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Identification of stable sources of resistance in sorghum to midge and their reaction to leaf diseases

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Abstract

Sorghum midge (*Stenodiplosis* (= *Contarinia*) *sorghicola* Coquillett) is an important pest of grain sorghum worldwide, and several sources of resistance have been identified in the world sorghum germplasm collection. DJ 6514 and the breading lines derived from it become susceptible to sorghum midge in Kenya. Therefore, we evaluated a diverse array of midge-resistant and -susceptible lines at Alupe, Kenya; and ICRISTAT Center, India, to identify lines with stable resistance across seasons and locations. The test material was also evaluated for resistance to leaf diseases at Alupe, Kenya; to identify lines with multiple resistance to sorghum midge and leaf diseases.

Across seasons and locations; IS 3461, IS 8884, IS 8887, IS 8891, IS 19476, IS 22806, and AF 28 showed high to moderate levels of resistance to midge, and these lines will be useful for use in resistance breeding programs. Thirty-nine lines showed resistance to midge both under natural infestation and no-choice headcage screening at ICRISTAT Center, India, over four seasons, of which IS 18696, IS 22806, ICSV, 197, ICSV 745, ICSV 88032, PM 20710-2, DJ 6514, and AF 28 were highly resistant. Genotypes IS 3461, IS 8884, IS 8887, IS 8589, IS 19476, IS 22806, ICSV 736, ICSV 90003, and AF 28 showed moderate levels of resistance to both midge and leaf diseases at Alupe, Kenya; and these lines can be used as sources of multiple resistance to these pests. Lines IS 2766, IS 7148, IS 8733, and IS 8589, showed high levels of resistance to leaf diseases in Kenya. Resistance to midge breaks down in some lines at Alupe, Kenya; possibly because of the influence of environment on the expression of resistance or the possible differences in midge populations at different geographic locations. © 1999 Published by Elsevier Science Ltd. All rights reserved.

Keywords: Sorghum; *Sorghum bicolor*; Plant resistance; Stability; Midge; *Stenodiplosis sorghicola*; Leaf diseases; Resistance breeding; Multiple resistance

1. Introduction

Sorghum, *Sorghum bicolor* (L.) Moench is one of the most important cereal crops in the semi-arid tropics (SAT). It provides food, feed and forage, but grain yields on peasant farms are generally low, due partly to insect pest damage. Of the 150 insect pests that damage sorghum (Jotwani et al., 1980), sorghum shoot fly (*Atherigona soccata* Rond.), stem borers (*Chilo partellus* Swin. in Asia, and East and southern Africa, and *Busseola fusca* Fuller in Africa), sorghum midge (*Stenodiplosis* (= *Contarinia*) *sorghicola* Coq.), aphids (*Schizaphis graminum* Rond., *Melanaphis sacchari* Zehnt., and *Rhopalosiphum maidis* Fitch.), armyworms (*Mythimna separata* Walk., *Spodoptera frugiperda* J.E. Smith, and *S. exempta* Walker), head bugs *Calocoris angustatus* Leth. in India, *Eurystylus oldi* Poppius in West Africa, *Taylorilygus vosseleri* Popp. in East Africa, and *Creontiades pallidus* Ramb. in India and Africa), and head caterpillars (*Helicoverpa*, *Heliothis*, *Eublemma*, *Cryptoblabes*, *Nola*, *Celama*, etc.) are the major pests. Insect pests cause an estimated loss of over $1000 million annually in the SAT (ICRISAT, 1992). Sorghum crop at Alupe, Kenya and at other locations with moderate to

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high rainfall is also infected by leaf diseases such as anthracnose [*Collectotrichum graminicola* (Cesti.) Wilson], zonate leaf spot [*Gloeocercospora sorghi* (Bains & Edgerton)], leaf blight [*Helminthosporium turcicum* Pass.], and rust [*Puccinia purpurea* Cooke].

Sorghum midge (*S. sorghicola*) is the most important pest of grain sorghum worldwide (Harris, 1976). Midge damage can be avoided through early and uniform planting of sorghum cultivars in a geographical area. However, it is difficult to plant at times when midge damage can be avoided because of uncertainties of rainfall, inability of the farmers to plant the entire sorghum crop in an area at the same time, and differential flowering of the sorghum cultivars. Chemical control is costly, ineffective, and beyond the reach of most farmers in the SAT. Natural enemies exist, but their populations buildup only after the damage has been caused. Host plant resistance is an effective means of keeping midge populations below economic threshold levels (Sharma, 1993), and therefore breeding for resistance to midge is an integral part of sorghum improvement programs.

Sources of resistance to sorghum midge have been identified by several workers (Johnson et al., 1973; Wiseman et al., 1973; Rossetto et al., 1975; Shyamsunder et al., 1975; Jotwani 1978; Page, 1979; Faris et al., 1979; Peterson et al., 1985). Nearly 15,000 sorghum germplasm accessions have been screened for resistance to sorghum midge between 1980 to 1990 at ICRISAT Center, Patancheru, India, and 25 lines have been found to be resistant to sorghum midge across seasons and locations. Most of the high yielding midge-resistant lines developed at the ICRISAT Center, India, have been derived from DJ 6514 (Sharma, 1985; Sharma et al., 1993). However, DJ 6514 and the breeding lines derived from it have shown susceptible reaction to midge at Alupe, Kenya, suggesting the possibility of the occurrence of a new biotype of sorghum midge in this region or the environment-induced breakdown of resistance mechanisms (Sharma et al., 1996). Therefore, the present studies were undertaken to identify sorghum lines with stable resistance to sorghum midge across seasons and locations, which is essential to develop sorghum cultivars with broad based resistance. Sorghum lines with different genes/mechanisms of resistance can be used to broaden the bases and possibly increase the levels of resistance to sorghum midge. Information on breakdown of resistance due to new biotypes or because of environmental interactions is useful in developing strategies for proper utilization and deployment of genes conferring resistance to sorghum midge.

