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# Identification and utilization of resistance to sorghum midge, *Contarinia sorghicola* (Coquillet), in India

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Sorghum midge, *Contarinia sorghicola* (Coquillet), is a most important and widespread pest of grain sorghum. Over 15 000 germplasm accessions and several thousand breeding lines have been screened for resistance to sorghum midge under field infestation and no-choice headcage conditions in India. Twenty-seven germplasm accessions showing resistance across seasons and locations have been identified, of which TAM 2566, AF 28, DJ 6514, IS 3461, IS 8918, IS 10712, IS 21871 and IS 27103 are diverse sources of resistance to sorghum midge. Substantial progress has been made in developing improved midge-resistant breeding lines with reasonable yield and grain quality. Forty-four lines improved for plant type and grain yield have been developed. ICSV 197, ICSV 745, ICSV 843, ICSV 88013 and ICSV 88032 have high levels of midge resistance and their yield potential is comparable to that of commercial cultivars. PM 7068, ICSV 690, ICSV 563, and ICSV 388 have been identified as non-restorers. ICSV 563 and PM 7068 have been converted into male-sterile hybrid parents. Sorghum lines with midge resistance are genetically and morphologically diverse, and can be adapted *per se* or used in sorghum improvement in different sorghum-growing regions.

**Keywords:** Sorghum; *Sorghum bicolor*; host-plant resistance; midge; *Contarinia sorghicola*; resistance breeding

The sorghum midge, *Contarinia sorghicola* (Coquillet) is one of the most destructive pests of grain sorghums in Asia, Africa, Australia, Europe and the Americas (Harris, 1976; Sharma, 1985a, b). Current recommendations for its control by cultural means are only moderately effective. Chemical control is not an economic proposition and is usually ineffective because the larva remains protected inside the glumes. Host-plant resistance is the most effective approach for keeping midge populations below economic threshold levels, especially under subsistence farming in the semi-arid tropics.

At the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India, major emphasis has been placed on developing techniques to screen for resistance to sorghum midge, to screen germplasm/breeding stocks to identify sources of resistance, and to transfer midge resistance from germplasm sources into improved and adapted cultivars. This paper reports the progress made in screening and breeding for resistance to sorghum midge between 1980 and 1989.

## Materials and methods

### Crop management and experimental design

This work was carried out at the ICRISAT Centre and its sub-station, Dharwad (Karnataka), India between 1980 and 1989. At the ICRISAT Centre, the crop was sown on ridges 4 m long (75 cm apart). The plants were thinned to a spacing of 10 cm between the plants 15 days after emergence. Carbofuran 3G (1.2 kg a.i. $ha^{-1}$) was incorporated in the soil at sowing to control the sorghum shoot fly, *Atherigona soccata* Rondani. In situations where carbofuran could not protect the plants from shoot fly damage during the rainy season, the seedlings were sprayed once or twice with cypermethrin 3D with an Electrodyn sprayer. At Dharwad, the crop was sown on flat beds in rows 45 cm apart. Normal agronomic practices were followed for raising the crop. No insecticide was applied during the reproductive phase of the crop.

In the preliminary midge-resistance screening nursery, the entries were sown in an unreplicated trial using an annotated design. Resistant (DJ 6514, TAM 2566 and AF 28) and susceptible (CSH 1, CSH 5, CSH 9, CSH 11 and Swarna) checks were planted after every 50 test entries. Each entry was planted in a two-row plot (4 m long). Another set of the test entries was sown 15 days after the first planting to avoid escapes. In the advanced trials, the test entries were sown in a randomized block design. The plot size was 1.5 × 4 m, with two replications. Data were recorded on plant height (cm), days to 50% flowering, grain colour, panicle type, 1000-grain mass, and midge damage.

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## Resistance screening techniques

To improve the efficiency of selection for midge resistance, planting dates were adjusted, and two sowings were undertaken at 2-week intervals to synchronize flowering with the peak density of the sorghum midge during October. Germplasm accessions and segregating breeding lines were initially screened by the infester row technique (Sharma, Vidyasagar and Leuschner, 1988a). Dharwad was used as a 'hot spot' location for initial large-scale screening. Natural midge infestation was increased by planting infester rows of a susceptible cultivar (CSH 1) 20 days earlier than the test material. Four infester rows were planted after every 16 rows of the test material. At the flag leaf stage, chaffy sorghum panicles (kept moist for 10 days) carrying diapausing midge larvae were spread between the infester rows. This practice increased the midge population three- to fivefold.

Lines selected as being potentially resistant to sorghum midge at Dharwad were sown at the ICRISAT Centre during the post-rainy season, and screened using the infester row technique. After two cycles of screening under conditions of natural infestation, lines with low susceptibility to midge were tested under no-choice conditions using the headcage technique (Sharma, Vidyasagar and Leuschner, 1988b). Five panicles were screened under the headcage in each genotype. Each panicle was infested with 40 midges for 2 consecutive days at the half-anthesis stage. Selected lines were evaluated for a further 5–8 seasons for midge resistance under natural and headcage conditions. These lines were also tested at different locations [Dharwad (rainy season), Warangal (post-rainy season), Bhavanisagar (summer) and ICRISAT Centre (rainy and post-rainy seasons)] in India to identify lines with stable resistance across locations.

