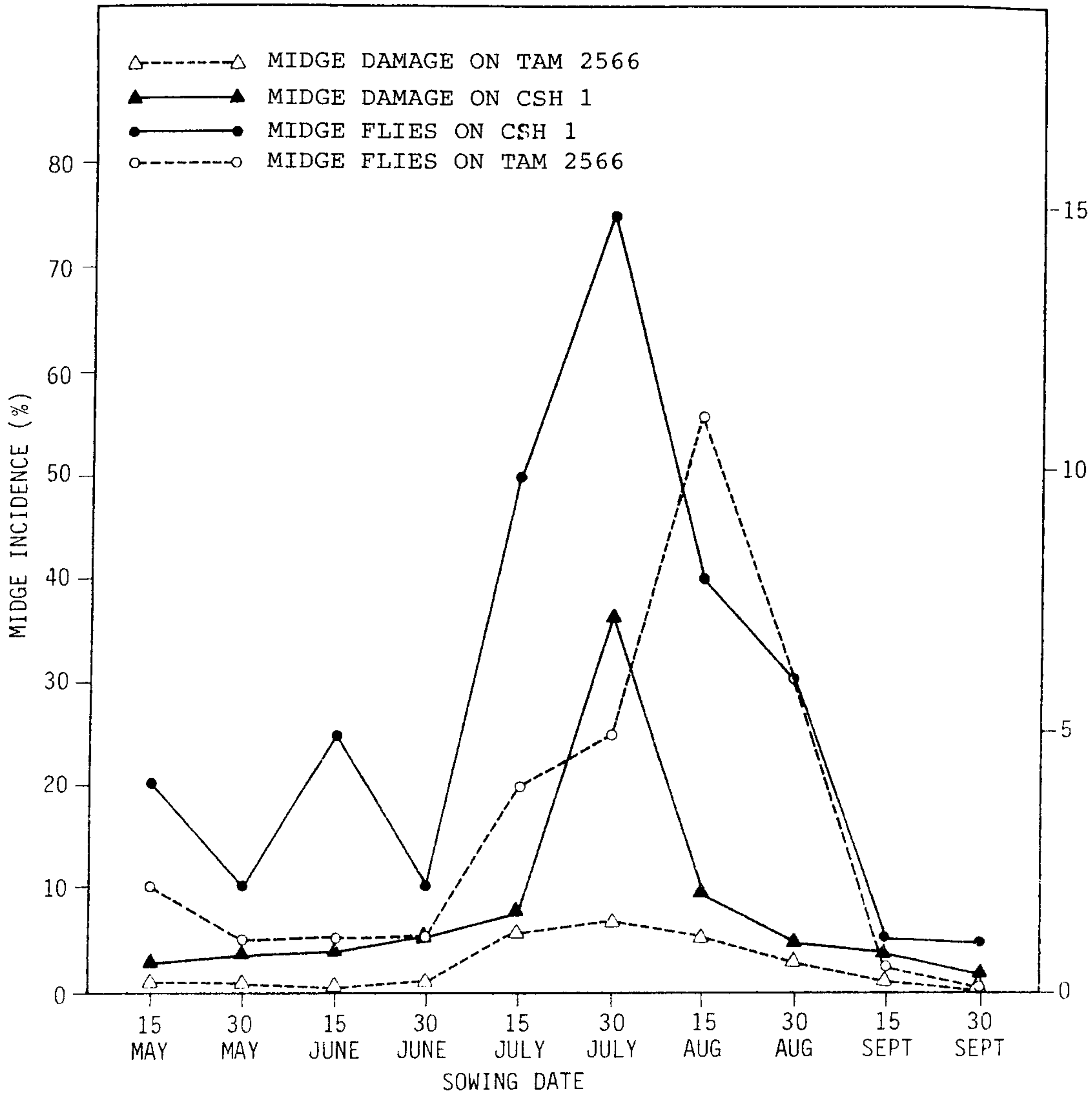

Fig. 1. Midge damage (percent florets with midge larvae) and adult midge numbers on 'CSH 1' and 'TAM 2566' in fortnightly plantings at ICRISAT Center, May to September 1980.