2. Materials and methods

Sorghum genotypes were sown during the short rainy season (Sept. to Dec.) between 1992 and 1994 at the Kenya Agricultural Research Institute, Regional Station, Alupe, Busia, Kenya; and 1995 and 1997 at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India.

In the first experiment, seventy germplasm and breeding lines showing resistance to midge at ICRISAT Center were initially evaluated for midge resistance at Alupe, Kenya; of which 42 lines were tested in replicated trials across two sowings during the 1992–1994 short rainy season at Alupe, Kenya.

In the second experiment, 203 germplasm accessions originating from eastern Africa, that flower in <80 days, were also screened for resistance to sorghum midge at Alupe, Kenya, and at ICRISAT Center, Patancheru, India. The germplasm lines were planted in a single row, 4 m long, in an augmented design (Nigam and Gupta, 1982); in which susceptible and resistant checks were planted after every 50 genotypes. The resistance/susceptibility of the test material was judged in comparison to the reactions of resistant and susceptible checks in the same block. At ICRISAT Center, the material was planted twice at 20 days interval to overcome the problem of escape from midge damage because of staggered flowering of sorghum genotypes, and variation in midge population overtime. At Alupe, only one planting was taken up since there is a continuous emergence of adult midges from the alternative host, *Sorghum sudanense*.

In the third experiment, 64 lines (selected from the midge-resistant lines identified at ICRISAT Center, and midge-resistant germplasm selections from the accessions originating from eastern Africa) were evaluated for four seasons at ICRISAT Center under natural infestation and no-choice headcage technique.

The test material was planted in a randomized complete block design (except the germplasm accessions from eastern Africa), and there were three replications. Each entry was planted in 2 rows, and 4 m long. The rows were 75 cm apart, and the plants were thinned to a spacing of 10 cm within the row, 15 days after seedling emergence. Carbofuran 3G (@ 1.2 kg ai per ha) was applied at the time of sowing to control the sorghum shoot fly, *Atherigona soccata* Rond. Normal agronomic practices were followed for raising the crop. No insecticide was applied during the reproductive stage of the crop.

Sorghum midge damage in the test material under natural infestation is influenced by staggered flowering of the sorghum genotypes (55 to 75 days after flowering) and day to day variation in midge density. Sorghum midges emerge every day in the morning, mate, and the females proceed in search of flowering sorghum panicles for oviposition. The midge females lay eggs between 0800 and 1400 h, and die in 4 to 6 h. Also, oviposition by the midge females is influenced by rain and cloudy weather. Therefore, it becomes difficult to compare the genotypes for their resistance/susceptibility to sorghum midge under variable insect pressure under natural infestation. To overcome these problems, the test material was also screened under uniform insect pressure using the headcage technique (Sharma et al., 1988). At flowering, the panicles were infested with 40 midges panicle^{-1}. Three panicles were infested with midges under headcage in each replication. The panicles were covered with muslin cloth bags at panicle emergence to avoid natural midge infestation. Midge females were collected in plastic bottle aspirators between 0800 and 1000 AM from flowering sorghum panicles, and were released inside the wire-framed cages tied around the sorghum panicles, and covered with blue colored cloth bags (Sharma et al., 1988). Since oviposition by the sorghum midge females is confined to spikelets at flowering on a particular day, each panicle was infested with midges for two consecutive days so that all the spikelets were exposed to midges at flowering. The cages were removed after 15 days. At maturity, the panicles were first rated visually for midge damage (damage rating, DR) on a 1 to 9 scale (1 = <10%, 2 = 11–20%, 3 = 21–30%, 4 = 31–40%, 5 = 41–50%, 5 = 51–60%, 7 = 61–70%, 8 = 71–80%, and 9 = >80% midge damaged spikelets), and then the samples were drawn from the infested panicles to record the number of midge damaged spikelets from a sample of 250 spikelets in each panicle, and expressed as percentage midge damaged spikelets.

Since leaf disease infection is severe at Alupe, overall leaf disease severity was also recorded in different genotypes. Leaf diseases (anthracnose, rust, leaf blight, and zonate leaf spot) severity (CLOR) was evaluated on a 1 to 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%, and 9 = >80% of the leaf area infected). The entries were also evaluated visually for their agronomic expression on a 1 to 5 scale (1 = good, and 5 = poor). Data were subjected to analysis of variance. Data on percentage midge damage was transformed to angular values before statistical analysis. Stability of 64 sorghum lines for their reaction to midge under natural and headcage screening over four seasons was assessed by the method of Eberhart and Russell (1966). The significance of *t*-value of the regression coefficient was tested from zero at *P* 0.05 and *P* 0.01, to identify lines with stable resistance to midge across seasons and testing procedures. Genotypes with *t*-value (of the regression coefficient) non-significant from zero are stable in their reaction to midge since their susceptibility/resistance does not change much across environments or infestation levels, and hence are considered stable. The genotypes were also grouped using the first two principal components cluster analysis of Snedecor and Cochran (1967) based on visual damage rating and the percentage midge damaged spikelets under headcage screening.