## Damage evaluation

Midge damage was rated visually on a 1–9 scale (1, < 10% 2, 11–20%; 3, 21–30%; 4, 31–40%; 5, 41–50%; 6, 51–60%; 7, 61–70%; 8, 71–80%; 9, > 80% spikelets

Table 1. Origin and characteristics of sources of resistance in sorghum to sorghum midge, *Contarinia sorghicola* (ICRISAT Centre, India)

| Cultivar | Origin | Plant height (cm) | Time to 50% flowering (days) | Grain colour[a] | Panicle type[b] | 1000-grain mass (g) |
|---|---|---|---|---|---|---|
| IS 3461 | Sudan | 385 | 71 | CW | SL | 15 |
| IS 7005 | Sudan | 380 | 75 | CW | L | 16 |
| IS 8671 | Swaziland | 185 | 75 | LB | C | 11 |
| IS 8571 | Tanzania | 390 | 60 | CW | L | 17 |
| IS 8884 | Uganda | 275 | 112 | R | C | 17 |
| IS 8887 | Uganda | 290 | 112 | R | C | 16 |
| IS 8891 | Uganda | 320 | 109 | RB | C | 16 |
| IS 8918 | Uganda | 290 | 111 | R | C | 12 |
| IS 9807 | Sudan | 370 | 75 | CW | L | 14 |
| IS 10712 | USA | 195 | 78 | LB | SC | 16 |
| IS 15107 | Cameroun | 260 | 84 | R | C | 32 |
| IS 18563 | Uganda | 240 | 74 | R | L | 21 |
| IS 18566 | Uganda | 255 | 82 | LB | SC | 21 |
| IS 18695 | USA | 75 | 65 | B | SC | 30 |
| IS 18698 | USA | 315 | 70 | CW | L | 16 |
| IS 19474 | Sudan | 365 | 76 | CW | L | 15 |
| IS 19476 | Sudan | 370 | 72 | CW | L | 16 |
| IS 21871 | USA | 90 | 71 | S | SC | 26 |
| IS 21873 | USA | 95 | 71 | S | C | 23 |
| IS 21879 | USA | 100 | 70 | R | L | 23 |
| IS 21881 | USA | 90 | 68 | R | SC | 28 |
| IS 21883 | USA | 110 | 69 | R | SC | 19 |
| IS 22778 | Somalia | 340 | 69 | R | L | 22 |
| IS 22806 | Sudan | 330 | 71 | CW | L | 17 |
| IS 26789 | S. Africa | 230 | 69 | S | C | 17 |
| IS 27103 | Zimbabwe | 195 | 71 | S | C | 13 |
| Resistant checks | | | | | | |
| DJ 6514 | India | 230 | 71 | S | C | 15 |
| TAM 2566 | USA | 85 | 64 | R | SC | 23 |
| AF 28 | USA | 320 | 71 | CW | L | 15 |
| Susceptible checks | | | | | | |
| CSH 1 | India | 155 | 58 | S | SC | 27 |
| CSH 5 | India | 200 | 67 | S | SC | 31 |
| CSH 9 | India | 210 | 68 | S | C | 29 |
| CSH 11 | India | 210 | 64 | S | SC | 30 |
| Swarna | India | 155 | 65 | Y | SC | 28 |
| ± s.e. | | 17.22 | 2.44 | | | 1.05 |
| l.s.d. at 5% | | 47.52 | 6.75 | | | 2.91 |

with midge damage). In the advanced tests, midge damage was also recorded from 500 spikelets sampled randomly from five panicles screened under natural or headcage conditions. The sampling procedure and data collection have been described by Sharma *et al.* (1988a).

## Breeding procedures

Both pedigree and population breeding methods were used. A broad-based population for resistance to panicle-feeding pests (midge and earhead bugs) was developed by using $ms_3$ and $ms_7$ male-sterility genes, and is being improved further using low to moderate insect pressure. The procedures involved in making crosses, screening and selecting for resistance, agronomic traits and grain quality have been outlined by Agrawal *et al.* (1986). The first step involved the identification, conversion and strengthening of the source material, followed by development of agronomically elite cultivars and hybrid parents. Agronomically elite midge-resistant lines were tested widely for adaptation and stability of resistance for use by farmers, or as sources of resistance by national sorghum improvement programmes in the semi-arid tropics.

## Statistical analysis

Standard errors of means were calculated for midge damage ratings across seasons and/or locations to assess

Table 2. Pedigrees and characteristics of sorghum breeding lines resistant to sorghum midge (ICRISAT Centre, India)