of head-bug damage in situations of heavy infestation are similar to those of midge damage. Also, adult head bugs prey on ovipositing midges at flowering (Sharma 1985). To control head bugs in midge resistance screening fields, eight contact insecticides (carbaryl [Sevin 50 wettable powder {WP}], fenvalerate [Sumicidin 20 emulsifiable concentrate {EC}], fenitrothion [Folithion 50 EC], chlorpyriphos [Dursban 25 EC], quinalphos [Ekalux 25 EC], endosulfan [Thiodan 35 EC], dichlorvos [Nuvan 100 EC], and malathion [Cythion 50 EC]) and an enriched neem extract were tested on sorghum hybrid 'CSH 1'. Insecticides were applied with a knapsack sprayer at a rate of 400 liters/ha at complete-anthesis and milk stages (i.e., 6 and 12 d after panicle emergence) when oviposition by the midge was completed and larvae were feeding inside the glumes. There were three replications and each plot measured 6 by 20 m (eight rows, 75 cm apart, 20 m long). The experiment was arranged in a randomized block design. Head bug numbers were recorded in 10 randomly selected panicles 24 h before and after each spray. Midge emergence was recorded from five panicles in each replication at milk stage 15 d after anthesis. Panicles for midge emergence were detached from the plants and kept in plastic jars (1 liter) in the laboratory. The number of midges emerged was recorded in each panicle. The number of midge-damaged florets was recorded from a sample of 500 florets taken from 15 randomly selected panicles in each replication at maturity. The samples were taken as described before. The data were transformed to $\sqrt{n+1}$ values. The transformed values were subjected to analysis