3. Results

3.1. Reaction of 42 lines to sorghum midge and leaf diseases at Alupe, Kenya

Of the 70 germplasm accessions and breeding lines (identified to be resistant to midge at ICRISAT Center, India) (Sharma et al., 1993) screened for resistance to midge at Alupe, Kenya, between 1992 and 1994; IS 3461, IS 8884, IS 8887, IS 8891, IS 19476, IS 22806, and AF 28 showed moderate to high levels (DR 3–5) of resistance to sorghum midge (Table 1). Genotypes IS 8884, IS 8887, IS 8891, ICSV 391, ICSV 736, ICSV 90003, PM 7422-1, PM 12695-1, PM 15936, AF 28, DJ 6514, and ICSV 197 were less susceptible to leaf diseases (DR <5 compared to DR >9.0 in IS 2290). Lines IS 18563, ICSV 391, ICSV 393, ICSV 736, ICSV 88035, ICSV 90003, PM 12695-1, PM 15936 and ICSV 197 showed good agronomic expression (agronomic score <2.0 compared to 4.0 in IS 2290).

3.2. Evaluation of germplasm accessions originating from eastern Africa for resistance to sorghum midge and leaf diseases

Of the 203 germplasm accessions screened for resistance to sorghum midge at Alupe, Kenya; and ICRISAT Center, Patancheru, India; IS 7141, IS 8151, IS 8190, IS 8196, IS 8198, IS 8205, IS 8577, IS 9009, IS 9135, IS 31635, IS 31636 and AF 28 showed moderate levels of resistance to sorghum midge both at ICRISAT Center, India, and at Alupe, Kenya (Table 2). Lines IS 7134, IS 7138, IS 7151, IS 8165, IS 8204, IS 8729, IS 8922, IS 8946, IS 8960, IS 8988, IS 9021, IS 9107, IS 9112, and IS 31626 showed moderate levels of resistance (DR 3–5) to midge at ICRISAT center, but showed susceptible reaction at Alupe, Kenya. However, there were no lines showing susceptible reaction to midge at ICRISAT Center, but resistant reaction at Alupe, Kenya. Genotypes IS 2739 and IS 8198 showed slightly greater susceptibility to sorghum midge at ICRISAT Center than at Alupe, Kenya. Lines IS 8190, IS 8196, IS 8577, IS 9135, and IS 31635 showed moderate levels of resistance to both sorghum midge and leaf diseases, while IS 8589, IS 7148, IS 8733, and IS 2766 showed high levels of resistance to leaf diseases (DR <3) in Kenya.

3.3. Stability of resistance to sorghum midge under natural infestation and no-choice headcage conditions at ICRISAT Center, India

Thirty lines showed resistant reaction to sorghum midge under natural infestation and headcage screening; of which IS 18696, IS 22806, ICSV 197, ICSV 745, ICSV 88032, PM 20710-2, AF 28, and DJ 6514 showed high levels of resistance (DR <3) to sorghum midge across seasons at ICRISAT Center, India (Tables 3–5). Lines IS

Table 1
Relative susceptibility of 42 sorghum genotypes to sorghum midge, *Stenodiplosis sorghicola* (Alupe, Kenya, 1992–1994 short rainy season)

Genotype	1992	MD[a] 1994			LDR[b]	AGS[c]	Days to 50% flowering
		S1	S2	Mean			
IS 2290	4	9	8	7	9	4	58
IS 3461	2	4	3	3	6	3	77
IS 8884	3	6	6	5	4	3	80
IS 8887	3	5	6	5	4	3	79
IS 8891	3	6	5	5	4	3	76
IS 12666C	—	7	7	7	9	3	—
IS 18563	4	7	8	6	8	2	65
IS 18695	5	6	8	6	9	3	61
IS 19476	3	5	4	4	6	3	75
IS 21871	4	6	8	6	7	3	66
IS 21873	5	7	8	7	7	3	69
IS 21879	6	7	8	7	9	3	66
IS 21881	4	7	7	6	9	4	69
IS 22400	4	8	9	7	8	3	59
IS 22464	5	7	8	7	7	3	61
IS 22471	6	7	8	7	7	3	63
IS 22806	2	5	6	4	6	3	75
ICSV 388	5	7	8	8	8	3	—
ICSV 391	3	7	8	6	5	2	—
ICSV 392	5	7	9	7	6	3	—
ICSV 393	4	7	7	6	6	2	—
ICSV 394	5	8	8	7	8	3	65
ICSV 563	4	7	8	6	6	3	77
ICSV 729	5	7	6	6	9	3	70
ICSV 730	4	8	7	6	8	3	68
ICSV 731	6	8	8	7	6	3	75
ICSV 736	3	6	7	5	4	2	71
ICSV 753	4	8	7	6	6	3	72
ICSV 88028	5	7	7	6	7	3	64
ICSV 88035	4	6	7	6	5	2	66
ICSV 89049	5	6	9	7	7	3	62
ICSV 90002	4	8	8	7	8	3	62
ICSV 90003	4	7	6	5	5	2	71
ICSV 90005	4	7	6	6	7	3	67
PM 7422-1	—	6	9	8	4	3	—
PM 12695-1	5	5	7	6	5	2	65
PM 15936	—	7	8	8	5	2	—
Controls							
AF 28 (IS 18698)	2	3	5	3	5	3	76
DJ 6514 (IS 18700)	—	7	8	8	3	3	71
ICSV 197 (PM 11344)	—	8	9	9	4	2	80
TAM 2566 (IS 18697)	—	7	8	8	6	3	—
Swarna	—	9	9	9	5	3	—
SE	±1.5	±0.6	±1	—	±1	±0.4	±3