| Cultivar | Origin | Pedigree | Plant height (cm) | Time to 50% flowering (days) | Grain colour | 1000-grain mass (g) |
|---|---|---|---|---|---|---|
| ICSV 197 | PM 11344 | (IS 3443 × DJ 6514)-1-1-1-1-1 | 278 | 80 | Straw | 19 |
| ICSV 386 | PM 7032 | (EC 64734 × DJ 6514)-5-1-1-1-1 | 141 | 82 | Straw | 15 |
| ICSV 387 | PM 7397 | (FLR(C)S8-119 × DJ 6514)-7-1-1-1-1 | 168 | 65 | Straw | 24 |
| ICSV 388 | PM 8787-2 | (ISPYT-1 E/13 × IS 2579C × ISPYT-1/E-13) | 91 | 62 | Straw | 27 |
| ICSV 389 | PM 13553 | (IS 18962 × SPV 393)-12-1-1-1 | 126 | 68 | Straw | 22 |
| ICSV 391 | PM 13644 | (PM 7348 × US(B-6)-5-2-6-3-1 | 145 | 73 | Straw | 25 |
| ICSV 393 | PM 13655 | (PM 7348 × SPV 351)-7-1-2-3-1 | 156 | 60 | Straw | 29 |
| ICSV 397 | PM 14411-2 | (PM 11344 × A 6250)-1-2-2-1 | 253 | 84 | Straw | 22 |
| ICSV 563 | PM 7061 | (IS 152 × DJ 6514)-8-1-1-1 | 149 | 59 | Straw | 18 |
| ICSV 564 | PM 7422-2 | (SC 108-3 × DJ 6514)-12-1-2-2 | 191 | 60 | Straw | 21 |
| ICSV 690 | PM 6751 | (SC 108-3 × S GIRL-MR-1)-19-1-1-1-1 | 152 | 57 | Straw | 21 |
| ICSV 692 | PM 7526 | (Diallel-50-1-1 ALS 7 × DJ 6514)-12-1-1-1-1 | 199 | 59 | Straw | 19 |
| ICSV 729 | PM 7104-1 | (IS 3443 × IS 2579C)-2-1-2-1-1 | 74 | 66 | Straw | 28 |
| ICSV 730 | PM 12652 | (PM 7348 × SPV 351)-2-6-1-1 | 130 | 78 | Straw | 23 |
| ICSV 731 | PM 12654 | (PM 7348 × SPV 351)-4-1-1-1 | 140 | 72 | Straw | 29 |
| ICSV 736 | PM 14358-7 | (PM 11344 × SPV 351)-10-1-1-1-7 | 239 | 76 | Straw | 20 |
| ICSV 737 | PM 14370-2 | (PM 11344 × SPV 475)-4-1-1-1-2 | 285 | 76 | Straw | 19 |
| ICSV 739 | PM 14386-1-6 | (PM 11344 × SPV 394)-3-1-1-1-6 | 241 | 70 | Straw | 18 |
| ICSV 744 | PM 14414-2-4 | (PM 11344 × A 6250)-3-2-2-4 | 282 | 77 | Straw | 22 |
| ICSV 745 | PM 14415-1-1 | (PM 11344 × A 6250)-4-1-1-1 | 215 | 71 | Straw | 31 |
| ICSV 746 | PM 14416-3 | (PM 11344-3 × A 6250)-4-2-1-3 | 259 | 77 | Straw | 26 |
| ICSV 748 | PM 14431-6 | (PM 11344 × A 6250)-8-5-6-1 | 279 | 81 | Straw | 24 |
| ICSV 752 | PM 13670-1 | (PM 7348 × SPV 351)-7-1-2-3-1 | 166 | 71 | Straw | 26 |
| ICSV 753 | PM 13668-1 | (PM 7348 × SPV 351)-7-1-2-1-1 | 147 | 72 | Straw | 23 |
| ICSV 757 | PM 14383 | (PM 11344 × SPV 422)-2-1-1-1-1 | 221 | 77 | Straw | 24 |
| ICSV 843 | PM 15952 | (PM 11344 × R 12034)-7-1-1-1-1 | 260 | 78 | Straw | 25 |
| ICSV 88006 | PM 15949 | (PM 11344 × R 12033)-5-2-1-1 | 250 | 68 | Straw | 27 |
| ICSV 88013 | PM 15936-2 | (PM 11344 × SPV 351)-22-1-1-2 | 217 | 70 | Straw | 22 |
| ICSV 88014 | PM 15926 | (PM 11344 × SPV 351)-12-3-1-1 | 267 | 69 | Straw | 18 |
| ICSV 88028 | PM 15908-3 | (PM 11344 × SPV 351)-1-1-1-3 | 149 | 70 | Straw | 24 |
| ICSV 88032 | PM 15936-1 | (PM 11344 × SPV 351)-22-1-1-1 | 201 | 61 | Straw | 25 |
| ICSV 88035 | PM 12695-2 | (PM 7348 × SPV 351)-9-6-2-1-1-2 | 200 | 69 | Straw | 21 |
| ICSV 88036 | PM 15908-4 | (PM 11344 × SPV 351)-1-1-1-4 | 145 | 66 | Straw | 25 |
| ICSV 88041 | PM 15929-2 | (PM 11344 × SPV 351)-12-3-1-1 | 123 | 66 | Straw | 21 |
| ICSV 89049 | PM 13613 | (PM 7348 × US/B)-3-1-4-1-1 | 129 | 67 | Straw | 32 |
| ICSV 89051 | PM 14410-1 | (PM 11344 × A 6250)-1-1-1-1-1 | 302 | 83 | Straw | 27 |
| ICSV 89052 | PM 14410-3 | (PM 11344 × A 6250)-1-1-1-1-3 | 302 | 84 | Straw | 28 |
| ICSV 89053 | PM 15908-2 | (PM 11344 × SPV 351)-1-1-1-2 | 160 | 74 | Straw | 22 |
| ICSV 89054 | PM 15930 | (PM 11344 × SPV 351)-18-1-1-1 | 246 | 68 | Straw | 21 |
| ICSV 90001 | PM 15908-1 | (PM 11344 × SPV 351)-1-1-1-1 | 160 | 65 | Straw | 25 |
| ICSV 90002 | PM 7017 | (IS 12573C × PHYR)-19-2-1-1-1-1 | 165 | 63 | Straw | 28 |
| ICSV 90003 | PM 14370-1 | (PM 11344 × SPV 475)-4-1-1-1-1 | 155 | 71 | Straw | 24 |
| ICSV 90004 | PM 15933-2 | (PM 11344 × SPV 351)-21-2-1-2 | 200 | 71 | Straw | 22 |
| ICSV 90005 | PM 13705 | (PM 7348 × SPV 351)-8-4-3-2-1 | 180 | 65 | Straw | 24 |
| Resistant check (DJ 6514) | | | 230 | 71 | Straw | 15 |
| Susceptible check (CSH 1) | | | 155 | 58 | Straw | 27 |
| ± s.e. | | | 8.65 | 1.07 | | 0.57 |
| l.s.d at 5% | | | 23.89 | 2.97 | | 1.57 |

levels and stability of resistance. Data on percentage midge damage were subjected to analysis of variance to compare the least significant difference between variety means.

## Results

### Diversity of midge-resistant sources and breeding lines

More than 15 000 germplasm accessions were screened for resistance to sorghum midge under natural and headcage conditions over several seasons and locations between the 1980 rainy season and the 1989/90 post-rainy season. Twenty-seven germplasm accessions were resistant to sorghum midge (*Table 1*); these originated from Sudan, Swaziland, South Africa, Uganda, USA, Cameroun, Somalia, Zimbabwe and India. The sources of midge resistance are diverse for plant height (75–385 cm), days to 50% flowering (65–112 days), grain colour (chalky-white, straw and red), panicle type (loose to compact) and 1000-grain mass (11–32 g per 1000 grains).