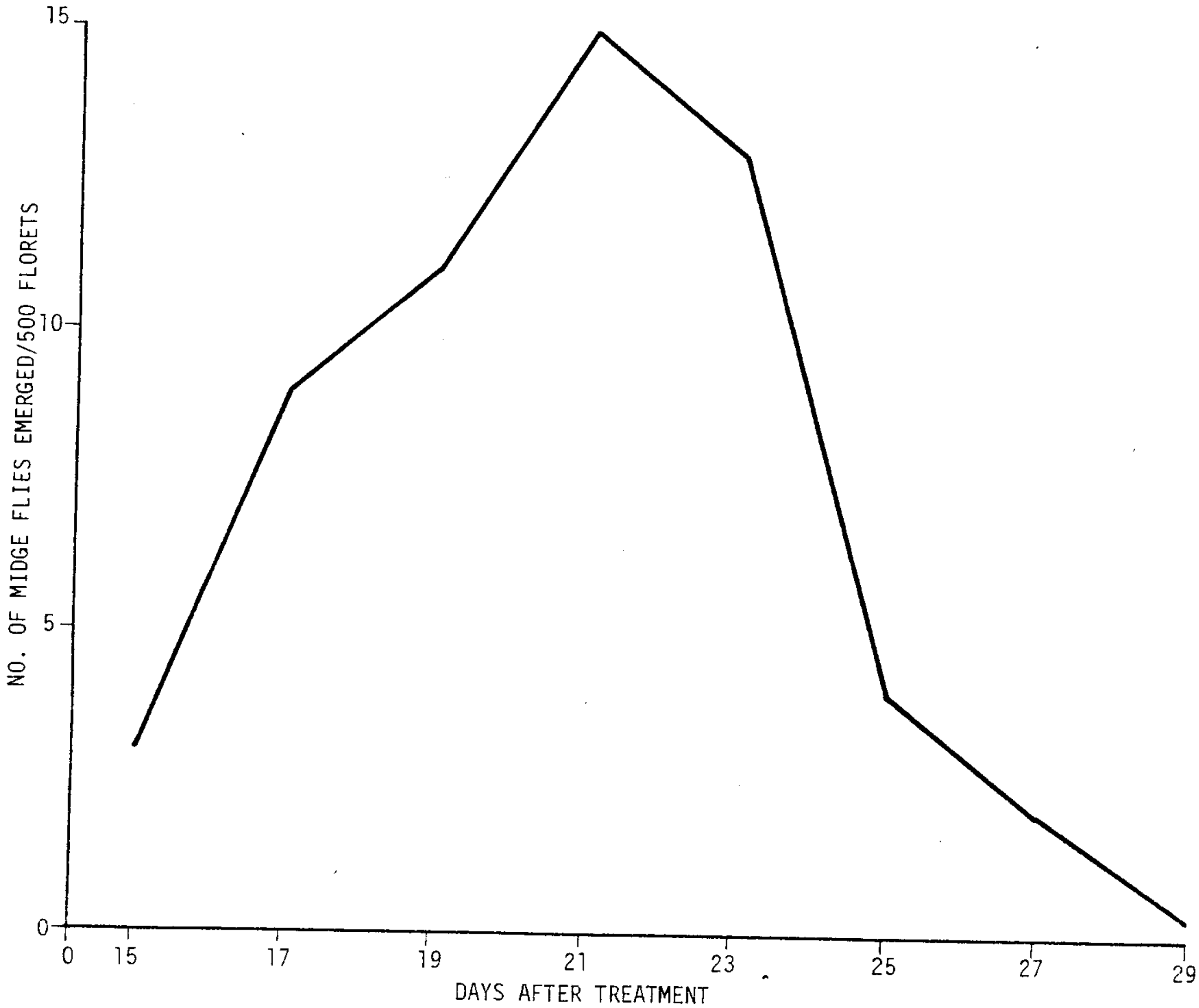

Fig. 2. Emergence of adult midges from diapausing midge larvae in midge-damaged chaffy florets at 100% RH and 30°C.

of variance and the treatment means were compared by LSD.

In another experiment to determine the optimum stage of panicle development to spray insecticides for the control of *T. diplosidis*, dichlorvos (0.05%) with honey (0.5%) and acetic acid (0.1%) were sprayed in a large plot (0.25 ha) of 'CSH 5' hybrid sorghum. An equivalent area of 0.25 ha served as an untreated control. Honey and acetic acid are highly attractive to *T. diplosidis* (unpublished data). At the time of spraying, both plots had panicles at pre-anthesis, half-anthesis, complete anthesis, and milk stage of development. Ten panicles were tagged at random at each stage of panicle development in each plot at the time of spraying. Data on parasitism of midge larvae by *T.*

Table 1. Effect of infester rows and midge-damaged sorghum panicles on augmentation of midge damage

Treatment	Florets with midge larvae (%)						Midge-damaged chaffy florets (%)					
	'CSH 1'			'TAM 2566'			'CSH 1'			'TAM 2566'		
	1980–81P	1981R	1981–82P	1980–81P	1981R	1981–82P	1980–81P	1981R	1981–82P	1980–81P	1981R	1981–82P
IR + MDSP	18^{abc}	5^{ac}	21^{abc}	6^{abc}	1	4^{bc}	31^{ab}	100^{bc}	25^{abc}	31^{abc}	74^{abc}	12^{bc}
IR	11^{bc}	1	7^{bc}	2	2	3^{bc}	12	100^{bc}	16^{bc}	11	19^{bc}	17^{bc}
MDSP	3	3^{c}	1	1	1	1	19	24^{c}	12^{c}	16	10^{c}	11^{c}
Untreated control	2	1	1	3	1	1	31	13	8	16	7	9

IR, Infester rows; MDSP, midge-damaged sorghum panicle; P, postrainy season; R, rainy season.
[a] Midge damage significantly higher than IR (Z test).
[b] Midge damage significantly higher than MDSP (Z test).
[c] Midge damage significantly higher than control (Z test).

diplosidis was recorded as the number of florets with parasite emergence holes in 100 midge-damaged florets at maturity.

Split Planting. Sorghum lines to be screened for midge resistance were planted twice in single rows, 2 m long, at an interval of 15 d. The lines were evaluated visually for midge damage at maturity; those having less damage than the control cultivar and with <40% midge-damaged florets were considered resistant.