S1 and S2 = Crops sown on 21-9-94 and 29-9-94, respectively.
[a] MD = Midge damage rating (1 = <10% midge damaged spikelets, and 9 = >80% midge damaged spikelets).
[b] LDR = Leaf disease severity rating (1 = <10% leaf area infected, and 9 = >80% leaf area infected by anthracnose, leaf blight, zonate leaf spot, and rust).
[c] AGS = Agronomic score (1 = good, and 5 = poor).

Table 2
Evaluation of sorghum germplasm accessions[a] originating from eastern Africa for resistance to midge, *Stenodiplosis sorghicola* (1991–1993)

Genotype	MD[b]			LDR[c]
	Kenya	ICRISAT 1994/95		Kenya
	1991/92	S1	S2	1994
IS 2739	5	4	7	8
IS 2766	9	7	9	3
IS 7134	8	5	5	5
IS 7138	8	5	5	6
IS 7141	5	4	6	8
IS 7148	9	9	9	3
IS 7151	9	5	5	5
IS 8144	8	6	5	6
IS 8151	6	5	5	9
IS 8157	7	9	6	9
IS 8165	8	5	5	7
IS 8190	5	5	6	5
IS 8196	6	5	5	5
IS 8198	3	5	5	7
IS 8204	9	4	5	6
IS 8205	5	5	6	9
IS 8577	6	4	5	5
IS 8589	9	9	9	2
IS 8729	7	4	3	8
IS 8733	8	7	9	3
IS 8922	7	3	4	8
IS 8946	9	5	4	9
IS 8960	9	3	6	5
IS 8961	9	3	6	5
IS 8988	8	3	3	6
IS 9009	6	5	3	8
IS 9021	9	3	5	5
IS 9040	9	5	6	5
IS 9104	7	3	9	7
IS 9107	9	4	5	4
IS 9112	9	3	5	5
IS 9135	5	5	6	5
IS 31626	9	3	5	7
IS 31635	5	5	4	5
IS 31636	5	2	3	6
Controls				
ICSV 197 (PM 11344)	7.5	1.5	2.0	4.5
AF-28 (IS 18698)	4.5	1.5	2.5	5.5
Swarna	8.5	9.0	9.0	4.0
SE[d]	±0.3	±0.28	±0.26	±0.27

Note: S1 and S2 = Crops sown on 9-12-94 and 9-1-95, respectively.

[a] Data on 34 accessions showing less susceptibility to sorghum midge has been presented in this table out of 203 accessions tested at Alupe, Kenya and ICRISAT, Patancheru.

[b] MD = Midge damage rating (1 = <10% midge damaged spikelets, and 9 = >80% midge damaged spikelets).

[c] LDR = Leaf diseases severity rating (1 = <10% leaf area infected, and 9 = >80% leaf area infected by anthracnose, leaf blight, zonal leaf spot, and rust).

[d] SE computed by univariate analysis.

Table 3
Stability of resistance of 64 sorghum lines to midge, *Stenodiplosis sorghicola* under natural infestation (ICRISAT Center, Patancheru 1995–1996)