Breeding lines developed by using some of the germplasm sources of resistance also showed considerable diversity for plant height (74–392 cm), days to 50% flowering (62–84) and 1000-grain mass (15–32 g per 1000 grains) (*Table 2*). Breeding lines have a straw-coloured grain, which is most acceptable for food preparation.

### Resistance to sorghum midge

The midge damage rating of the resistant sources was < 4.3 compared with 7.4–8.4 for the susceptible checks CSH 1, CSH 5, CSH 9, CSH 11 and Swarna (*Table 3*). Under headcage conditions, the damage rating of resistant sources was 1.4–5.0, compared with 7.2–9.0 for the susceptible checks. IS 3461, IS 7005, IS 8751, IS 8884, IS 8887, IS 8918, IS 9807, IS 10712, IS 18698, IS 19474, IS 19476, IS 21871, IS 22806, IS 27103, DJ 6514 and AF 28 showed high levels of midge resistance (damage rating < 3) under natural infestation and headcage conditions; these lines had < 30% spikelets with midge damage (except IS 10712 and IS 21871), compared with > 90% damage in the susceptible check, CSH 1.

Table 3. Midge damage ratings of sources of resistance to sorghum midge under natural and headcage conditions (ICRISAT Centre, India)

| Cultivar | Damage rating[a] | | Midge damage (%) | |
|---|---|---|---|---|
| | Natural infestation | Headcage condi | ral infestation | Headcage conditions |
| IS 3461 | 2.0 ± 0.15 | 2.0 ± 0.00 | 21 | 19 |
| IS 7005 | 2.3 ± 0.15 | 2.4 ± 0.24 | 24 | 18 |
| IS 8671 | 2.6 ± 0.69 | 4.0 ± 0.00 | 24 | 16 |
| IS 8751 | 2.4 ± 0.16 | 2.8 ± 0.37 | 26 | 22 |
| IS 8884 | 2.0 ± 0.24 | 2.6 ± 0.37 | 18 | 26 |
| IS 8887 | 2.4 ± 0.20 | 2.6 ± 0.24 | 20 | 28 |
| IS 8891 | 1.7 ± 0.19 | 4.0 ± 0.50 | 24 | 11 |
| IS 8918 | 2.0 ± 0.00 | 2.0 ± 0.00 | 26 | 18 |
| IS 9807 | 2.5 ± 0.17 | 2.6 ± 0.24 | 23 | 26 |
| IS 10712 | 2.5 ± 0.43 | 3.0 ± 0.36 | 31 | 31 |
| IS 15107 | 3.0 ± 0.22 | 3.4 ± 0.40 | 33 | 32 |
| IS 18563 | 3.3 ± 0.33 | 2.5 ± 0.50 | 23 | 28 |
| IS 18695 | 3.6 ± 0.26 | 3.4 ± 0.51 | 18 | 14 |
| IS 18698 | 2.2 ± 0.39 | 2.8 ± 0.48 | 20 | 23 |
| IS 19474 | 1.9 ± 0.29 | 1.9 ± 0.52 | 22 | 24 |
| IS 19476 | 2.3 ± 0.13 | 2.0 ± 0.00 | 16 | 15 |
| IS 21871 | 2.0 ± 0.28 | 1.4 ± 0.38 | 26 | 46 |
| IS 21873 | 4.3 ± 0.64 | 5.0 ± 0.00 | 22 | 48 |
| IS 21879 | 2.5 ± 0.34 | 3.8 ± 0.75 | 21 | 21 |
| IS 21881 | 3.1 ± 0.43 | 3.9 ± 0.70 | 28 | 28 |
| IS 21883 | 3.0 ± 0.26 | 4.0 ± 0.76 | 25 | 27 |
| IS 22806 | 1.9 ± 0.26 | 1.6 ± 0.29 | 13 | 12 |
| IS 26789 | 2.9 ± 0.22 | 3.2 ± 0.44 | 39 | 23 |
| IS 27103 | 1.6 ± 0.21 | 1.6 ± 0.37 | 22 | 17 |
| Resistant checks | | | | |
| DJ 6514 | 1.3 ± 0.14 | 1.8 ± 0.43 | 21 | 20 |
| TAM 2566 | 2.2 ± 0.40 | 3.3 ± 0.63 | 22 | 17 |
| AF 28 | 1.7 ± 0.29 | 1.0 ± 0.00 | 25 | 18 |
| Susceptible checks | | | | |
| CSH 1 | 8.4 ± 0.28 | 9.0 ± 0.16 | 92 | 90 |
| CSH 5 | 8.3 ± 0.25 | 8.8 ± 1.03 | 77 | 82 |
| CSH 9 | 7.4 ± 0.55 | 8.5 ± 0.00 | 72 | 85 |
| CSH 11 | 6.3 ± 1.02 | 7.2 ± 1.11 | 84 | 89 |
| Swarna | 8.2 ± 0.40 | 8.2 ± 1.01 | 88 | 95 |
| ± s.e. | | | 6.68 | 4.79 |
| l.s.d. at 5% | | | 18.43 | 13.22 |

[a] 1, < 10% midge damage; 9, > 80% midge damage

Midge damage ratings were 1.4–4.8 in the breeding lines, compared with 8.4–9.0 in the susceptible controls (*Table 4*). ICSV 197, ICSV 386, ICSV 387, ICSV 388, ICSV 397, ICSV 563, ICSV 692, ICSV 739, ICSV 745, ICSV 746, ICSV 753, ICSV 757, ICSV 88036, ICSV 88041 and ICSV 89052 showed high levels of midge resistance (damage rating < 3, and < 31% spikelets with midge damage (except ICSV 563 and ICSV 753).