Planting Density. The effect of planting density on midge damage was studied in unreplicated plots (0.5 ha) of 'CSH 5' hybrid sorghum. Planting densities of 100,000 and 10,000 plants per ha were established. The number of adult sorghum midges per 100 randomly selected panicles was recorded visually at flowering stage in each plot from 0900 to 1000 hours. The number of midge-damaged flo-

Table 2. Effect of overhead sprinkler irrigation on midge damage (1980–81 postrainy season)

Cultivar	Midge-damaged chaffy florets (%)	
	With sprinkler	Without sprinkler
'AF 28'	32.1 (5.57)[a]	21.6 (4.59)[a]
'SGIRL-MR-1'	47.3 (6.84)	35.2 (5.85)
'IS 12573C'	61.2 (7.78)	44.7 (6.59)
'DJ 6514'	16.0 (3.97)	18.7 (4.19)
'CSH 1'	49.0 (6.98)	48.7 (6.90)
Main effect means	(6.23)	(5.63)
LSD[b] for main effect means	(0.56)	
LSD[b] for cultivars at the same level of main treatment	(0.39)	

[a] Figures in parentheses are transformed values.

[b] Least significant difference ($P = 0.05$) for comparing treatment means of transformed values.

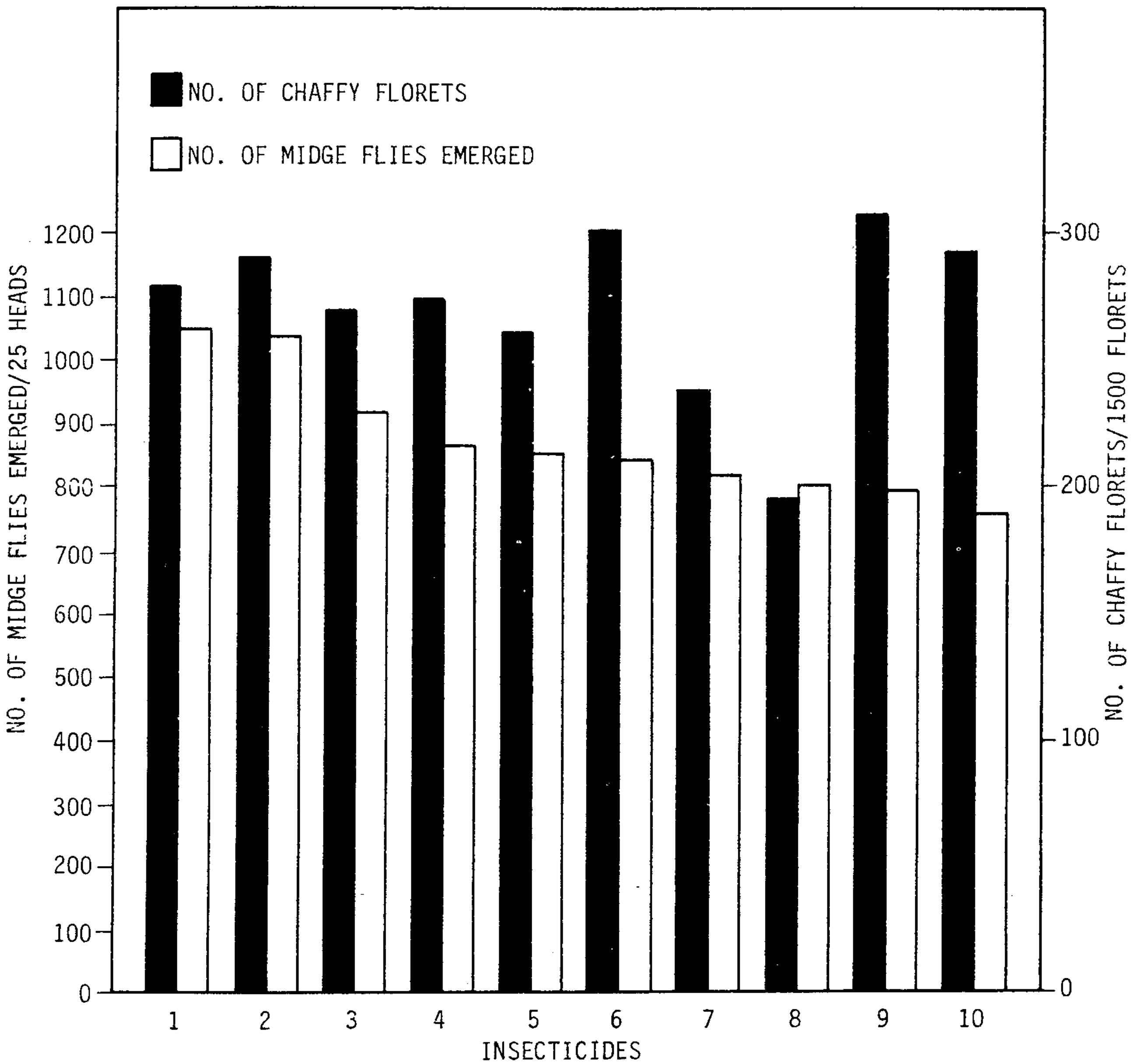