Genotype	DR[1]	SE±	CV (%)	*b*
IS 2124	5.9	0.88	15.0	1.26**
IS 2687	3.8	0.66	17.6	1.06*
IS 2739	3.5	0.87	24.7	1.47**
IS 3461	4.3	0.44	10.2	0.20
IS 7134	4.0	1.02	25.5	1.07*
IS 7138	3.4	0.78	23.0	1.27**
IS 7151	4.1	0.72	17.5	0.83*
IS 8151	4.9	0.97	19.8	1.29**
IS 8165	3.5	0.36	10.1	0.57
IS 8190	3.9	1.25	32.3	2.07**
IS 8196	4.0	0.84	21.0	1.34**
IS 8198	3.4	0.75	22.1	1.27**
IS 8204	4.5	1.02	22.7	1.35**
IS 8533	7.3	1.30	17.9	0.72
IS 8577	3.5	0.54	15.4	0.76
IS 8729	3.4	0.48	14.1	0.57
IS 8849	4.0	0.54	13.5	1.76
IS 8884	4.0	1.17	29.3	1.73**
IS 8887	4.1	0.85	20.6	1.22**
IS 8891	4.4	0.90	20.6	1.39**
IS 8922	3.8	1.05	28.0	1.74*
IS 8946	3.9	0.66	16.9	0.81*
IS 8988	3.6	0.63	17.3	0.97*
IS 9009	6.4	0.88	13.7	1.40**
IS 9021	4.3	1.27	29.8	2.10**
IS 9045	4.3	1.01	23.8	1.64**
IS 9107	4.4	0.88	20.0	1.38**
IS 9112	5.1	0.92	18.0	1.12*
IS 15107	3.9	1.20	30.9	1.81**
IS 18563	3.4	0.75	22.1	1.26**
IS 18573	4.1	0.43	10.3	0.63
IS 18695	2.9	0.56	19.3	0.93*
IS 18696	2.9	0.43	14.8	0.60
IS 19476	3.3	0.97	29.8	1.64**
IS 21006	5.1	0.48	9.30	0.77*
IS 21031	5.3	0.63	12.0	0.87*
IS 21155	6.4	0.97	15.1	1.29**
IS 21185	4.9	1.07	22.0	1.73**
IS 21211	5.3	1.09	20.8	1.65**
IS 21219	4.8	0.33	6.80	0.30
IS 21873	3.9	0.56	14.3	0.55
IS 21879	4.1	0.52	12.5	0.55
IS 21881	3.4	0.43	12.6	0.60
IS 22464	5.0	0.89	17.8	1.38**
IS 22471	5.0	0.29	5.80	0.32
IS 22806	3.0	0.54	18.0	0.90*
IS 31626	4.4	0.92	21.1	1.47**
IS 31635	3.6	0.56	15.3	0.50
IS 31636	4.5	0.74	16.3	1.10*
ICSV 197	2.9	0.52	17.9	0.71
ICSV 392	3.5	0.36	10.1	0.22
ICSV 393	3.1	0.56	17.8	0.57
ICSV 730	3.5	0.68	19.3	1.04*
ICSV 745	3.1	0.83	26.4	1.34**
ICSV 88032	3.3	0.60	18.3	0.58
ICSV 93073	4.0	0.21	5.10	0.23
PM 12652-2	3.3	0.88	26.7	0.43
PM 20710-2	2.6	0.48	18.1	0.77

(*Continued on next page*)

Table 3 (*Continued*)

Genotype	DR[1]	SE±	CV (%)	*b*
Controls				
AF 28	2.6	0.38	14.3	0.54
DJ 6514	3.4	0.78	23.0	1.15*
KAT 369	5.0	0.54	10.8	0.45
Seredo	4.3	0.72	16.9	0.81
Serena	3.1	0.25	7.7	0.30
Swarna	8.0	0.46	5.7	0.32
SE ±	0.58	—	—	—

Note: DR[1] = Damage rating (1 = <10% midge damage, and 9 = >80% midge damage), SE = standard error, and *b* = regression coefficient.

* Regression coefficient significantly different from zero at $P = 0.05$.

** Regression coefficient significantly different from zero at $P = 0.01$.

Table 4

Stability of resistance (damage rating) of 64 sorghum genotypes to midge, *Stenodiplosis sorghicola* under no-choice headcage screening (ICRISAT Center, Patancheru 1995–1996)

Genotype	DR[1]	SE±	CV (%)	*b*
IS 2124	7.7	0.55	7.10	1.03
IS 2687	5.1	0.84	16.5	1.15
IS 2739	6.2	1.22	19.6	1.75*
IS 3461	3.8	0.67	17.7	1.09*
IS 7134	6.6	1.13	17.1	0.68
IS 7138	6.3	1.08	17.1	−0.60
IS 7151	7.1	1.22	17.1	1.41*
IS 8151	8.0	0.50	6.30	0.13
IS 8165	4.9	1.27	25.8	2.00**
IS 8190	7.5	0.74	9.90	1.02
IS 8196	5.7	1.06	18.6	1.16
IS 8198	5.1	0.81	15.7	0.79
IS 8204	4.4	0.81	18.5	1.49*
IS 8533	9.0	0.06	0.70	0.04
IS 8577	5.1	0.61	12.0	1.16
IS 8729	6.0	1.23	20.6	1.78*
IS 8849	6.1	1.57	25.9	2.85**
IS 8884	3.5	0.94	27.1	1.47*
IS 8887	3.2	1.14	36.0	1.59*
IS 8891	3.7	1.21	33.0	1.65*
IS 8922	5.2	1.01	19.3	1.65*
IS 8946	4.2	0.80	19.0	1.25
IS 8988	4.1	0.82	19.9	1.53*
IS 9009	6.7	0.58	8.60	1.05
IS 9021	5.7	0.61	10.6	0.95
IS 9045	6.1	1.01	16.4	1.69*
IS 9107	3.9	0.84	21.3	1.29
IS 9112	7.0	0.83	11.8	1.11
IS 15107	4.1	0.35	8.60	0.55
IS 18563	4.9	0.82	16.5	0.33
IS 18573	6.3	0.51	8.10	0.81
IS 18695	3.6	0.19	5.10	−0.16
IS 18696	3.2	0.60	18.7	1.15
IS 19476	3.4	1.14	33.4	1.80*
IS 21006	6.3	0.85	13.5	1.17
IS 21031	5.4	0.72	13.2	1.09
IS 21155	5.9	1.03	17.4	1.17
IS 21185	5.9	0.55	9.30	0.95
IS 21211	5.8	1.30	22.5	1.23
IS 21219	6.1	0.72	11.8	1.09
IS 21873	6.3	0.42	6.60	0.67
IS 21879	4.3	0.64	14.7	0.74
IS 21881	4.3	0.53	12.1	0.52
IS 22464	6.3	1.02	16.0	0.25
IS 22471	6.7	0.26	3.90	−0.07
IS 22806	3.2	1.02	31.8	1.58*
IS 31626	4.8	1.28	26.4	2.36*
IS 31635	5.1	0.66	12.8	1.23
IS 31636	3.9	0.79	20.0	1.44*
ICSV 197	2.8	0.66	23.3	1.31*
ICSV 392	4.9	0.88	17.7	1.35*
ICSV 393	4.6	1.10	24.0	2.14**
ICSV 730	3.3	0.22	6.60	0.32
ICSV 745	2.7	0.43	15.6	0.63
ICSV 88032	2.7	0.42	15.5	0.54
ICSV 93073	3.7	0.34	9.10	0.29
PM 12652-2	5.0	0.92	18.4	0.22
PM 20710-2	2.7	0.26	9.70	0.18
Controls				
AF 28	3.6	0.94	26.3	1.77*
DJ 6514	2.5	0.63	25.2	0.93
KAT 369	7.8	0.39	5.00	−0.39
Seredo	6.2	0.57	9.10	0.69
Serena	6.9	0.72	10.40	−0.42
Swarna	8.0	0.29	3.50	−0.42
SE ±	0.8	—	—	—