## Multilocation testing

Midge damage ratings of the resistant germplasm accessions were <5 across locations (except IS 26789 at Bhavanisagar), compared with a damage rating of 7–9 for the susceptible controls. Sixteen lines showed a damage rating of < 3 across locations (*Table 5*). ICSV 197, ICSV 737, ICSV 89049, ICSV 89051, and ICSV 90005 showed high levels of midge resistance (damage rating < 3 compared with 8–9 in the susceptible controls) across locations (*Table 6*). ICSV 392, ICSV 692, ICSV 736, ICSV 746, ICSV 757, and ICSV 88036 suffered moderate damage (damage rating 2–6) at some test locations.

ICSV 388, ICSV 690, ICSV 563 and PM 7068 have been identified as non-restorers, and are being converted into male steriles for the production of midge-resistant hybrids. ICSV 563A and PM 7068A are being tested for their hybrid potential.

Table 4. Midge damage ratings of sorghum breeding lines resistant to sorghum midge under natural infestation and headcage conditions (ICRISAT Centre, India)

| Cultivar | Origin | Damage rating[a]: Natural infestation | Damage rating[a]: Headcage screening | Midge damage (%): Natural infestation | Midge damage (%): Headcage screening |
|---|---|---|---|---|---|
| ICSV 197 | PM 11344 | 1.4 ± 0.18 | 1.4 ± 0.19 | 15 | 18 |
| ICSV 386 | PM 7032 | 2.0 ± 0.30 | 2.8 ± 1.44 | 22 | 26 |
| ICSV 387 | PM 7397 | 2.9 ± 0.35 | 3.0 ± 0.52 | 24 | 22 |
| ICSV 388 | PM 8787-2 | 2.4 ± 0.51 | 1.8 ± 0.25 | 17 | 19 |
| ICSV 389 | PM 13553 | 2.9 ± 0.32 | 3.2 ± 0.73 | 30 | 20 |
| ICSV 391 | PM 13644 | 3.7 ± 0.36 | 3.8 ± 0.41 | 18 | 15 |
| ICSV 393 | PM 13655 | 3.3 ± 0.44 | 4.5 ± 0.96 | 26 | 31 |
| ICSV 397 | PM 14411-2 | 3.0 ± 0.00 | 2.0 ± 0.00 | 28 | 31 |
| ICSV 563 | PM 7061 | 2.8 ± 0.23 | 2.5 ± 0.00 | 28 | 35 |
| ICSV 564 | PM 7422-2 | 3.4 ± 0.26 | 3.6 ± 0.47 | 10 | 22 |
| ICSV 690 | PM 6751 | 4.3 ± 1.36 | 2.3 ± 0.75 | 14 | 28 |
| ICSV 692 | PM 7526 | 2.9 ± 0.40 | 2.7 ± 0.60 | 21 | 18 |
| ICSV 729 | PM 7104-1 | 2.3 ± 0.36 | 2.4 ± 0.43 | 21 | 16 |
| ICSV 730 | PM 12652 | 3.1 ± 0.46 | 3.2 ± 0.73 | 18 | 15 |
| ICSV 731 | PM 12654 | 3.1 ± 0.44 | 4.3 ± 0.60 | 22 | 27 |
| ICSV 736 | PM 14358-7 | 3.9 ± 0.47 | 3.3 ± 0.33 | 18 | 13 |
| ICSV 737 | PM 14370-2 | 2.8 ± 0.33 | 3.2 ± 1.03 | 24 | 27 |
| ICSV 739 | PM 14386-1-6 | 3.0 ± 0.82 | 2.5 ± 0.00 | 22 | 28 |
| ICSV 744 | PM 14410-2-4 | 3.8 ± 0.52 | 2.2 ± 0.33 | 22 | 8 |
| ICSV 745 | PM 14415-1-1 | 2.0 ± 0.50 | 2.5 ± 0.20 | 18 | 22 |
| ICSV 746 | PM 14416-3 | 2.4 ± 0.26 | 2.4 ± 0.21 | 17 | 11 |
| ICSV 748 | PM 14431-6 | 2.8 ± 0.18 | 4.0 ± 0.00 | 12 | 15 |
| ICSV 752 | PM 13668-1 | 3.1 ± 0.52 | 3.5 ± 0.50 | 26 | 19 |
| ICSV 753 | PM 13670-1 | 2.9 ± 0.52 | 2.5 ± 0.50 | 40 | 32 |
| ICSV 757 | PM 14383 | 2.5 ± 0.54 | 3.0 ± 0.00 | 16 | 9 |
| ICSV 843 | PM 15952 | 4.0 ± 1.00 | 3.5 ± 0.00 | 14 | 28 |
| ICSV 88006 | PM 15949 | 3.8 ± 1.25 | 2.5 ± 0.00 | 14 | 32 |
| ICSV 88013 | PM 15936-2 | 4.1 ± 0.69 | 2.8 ± 0.32 | 21 | 15 |
| ICSV 88014 | PM 15926 | 3.4 ± 0.37 | 3.5 ± 0.00 | 17 | 10 |
| ICSV 88028 | PM 15908-3 | 3.4 ± 0.42 | 3.0 ± 0.29 | 28 | 19 |
| ICSV 88032 | PM 15936-1 | 3.4 ± 0.76 | 2.1 ± 0.13 | 14 | 12 |
| ICSV 88035 | PM 12695-2 | 3.0 ± 0.34 | 4.8 ± 1.25 | 10 | 39 |
| ICSV 88036 | PM 15908-4 | 2.9 ± 0.41 | 2.6 ± 0.24 | 17 | 30 |
| ICSV 88041 | PM 15929-2 | 2.6 ± 0.49 | 2.3 ± 0.43 | 18 | 11 |
| ICSV 89049 | PM 13613 | 3.0 ± 0.55 | 3.1 ± 0.51 | 16 | 18 |
| ICSV 89051 | PM 14410-1 | 3.1 ± 0.38 | 2.7 ± 0.30 | 17 | 11 |
| ICSV 89052 | PM 14410-3 | 2.5 ± 0.38 | 2.7 ± 0.30 | 22 | 8 |
| ICSV 89053 | PM 15908-2 | 3.1 ± 0.39 | 3.0 ± 0.29 | 20 | 28 |
| ICSV 89054 | PM 15930 | 3.1 ± 0.23 | 3.5 ± 0.50 | 19 | 18 |
| ICSV 90001 | PM 15908-1 | 3.0 ± 0.61 | 3.8 ± 0.52 | 21 | 17 |
| ICSV 90002 | PM 7017 | 3.0 ± 0.50 | 3.3 ± 0.80 | 14 | 32 |
| ICSV 90003 | PM 14370-1 | 3.5 ± 0.61 | 3.4 ± 0.58 | 24 | 27 |
| ICSV 90004 | PM 15933-2 | 3.3 ± 0.31 | 3.9 ± 1.20 | 19 | 18 |
| ICSV 90005 | PM 13705 | 2.5 ± 0.32 | 3.4 ± 0.48 | 22 | 27 |
| Resistant check (DJ 6514) | | 1.3 ± 0.14 | 1.8 ± 0.43 | 18 | 20 |
| Susceptible check (CSH 1) | | 8.4 ± 0.28 | 9.0 ± 0.16 | 90 | 94 |
| ± s.e. | | | | 6.68 | 7.54 |
| l.s.d. at 5% | | | | 18.43 | 21.00 |