Fig. 3. Adult midge emergence and midge-damaged chaffy florets in sorghum panicles sprayed at postanthesis and milk stage to control head bugs (1, fenvalerate; 2, chlorpyriphos; 3, untreated control; 4, malathion; 5, dichlorvos; 6, neem extract; 7, quinalphos; 8, fenitrothion; 9, endosulfan; and 10, carbaryl).

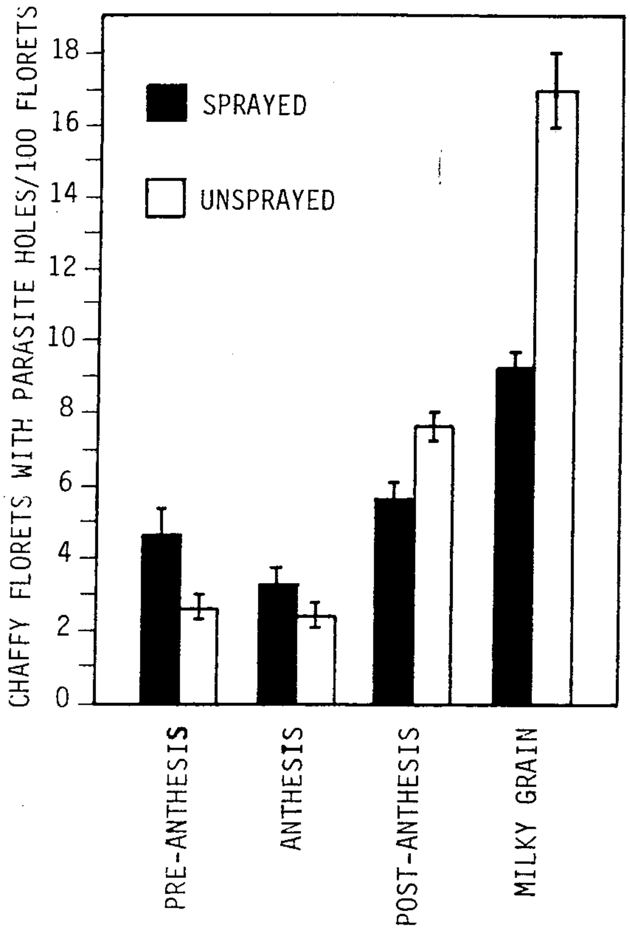

Fig. 4. Effect of dichlorvos (0.01%) + honey (5%) + acetic acid (0.1%) spray on midge parasitism in 'CSH 5' panicles at different stages of development (1981–82 postrainy season).

rets was recorded from a sample of 500 florets taken from five randomly selected panicles in the middle of each plot at maturity as previously described.

Results and Discussion

Planting Date. Maximum adult midge numbers and damage in 'CSH 1', the susceptible control, were observed in the crop planted on 20 July. 'TAM 2566' had maximum adult midges on a crop planted on 15 August. Midge damage was higher on the crop planted between 15 July and 15 August, with a peak in the crop planted on 30 July (Fig. 1). Therefore, the optimum time to plant a crop to screen for midge resistance is around 30 July, and this information has been used to screen sorghums for midge resistance under natural conditions at the ICRISAT Center.