Note: DR 1 = Damage rating (1 = <10% midge damage, and 9 = >80% midge damage), SE = standard error, and *b* = regression coefficient.

* Regression coefficient significantly different from zero at $P = 0.05$.

** Regression coefficient significantly different from zero at $P = 0.01$.

2739, IS 7134, IS 7138, IS 7151, IS 8151, IS 8190, IS 8729, IS 18573, IS 21873, and IS 22471 were resistant to sorghum midge under natural infestation, but became susceptible under no-choice headcage conditions.

Under natural infestation; IS 3461, IS 8165, IS 18573, IS 21219, IS 22471, ICSV 392, ICSV 93073, KAT 369, Serena, and Swarna were most stable in their reaction to sorghum midge across seasons as their coefficient of variance was <10%, and the *t*-value of the regression coefficient was not significantly different from zero (which is taken as a measure of the stability of performance of a genotype) (Eberhart and Russell, 1966). Lines IS 2124, IS 8151, IS 8190, IS 18695, IS 8533 IS 9009, IS 9021, IS 15107, IS 18573, IS 21873, IS 21185, ISCV 23073, PM 20710-2 and ICSV 730 were stable under headcage screening. These lines showed <10% CV and their *t*-value of the regression coefficient was not significantly different from zero.

The *t*-value of the regression coefficient was not significantly different from zero for IS 8533, IS 8577, IS 18573, IS 18696, IS 21219, IS 21873, IS 21879, IS 21881, IS 22464, IS 22471, IS 31635, ICSV 88032, ICSV 93073,

Table 5
Stability of resistance (% damaged spikelets) of 64 sorghum lines to midge, *Stenodiplosis sorghicola* (ICRISAT Center, Patancheru 1995–1996)

Genotype	% midge damage	SE±	CV (%)	*b*
IS 2124	81.8	7.80	9.5	−0.44
IS 2687	44.6	9.27	20.8	2.79
IS 2739	51.5	11.10	21.5	4.66*
IS 3461	26.9	2.8	10.3	0.52
IS 7134	55.2	11.0	20.0	0.37
IS 7138	53.9	11.30	20.9	−2.87
IS 7151	64.8	10.0	15.4	2.00
IS 8151	67.3	7.90	11.7	0.55
IS 8165	41.8	11.7	28.0	5.21**
IS 8190	56.1	9.75	17.4	2.46
IS 8196	43.3	8.42	19.4	1.17
IS 8198	39.0	7.31	18.8	2.44
IS 8204	35.4	4.38	12.4	0.46
IS 8533	81.8	8.94	10.9	2.97
IS 8577	42.5	9.20	21.6	3.31
IS 8729	51.6	4.82	9.3	0.85
IS 8849	48.0	10.00	20.9	2.89
IS 8884	22.0	2.95	13.4	0.48
IS 8887	27.2	9.25	34.0	0.12
IS 8891	27.4	9.34	34.1	0.23
IS 8922	45.5	7.76	17.0	3.28
IS 8946	37.9	6.08	16.1	2.23
IS 8988	37.9	3.51	9.3	1.43
IS 9009	51.0	2.59	5.1	−0.73
IS 9021	47.9	3.94	8.2	0.29
IS 9045	49.0	6.68	13.6	2.41
IS 9107	41.0	8.37	20.4	2.44
IS 9112	65.0	6.44	9.9	1.48
IS 15107	37.5	6.57	17.5	−1.59
IS 18563	29.4	6.51	22.1	3.05
IS 18573	59.8	3.91	6.5	1.79
IS 18695	32.7	8.10	24.8	−3.09
IS 18696	28.2	2.35	8.3	1.13
IS 19476	28.4	8.56	30.1	0.71
IS 21006	51.5	3.74	7.3	1.21
IS 21031	42.3	9.34	22.1	1.26
IS 21155	49.6	9.48	19.1	−0.74
IS 21185	40.2	6.11	15.2	1.88
IS 21211	32.7	12.20	37.2	1.58
IS 21219	44.2	4.50	10.2	0.16
IS 21873	46.5	5.83	12.6	2.52
IS 21879	31.6	3.28	10.4	−0.69
IS 21881	34.6	4.71	13.6	−0.35
IS 22464	57.8	7.56	13.1	2.13
IS 22471	49.3	5.79	11.7	−0.55
IS 22806	26.9	9.39	34.9	0.85
IS 31626	43.4	7.76	17.9	3.44*
IS 31635	43.3	5.25	12.1	2.10
IS 31636	38.0	6.06	16.0	2.35
ICSV 197	22.6	3.94	17.4	1.72
ICSV 392	34.1	1.86	5.4	−0.10
ICSV 393	33.0	5.40	16.4	1.55
ICSV 730	21.2	1.29	6.1	−0.21
ICSV 745	19.0	2.14	11.3	−0.10
ICSV 88032	22.1	2.81	12.7	−0.74
ICSV 93073	26.2	3.86	14.7	−1.79
PM 12652-2	49.1	9.13	18.6	0.41
Controls				
PM 20710-2	18.0	4.07	22.6	−1.85
AF 28	25.6	6.22	24.3	0.91
DJ 6514	12.2	4.13	33.8	−0.43
KAT 369	65.5	4.57	7.00	−1.88
Seredo	53.6	6.35	11.8	1.94
Serena	56.4	9.10	16.1	0.72
Swarna	60.4	9.77	16.2	1.03
SE ±	8.5	—	—	—