[a] 1, < 10% midge damage; 9, > 80% midge damage

Table 5. Midge damage ratings[a] of sources of resistance to sorghum midge at five locations in India

| Cultivar | Dharwad | Patancheru (rainy season) | Patancheru (post-rainy season) | Bhavanisagar | Warangal | Average ± s.e. |
|---|---|---|---|---|---|---|
| IS 3461 | 2 | 2 | 2 | 2 | 2 | 2.00 ± 0.00 |
| IS 7005 | 2 | 2 | 2 | 2 | 2 | 2.00 ± 0.00 |
| IS 8671 | 2 | 2 | 3.5 | 2 | 3 | 2.50 ± 0.28 |
| IS 8571 | 2 | 2 | 2 | 2 | 2 | 2.00 ± 0.00 |
| IS 8884 | 2 | 2 | 3 | - | 1 | 1.60 ± 0.51 |
| IS 8887 | 2 | 2 | 2 | - | 1 | 1.40 ± 0.40 |
| IS 8891 | 2 | 2 | 2 | - | 2 | 1.60 ± 0.40 |
| IS 8918 | 2 | 2 | 2 | - | 2 | 1.60 ± 0.40 |
| IS 9807 | 2 | 2 | 2 | 3 | 2 | 2.20 ± 0.17 |
| IS 15107 | 2.5 | 3 | 3 | 3 | 3 | 2.90 ± 0.08 |
| IS 18563 | 3.5 | 3 | 3 | 5 | 4 | 3.70 ± 0.33 |
| IS 18695 | 2 | 1 | 2 | 2 | 3 | 2.00 ± 0.28 |
| IS 18698 | 3 | 2 | 3 | 4 | 1 | 2.60 ± 0.45 |
| IS 19474 | 3 | 2 | 2 | 2 | 2 | 2.20 ± 0.17 |
| IS 19476 | 3 | 2 | 2 | 2 | 1 | 2.00 ± 0.28 |
| IS 21871 | 2 | 3 | 2.5 | 2 | 3 | 2.50 ± 0.20 |
| IS 21873 | 2 | 2 | 2.5 | 2 | 3 | 2.30 ± 0.17 |
| IS 21879 | 2 | 1 | 2 | 3 | 4 | 2.40 ± 0.45 |
| IS 21881 | 3 | 2 | 3 | 5 | 3 | 3.20 ± 0.43 |
| IS 21883 | 2 | 2 | 3 | 3 | 3 | 2.60 ± 0.21 |
| IS 22806 | 2 | 1 | 2 | 3 | 2 | 2.00 ± 0.28 |
| IS 26789 | 3 | 3 | 3 | 6 | 5 | 4.00 ± 0.56 |
| IS 27103 | 3 | 2 | 1 | 5 | 1 | 2.40 ± 0.66 |
| Resistant checks | | | | | | |
| DJ 6514 | 2 | 1 | 1.5 | 2 | 1 | 1.50 ± 0.20 |
| TAM 2566 | 3 | 1 | 2 | 3 | 2 | 2.20 ± 0.33 |
| AF 28 | 3 | 1 | 2 | 2 | 2 | 2.00 ± 0.28 |
| Susceptible checks | | | | | | |
| CSH 1 | 9 | 8 | 9 | 8 | 8 | 8.40 ± 0.21 |
| CSH 5 | 8 | 9 | 9 | 7 | 8 | 8.20 ± 0.33 |
| CSH 9 | 8 | 8 | 8 | 7 | 7 | 7.60 ± 0.21 |
| CSH 11 | 8 | 8 | 9 | 7 | 7 | 7.80 ± 0.33 |
| Swarna | 9 | 8 | 9 | 7 | 8 | 8.20 ± 0.33 |
| ± s.e | 0.44 | 0.43 | 0.44 | 0.39 | 0.39 | |
| l.s.d. at 5% | 1.14 | 1.20 | 1.23 | 1.07 | 1.09 | |

[a]1, < 10% midge damage; 9, > 80% midge damage

## Discussion

Sources of resistance to sorghum midge are diverse in origin, and show considerable variation in plant height, days to 50% flowering, grain colour and 1000-grain mass. Genotypes with an appropriate combination of plant characteristics can be selected for use in the crop improvement programmes in different regions. IS 18695, IS 21873, IS 21871, IS 21879, IS 21883 and TAM 2566 flower in 65–71 days and are dwarf (< 150 cm), with red or straw-coloured grain. These lines may be useful in South-East Asia, Australia, USA and other regions growing dwarf and early-flowering genotypes for animal feed. IS 3461, IS 7005, IS 18563, IS 22778, IS 22806, IS 26789 and IS 27103 are medium tall and flower in < 75 days; they may be useful for regions where both grain and fodder are important (e.g. India and Africa).