Augmentation of Midge Density. The number of florets with midge larvae and the number of midge-damaged chaffy florets that failed to produce grain were maximum in the plots where sorghum panicles containing diapausing midge larvae were spread between the infester rows (Table 1). Plots with infester rows only had the next highest numbers of midge-damaged chaffy florets. High relative humidity stimulated the termination of larval diapause in the midge-damaged florets (Fig. 2). Adult emergence began on the 15th day and continued until the 29th day, with a peak emergence on the 21st day after moistening the florets. Passlow (1965) had recorded adult emergence from diapausing larvae 13 d after moistening the florets at 98–100% RH. Sixty midges emerged from 500 midge-damaged chaffy florets. Thus, spreading of midge-damaged sorghum panicles is helpful in augmenting midge abundance. Midge adults that emerged from diapausing larvae in the midge-damaged sorghum panicles from the previous season multiplied for two generations on the infester rows. The staggered flowering of 'CSH 1' and 'CSH 5' is enough to allow completion of two generations on the infester rows before the insect infests the test material. Thus, midge abundance can be significantly increased by spreading midge-infested sorghum panicles containing diapausing midge larvae in the infester rows at the flag leaf stage to screen sorghums for midge resistance.

Sprinkler Irrigation. During the postrainy season, the use of sprinkler irrigation to increase relative humidity significantly increased the extent of midge damage (df = 43, P = 0.05) (Table 2). The use of sprinkler irrigation increased the relative

Table 3. Relative effectiveness of two sprays of some insecticides for *C. angustatus* control in sorghum hybrid 'CSH 1'

Insecticide	Dosage g (AI)/ha	No. of head bugs per panicle[a]			
		Complete anthesis		Milk stage	
		Before spray	After spray	Before spray	After spray
Carbaryl	500	26 (5.1)	1 (1.1)	21 (4.6)	1 (0.5)
Fenvalerate	50	29 (5.4)	1 (1.2)	57 (7.4)	1 (0.7)
Fenitrothion	250	25 (5.0)	1 (1.4)	39 (6.2)	1 (0.7)
Chlorpyriphos	250	30 (5.5)	1 (1.3)	22 (4.7)	2 (1.3)
Quinalphos	250	24 (4.9)	4 (2.1)	41 (6.3)	3 (1.7)
Endosulfan	250	23 (4.7)	1 (1.2)	46 (6.7)	3 (1.7)
Dichlorvos	250	24 (4.8)	4 (2.1)	89 (9.2)	4 (2.0)
Malathion	250	31 (5.5)	2 (1.8)	61 (7.3)	6 (2.3)
Neem extract	500	27 (5.2)	8 (2.7)	44 (6.6)	51 (7.1)
Untreated control	—	25 (5.0)	22 (4.8)	73 (8.5)	77 (8.8)
LSD[b]		(0.28)	(0.42)	(1.12)	(0.30)

[a] Figures in parentheses are $\sqrt{N + 1}$ transformed values.
[b] Least significant difference (P = 0.05) for comparing treatment means of transformed values.

humidity up to 80–90% at the crop canopy compared with <50% RH in the unirrigated plot. Midges emerging from diapausing larvae under the stimulus of a high relative humidity multiplied on the infester rows. High relative humidity (90%) also helps to increase adult emergence (Fisher & Teetes 1982) and results in higher oviposition and damage by the midge. Use of sprinkler irrigation over the crop canopy from 1500 to 1600 hours did not affect midge activity because the peak midge abundance and oviposition occur from 0730 to 1100 hours. In the temperate region of the United States, the peak in midge abundance has been reported between 1230 and 1430 hours (Summers 1975). Because of higher temperatures (>35°C) and lower relative humidity (<50%), the peak in midge abundance occurs much earlier in the semiarid tropics in India. The effect of sprinkler irrigation was also evaluated through the number of entries selected as less susceptible in plots with and without sprinkler irrigation. Of the 140 cultivars screened for midge resistance, 41 were selected as less susceptible under sprinkler irrigation, compared with 65 in the control plot using the cage screening. Under natural conditions, 75 of 170 sorghum lines were selected as less susceptible in both treatments, of which 52 entries were common between the two treatments.