(*Continued in next column*)

Table 5 (*Continued*)

Note: SE = standard error, and b = regression coefficient.
* Regression coefficient significantly different from zero at $P = 0.05$.
** Regression coefficient significantly different from zero at $P = 0.01$.

PM 12652-2, PM 20710-2, KAT 369, Serena, and Swarna, and thus these genotypes were stable in their reaction to sorghum midge across seasons and screening methods. The lines IS 2124, IS 2687, IS 8151, IS 8190, IS 8196, IS 8198, IS 8946, IS 9009, IS 9021, IS 9107, IS 9112, IS 15107, IS 18563, IS 18695, IS 21006, IS 21031, IS 21155, IS 21185, IS 21211, IS 22464, ICSV 730, ICSV 745, and DJ 6514 showed a stable reaction under headcage screening, but were unstable under natural infestation.

The sorghum lines were divided into seven groups using first two principal component analysis based on visual damage rating and percentage midge damage under headcage screening (Fig. 1). These results suggest that there is a considerable diversity in sources of resistance to sorghum midge.

4. Discussion

Thirty-nine lines showed resistance to sorghum midge both under natural infestation and no-choice headcage screening at ICRISAT Center over four seasons, but fourteen lines selected as resistant to midge under natural infestation showed susceptible reaction under no-choice headcage screening. This may be due to the absence of a non-preference mechanism of resistance to visiting females under headcage screening these lines may have flowered at times when the natural midge density was low under natural conditions.

Genotypes such as IS 3461 with high to moderate levels of resistance to midge across seasons and locations can be used to develop cultivars with stable resistance to sorghum midge. Unfortunately many lines showing resistance to sorghum midge at ICRISAT Center, India, were susceptible to midge in Kenya. Some lines were stable in their resistance to sorghum midge across seasons and screening methods.

Genotypes which showed moderate levels of resistance to both midge and leaf diseases at Alupe, Kenya can be