Of the breeding lines, ICSV 388, ICSV 389, ICSV 563, ICSV 729, ICSV 88028, ICSV 88036, ICSV 88041, ICSV 88049, ICSV 90001 and ICSV 90002 are dwarf (< 150 cm), and flower in < 70 days during the rainy season at the ICRISAT Centre. ICSV 197, ICSV 397, ICSV 737, ICSV 744, ICSV 746, ICSV 748, ICSV 752, ICSV 843, ICSV 88014, ICSV 89041 and ICSV 89052 are tall (> 250 cm); ICSV 197, ICSV 748 and ICSV 843 combine high levels of midge resistance with a grain yield potential comparable to that of commercial cultivars. These lines can be useful in several regions of Asia, Africa and Latin America as dual-purpose medium-maturity cultivars.

Most of the breeding lines derived from DJ 6514 or its progeny PM 11344 (ICSV 197) have a smaller grain size (15–20 g per 1000 grains). However, ICSV 729, ICSV 731, ICSV 745, ICSV 746, ICSV 88006, ICSV 88049, ICSV 88051, ICSV 88052 and ICSV 90002 have bold grain (> 25 g per 1000 grains), and compare favourably with commercially released varieties and hybrids in India.

Although several sources of resistance were used in the midge-resistance breeding programme, the majority of the midge-resistant lines were derived from crosses involving DJ 6514 or its progeny PM 11344 (DJ 6514 × IS 3443). Some resistant lines were also identified in the crosses involving PM 7348 (IS 12573C × IS 12666C), IS 2579C, IS 18962, SGIRL-MR 1 and IS 12573C. Major progress was made by using ICSV 197 as a midge-resistance donor. Transfer of midge resistance from DJ

Table 6. Midge damage ratings[a] of midge-resistant breeding lines at five locations in India

| Cultivar | Origin | Dharwad (rainy season) | Patancheru (rainy season) | Patancheru (post-rainy season) | Bhavnisagar | Warangal | Average ± s.e. |
|---|---|---|---|---|---|---|---|
| ICSV 197 | PM 11344 | 2 | 1 | 2 | 2 | 2 | 1.80 ± 0.17 |
| ICSV 386 | PM 7032 | 2 | 3 | 2 | 3 | 4 | 2.80 ± 0.33 |
| ICSV 387 | PM 7397 | 2 | 3 | 3 | 4 | 4 | 3.20 ± 0.33 |
| ICSV 388 | PM 8787-2 | 4 | 4 | 3 | 2 | 4 | 3.40 ± 0.35 |
| ICSV 389 | PM 13553 | 3 | 3 | 3 | 4 | 4 | 3.40 ± 0.21 |
| ICSV 391 | PM 13644 | 3.5 | 3 | 3 | 5 | 4 | 3.70 ± 0.33 |
| ICSV 392 | PM 13654 | 2 | 3 | 2 | 6 | 4 | 3.40 ± 0.66 |
| ICSV 393 | PM 13655 | 2.5 | 3 | 5 | 3 | 4 | 3.50 ± 0.40 |
| ICSV 397 | PM 14411-2 | 3 | 3 | 3 | 3 | 4 | 3.20 ± 0.17 |
| ICSV 563 | PM 7061 | 2 | 2 | 4 | 5 | 3 | 3.20 ± 0.52 |
| ICSV 564 | PM 7422-2 | 4 | 3 | 3 | * | 2 | 3.00 ± 0.67 |
| ICSV 690 | PM 6751 | 4 | 4 | 3.5 | 4 | 3 | 3.70 ± 0.17 |
| ICSV 692 | PM 7526 | 3 | 3.5 | 2 | 5 | 6 | 3.90 ± 0.63 |
| ICSV 729 | PM 7104-1 | 2 | 2.5 | 2 | 3 | 4 | 2.70 ± 0.33 |
| ICSV 730 | PM 12652 | 2 | 2 | 2 | 5 | 5 | 3.20 ± 0.65 |
| ICSV 731 | PM 12654 | 3 | 4 | 3 | 5 | 5 | 4.00 ± 0.40 |
| ICSV 736 | PM 14358-7 | 3 | 3 | 3 | 6 | 4 | 3.80 ± 0.52 |
| ICSV 737 | PM 14370-2 | 2 | 3 | 1 | 3 | 3 | 2.40 ± 0.35 |
| ICSV 739 | PM 14386-1-6 | 1 | 2.5 | 1 | 3 | 4 | 2.30 ± 0.52 |
| ICSV 744 | PM 14410-2-4 | 3 | 3 | 3.5 | 3 | 5 | 3.50 ± 0.34 |
| ICSV 745 | PM 14415-1-1 | 2 | 1 | 1.5 | 5 | 3 | 2.50 ± 0.63 |
| ICSV 746 | PM 14416-3 | 4 | 2.5 | 2.5 | 6 | 5 | 4.00 ± 0.61 |
| ICSV 752 | PM 13668-1 | 2 | 4 | 3 | 2 | 3 | 2.80 ± 0.33 |
| ICSV 753 | PM 13670-1 | 2.5 | 3.5 | 2.5 | 5 | 4 | 3.50 ± 0.42 |
| ICSV 757 | PM 14383 | 2.5 | 5 | 2.5 | 5 | 6 | 4.20 ± 0.64 |
| ICSV 758 | PM 14403-1-1 | 2 | 2 | 2 | 5 | 4 | 3.00 ± 0.56 |
| ICSV 843 | PM 15952 | 5 | 3 | 3.5 | 3 | 4 | 3.70 ± 0.33 |
| ICSV 88006 | PM 15949 | 5 | 2.5 | 2.5 | * | * | 3.33 ± 1.08 |
| ICSV 88013 | PM 15936-2 | 4 | 2.5 | 2.5 | 3 | 3 | 3.00 ± 0.24 |
| ICSV 88014 | PM 15926 | 5 | 3 | 3 | 5 | 5 | 4.20 ± 0.43 |
| ICSV 88028 | PM 15908-3 | 5 | 3 | 3 | * | 5 | 4.00 ± 0.91 |
| ICSV 88032 | PM 15936-1 | 3.5 | 2 | 2 | 3 | 3 | 2.70 ± 0.26 |
| ICSV 88035 | PM 12695-2 | 4 | 4 | 3.5 | 3 | 3 | 3.50 ± 0.20 |
| ICSV 88036 | PM 15908-4 | 5 | 2.5 | 2.5 | 4 | 6 | 4.00 ± 0.61 |
| ICSV 88041 | PM 15929-1 | 5 | 2.5 | 2.5 | 3 | 3 | 3.20 ± 0.41 |
| ICSV 89049 | PM 13613 | 2 | 3 | 2 | 3 | 3 | 2.60 ± 0.21 |
| ICSV 89051 | PM 14410-1 | 2 | 3 | 3 | 3 | 2 | 2.60 ± 0.21 |
| ICSV 89052 | PM 14410-3 | 2 | 2 | 3 | 5 | 4 | 3.20 ± 0.52 |
| ICSV 89053 | PM 15908-2 | 5 | 2.5 | 2.5 | * | 3 | 3.25 ± 0.79 |
| ICSV 89054 | PM 15930 | 3.5 | 2 | 3.5 | * | 5 | 3.50 ± 0.84 |
| ICSV 90001 | PM 15908-1 | 5 | 1 | 2 | 4 | 4 | 3.20 ± 0.65 |
| ICSV 90002 | PM 7017 | 3.5 | 3 | 2.5 | 2 | 3 | 2.80 ± 0.22 |
| ICSV 90003 | PM 14370-1 | 2 | 3 | 2 | 3 | 4 | 2.80 ± 0.33 |
| ICSV 90004 | PM 15933-2 | 4 | 3 | 3 | 5 | 5 | 4.00 ± 0.40 |
| ICSV 90005 | PM 13705 | 3 | 3 | 1 | 3 | 3 | 2.60 ± 0.35 |
| Resistant check (DJ 6514) | | 2 | 1 | 1.5 | 2 | 1 | 1.50 ± 0.20 |
| Susceptible check (CSH 1) | | 9 | 8 | 9 | 8 | 8 | 8.40 ± 0.21 |
| ± s.e. | | 0.208 | 0.164 | 0.178 | 0.210 | 0.183 | |
| l.s.d. at 5% | | 0.574 | 0.453 | 0.491 | 0.580 | 0.505 | |