Selective Use of Insecticides to Control *C. angustatus* and *T. diplosidis*. All insecticides gave good control of *C. angustatus* (Table 3). Fenitrothion and dichlorvos were phytotoxic. Midge damage and emergence did not differ significantly between the insecticide-treated and untreated control plots (df = 28, P = 0.05) (Fig. 3). Thus, sprays with contact insecticides at complete anthesis (when midge larvae are feeding inside the glumes) and at milk stage (before adult emergence) can be used to control head bugs to minimize interspecies competition. Midge parasitism by *T. diplosidis* was less in panicles sprayed at complete anthesis and milk stages (Fig. 4). Thus, insecticides can be used selectively to control head bugs and midge parasites in screening trials by spraying contact insecticides carefully at complete anthesis and milk stages after oviposition and before adult midge emergence.

Split Planting. Split planting of the material at 15-d intervals increased the chances of discarding the susceptible materials. During the 1982 rainy season at Dharwar, 55 of 224 lines were selected as resistant in the second planting, compared with 80 in the first planting. Of the 144 lines tested during the 1983–84 postrainy season at the ICRISAT center, 85 lines were selected as less susceptible in the first planting compared with 62 lines in the second planting.

Planting Density. The level of midge damage can be increased to some extent by planting at lower plant densities (Fig. 5). This may help to avoid the population dilution due to fewer numbers of panicles per unit area.

Conclusions. Midge damage and efficiency of screening for midge resistance can be substantially increased under field conditions through a combination of timely planting, spreading midge-damaged sorghum panicles containing diapausing larvae in the infester rows, split sowings, and selective use of contact insecticides for the control of head bugs and midge parasites. These techniques have been very useful in the initial large-scale screening of germ plasm and breeding materials for resistance to sorghum midge.

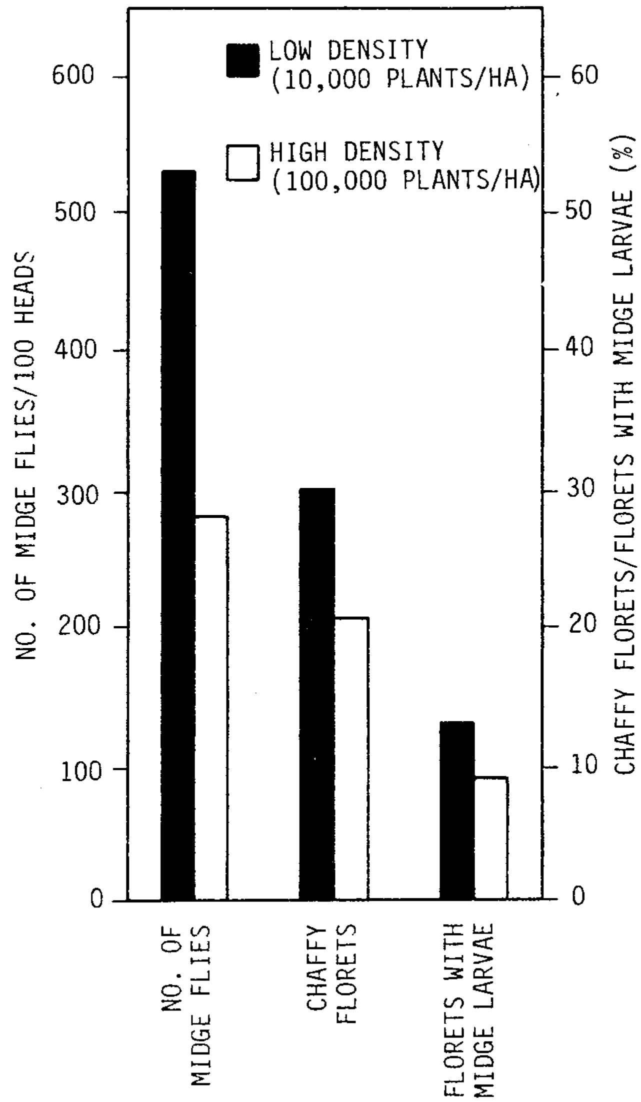

Fig. 5. Effect of planting density on adult midge abundance and damage in 'CSH 5' sorghum hybrid (1981–82 postrainy season).

Acknowledgment

We thank A. B. Mohammed for reviewing the manuscript, K. J. Chari for helping in the field, and I. Krishna Murthy for typing the manuscript. This paper was approved as Journal Article No. 558 by ICRISAT, Patancheru P.O., Andhra Pradesh 502 324, India.

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Received for publication 21 February 1986; accepted 2 September 1987.