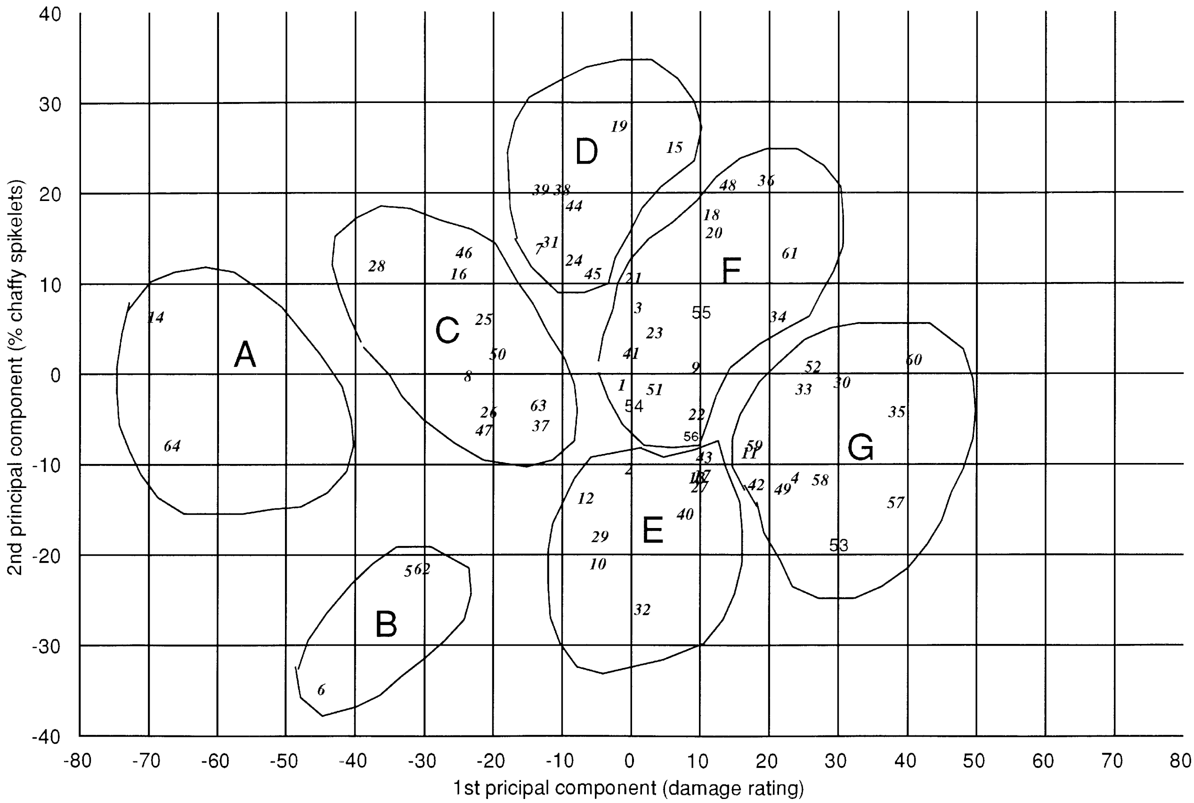

Fig. 1. Principal component analysis of 64 sorghum genotypes based on visual damage rating and percentage spikelets with midge damage. 1 = IS 2124, 2 = IS 2687, 3 = IS 2739, 4 = IS 4361, 5 = IS 7134, 6 = IS 7138, 7 = IS 7151, 8 = IS 8151, 9 = IS 8165, 10 = IS 8196, 11 = IS 8198, 12 = IS 8190, 13 = IS 8204, 14 = IS 8533, 15 = IS 8577, 16 = IS 8729, 17 = IS 8884, 18 = IS 8887, 19 = IS 8849, 20 = IS 8891, 21 = IS 8922, 22 = IS 8946, 23 = IS 8988, 24 = IS 9009, 25 = IS 9021, 26 = IS 9045, 27 = IS 9107, 28 = IS 9112, 29 = IS 15107, 30 = IS 18563, 31 = IS 18573, 32 = IS 18695, 33 = IS 18696, 34 = IS 18700, 35 = IS 19476, 36 = IS 21006, 37 = IS 21031, 38 = IS 21155, 39 = IS 21185, 40 = IS 21873, 41 = IS 21879, 42 = IS 21881, 43 = IS 21211, 44 = IS 21219, 45 = IS 22464, 46 = IS 22471, 47 = IS 22806, 48 = PM 12652, 49 = PM 12652-2, 50 = PM 13654, 51 = PM 13655, 52 = PM 20710-2, 53 = IS 31635, 54 = IS 31636, 55 = IS 31626, 56 = ICSV 745, 57 = ICSV 88032, 58 = ICSV 93073, 59 = ICSV 197, 60 = AF 28, 61 = Serena, 62 = Seredo, 63 = KAT 369, and 64 = Swarna.

used as sources of multiple resistance to these pests in sorghum breeding programs. In addition, IS 8589, IS 7148, IS 8733, and IS 2766 with high levels of resistance to leaf diseases original from eastern Africa can be useful for sorghum improvement programs in this region.

Several lines showing resistance to midge in India were susceptible in Kenya, while only a few lines suffered comparatively greater damage at ICRISAT Center, India, than in Kenya. Differences in midge damage at ICRISAT Center under natural infestation and headcage screening, and across seasons indicates that resistance to midge is influenced by several factors, and that there are possibilities of increasing the levels and stability of resistance to this insect by involving lines with diverse reactions/mechanisms of resistance. There is also a possibility of a different biotype of midge occurring in eastern Africa. Reports on the breakdown of resistance in lines derived from DJ 6514 have also been received from Yemen. Several factors govern the expression of resistance to midge (Sharma et al., 1990, 1993), and the variation of the chemical composition of sorghum grain and rate of grain development over seasons are associated with expression of resistance to sorghum midge (Sharma, H.C., unpublished).

Thus, reactions of sorghum genotypes to midge vary across seasons and locations. Sharma et al. (1988) observed that TAM 2566, DJ 6514, and IS 12666C are stable for resistance to midge over four seasons under no-choice headcage screening at ICRISAT Center, India. Faris et al. (1979) observed that AF 28 was the most stable line for resistance to sorghum midge across planting dates. Present studies confirmed that some sources of resistance to sorghum midge are stable across seasons and locations. Using Canonical variate and D^2 cluster analyses, AF 28 was distinct from other genotypes, while DJ 6514 and TAM 2566 are placed in the same group (Sharma et al., 1990). While AF 28 was stable in its reaction to sorghum midge across locations, TAM 2566 and DJ 6514 became susceptible at Alupe, Kenya.

Midge-resistant lines AF 28 and IS 8891 have stable resistance to midge across planting dates and infestation levels at Alupe, Kenya (Sharma et al., 1996). However, midge damage in these lines is greater in Kenya than that observed at ICRISAT Center. DJ 6514 and ICSV 197 showed moderate levels of resistance/susceptibility in Kenya (suffered 4 to 5 times more damage in Kenya than at ICRISAT Center, India). These observations suggest that factors other than midge density result in the break down of resistance in some genotypes at Alupe, Kenya. There are therefore considerable differences in the reactions of midge-resistant lines across seasons, and between the two sites in this study. Sources of resistance to sorghum midge are diverse, but there are possibilities for broadening the bases and increasing the levels of resistance to this insect by combining lines with diverse reactions/mechanism of resistance.

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