[a]1, < 10% midge damage; 9, > 80% midge damage

6514 to ICSV 197 was the most significant development in the midge-resistance breeding programme. ICSV 197 is highly resistant to sorghum midge, and yields 54% higher than the resistant parent, DJ 6514 (Agrawal, Sharma and Leuschner, 1987). It also has larger seeds than the resistant parent (19 g compared with 15 g per 1000 grains in DJ 6514). The yield potential of ICSV 197 is on a par with that of the commercially released varieties in India (Agrawal *et al.*, 1987). ICSV 745, ICSV 843, ICSV 88013 and ICSV 88032 show considerable improvement over ICSV 197 in grain yield, plant height and seed size. Of these, ICSV 745 and ICSV 88013 have an optimum combination of plant height (215–217 cm), time to flowering (70–71 days) and seed size (22–31 g per 1000 grains compared with 29 g per 1000 grains for the commercial hybrid, CSH 5). These are also displaying good performance, adaptation and acceptance by farmers in the midge-endemic areas in Karnataka, India (unpublished data).

Several sources of resistance to sorghum midge have been reported previously (Bowden and Neve, 1953; Pradhan, 1971; Johnson, Rosenow and Teetes, 1973; Wiseman, McMillian and Widstrom, 1973; Rossetto *et al.*, 1975; Shyamsunder *et al.*, 1975; Jotwani, 1978; Faris, Lira and Viega Leo, 1979; Sharma, 1985b). Many of these sources were also tested in the studies described here. Resistance to sorghum midge in TAM 2566, DJ 6514, AF 28, IS 2579C and IS 12666C was confirmed under natural infestation and headcage tests. However, not all sources of resistance identified under natural infestation maintained their level of resistance under no-choice conditions in the headcage (Sharma *et al.*, 1988b); nevertheless, such lines were relatively less susceptible than the susceptible controls. This may be attributed to a non-preference mechanism of resistance, which does not function under no-choice headcage conditions (Harris, 1961; Sharma *et al.*, 1988b). Levels of midge resistance were unstable or inadequate in ICSV 392, ICSV 692, ICSV 736, ICSV 746, ICSV 757 and ICSV 88036 at some locations. This may be attributed to environmental effects on host-plant resistance to insects (Faris *et al.*, 1979; Sharma *et al.*, 1988b).

Sources of resistance to sorghum midge are diverse (Sharma *et al.*, 1988b). AF 28, DJ 6514, TAM 2566 and IS 15107 have different combinations of the factors associated with resistance to sorghum midge (Sharma, Vidyasagar and Leuschner, 1990a, b) and there is a possibility of increasing the levels and diversity of resistance to this insect. Sources of resistance to sorghum midge are available for different purposes. Midge resistance has been transferred to an array of breeding lines differing in plant height, days to flower, panicle type and grain size. These lines can be adapted *per se* or used in sorghum resistance-breeding programmes in sorghum-growing regions.

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