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Components of resistance to the sorghum midge, *Contarinia sorghicola*

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Summary

Studies were conducted on components of resistance to sorghum midge on four resistant (DJ 6514, AF 28, TAM 2566 and IS 15107) and two susceptible cultivars (CSH 1 and Swarna). Data were recorded on the numbers of eggs, larvae, emerged adults and grain damage in panicles of different genotypes infested with 60 midge females/panicle under no-choice conditions. The size of floral parts (glume, lemma, palea, lodicule, stigma, style, ovary and anther), rate of grain development and tannin content of grain were measured. The lengths of glume g1 and g2, lemma L1 and L2, palea, lodicule, anther, style and stigma were positively associated with susceptibility to sorghum midge. Rate of grain development (between 3rd and 7th day after anthesis) was negatively associated with susceptibility to sorghum. Tannin content of grain was also negatively correlated with midge susceptibility, although there were distinct exceptions (e.g. DJ 6514 is highly resistant but has a low tannin content).

Key words: Sorghum midge, *Contarinia sorghicola,* sorghum, resistance mechanisms, host-plant resistance.

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the most important cereal crops in Asia, Africa and Latin America. The grain yield on peasant farms is generally low, and insect pests are one major factor limiting production. Sorghum midge, *Contarinia sorghicola* Coq., is the most destructive pest of grain sorghum all over the world (Harris, 1976) and resistant cultivars are an important means of minimising midge damage to sorghum (Sharma, 1985*a,b*). Sorghum midge females have a life span of less than 24 h. They mate soon after emergence in the morning (0700-1100 h), and search for sorghum panicles at anthesis for oviposition. Eggs are laid inside the glumes. The larvae suck the sap of developing grain inside the glumes. As a result of larval feeding, the ovary remains undeveloped and the spikelets become chaffy.

There are a number of conflicting reports about the nature and mechanisms of resistance to sorghum midge. Short glumes (Ball & Hastings, 1912), cleistogamous glume character (long glumes) (Bowden & Neve, 1953), and nature of glume coupling (Geering, 1953; Bergquist, Rotar & Mitchell, 1974; Rossetto, Goncalves & Diniz, 1975) have been reported to be associated with midge resistance. However, Murty & Subramaniam (1978) reported that glume length, rachis length, and the presence of awns were not associated with midge resistance. The role of morphological characters of the florets, rate of grain development and the tannin content of sorghum grain as components of resistance to sorghum midge were studied.

Materials and Methods

The studies were conducted over four seasons (1982 to 1984) on four resistant cultivars – DJ 6514 (Shyamsunder, Parameshwarappa, Nagaraja & Kajjari, 1975), TAM 2566 (Johnson, Rosenow & Teetes, 1973), AF 28 (Rossetto *et al.*, 1975) and IS 15107 (Sharma, 1985*b*) and two susceptible (CSH 1 and Swarna) cultivars. The cultivars were planted in a randomised complete block design with three replications. Each plot was 12 m^2, and contained four ridges, 4 m long and 75 cm apart. The plants were thinned to 10 cm spacing within the row 15 days after emergence. Carbofuran 3G was applied to the soil at the rate of 1.2 kg a.i. ha^{-1} at sowing to protect the crop from shoot fly (*Atherigona soccata* Rond.). No insecticide was applied during the reproductive phase of the crop.

Assessment of numbers of eggs, larvae, emerging adults and grain damage. The numbers of eggs, larvae and adults were recorded in six cultivars over four seasons by artificially infesting the sorghum panicles at the top-anthesis stage. Sixty female midges were released on each panicle, using the headcage technique (Sharma, Vidyasagar & Leuschner, 1988). Midge females were collected with aspirators from sorghum panicles at anthesis. Midge adults emerge in the morning, mate within half an hour, and the females then search for sorghum panicles at anthesis for oviposition. Most of the oviposition takes place before 1400 h and the adults die within 24 h. Only freshly emerged females were collected and used for infestation between 0800-1000 h. The panicles were covered with muslin cloth bags at panicle emergence to avoid oviposition by the natural midge population. Nine randomly selected panicles were caged in each plot, of which three panicles each were utilised to record data on egg number, larval number and adult emergence. Grain damage was recorded in panicles used for recording larval numbers.

Eggs in florets were counted 2 days after caging midges on the sorghum panicles. Primary branches were taken from the top, middle and lower portion of the infested panicles and split into smaller secondary branches. From these, 250 florets were randomly selected to record the number of florets with eggs and the total number of eggs. Ten days after caging, the same sampling method was used on another three caged panicles/plot to assess the number of florets with midge larvae and the total number of larvae/300 florets. Five days later, grain damage was assessed from a sample of 500 florets by counting the number of chaffy florets (i.e. florets without grain as a result of larval feeding). Eggs, larvae and grain damage were expressed as a percentage or numbers/100 florets. The remaining three panicles/plot were used to record adult emergence. Midge emergence in the headcages was recorded daily between 15 and 30 days after infestation. The midges were collected with an aspirator and counted.

Floral morphology. The length of glumes (g1 and g2), lemmas (L1 and L2), palea, style and stigma and the length and breadth of lodicule, anther and ovary, were recorded on 10 randomly selected florets from the mid portion of three panicles in each genotype at anthesis using a binocular microscope fitted with an ocular micrometer.

Rate of grain development. The rate of grain development was measured in terms of grain width (size), fresh weight and dry weight. Random samples of 300 grains from the mid portion of three panicles of each cultivar were taken on alternate days between anthesis and 15 days after anthesis to record fresh weight and dry weight of the grain. Grains were oven-dried at 80°C to a constant weight. Grain width was measured with a specially designed grain-size metre on alternate days between anthesis and 15 days after anthesis. The rate of grain development between the 3rd and 7th day after anthesis showed the maximum association with midge resistance, and was used in correlation coefficient analysis. The rate of grain development was calculated as follows:

$$\text{Rate of grain development (G1, G2 and G3)} = \frac{\begin{array}{c}\text{Diameter or wt}\\ \text{of grain on 7th}\\ \text{day after anthesis}\end{array} - \begin{array}{c}\text{Diameter or wt}\\ \text{of grain on 3rd}\\ \text{day after anthesis}\end{array}}{\begin{array}{c}\text{Mean diameter or wt}\\ \text{of grain during}\\ \text{observation period}\end{array} \times \begin{array}{c}\text{Duration of}\\ \text{observation}\\ \text{period (days)}\end{array}}$$

G1 = Rate of grain development based on size
G2 = Rate of grain development based on fresh weight
G3 = Rate of grain development based on dry weight

Tannin content of grain. The tannin content of 10-day-old and mature grain was determined by the method of Mertin, Scoyoc & Butler (1978). The grain samples were collected from three uninfested panicles of each cultivar 10 days after anthesis and at maturity. The samples were taken from the mid portion of three panicles selected at random, and brought to the laboratory. The grains were oven-dried at 80°C before analysis.

Statistical analysis. Data were statistically analysed to determine the least significant differences between cultivars for the characters measured. Correlation coefficients between six dependent variables (number of eggs/100 florets, % florets with eggs, number of larvae/100 florets, % florets with larvae, % grain damage and adult emergence) and 12 independent variables (glume length g1 and g2, lemma length L1 and L2, palea length, lodicule length, anther length and breadth, rate of grain development G1, G2 and G3, and tannin content of 10-day-old and mature grain) were calculated.

Table 1. *Oviposition, larval numbers, adult emergence, and grain damage in six sorghum cultivars under no-choice conditions over four seasons at ICRISAT Center*

Cultivar	% florets with eggs	No. of eggs/100 florets	% florets with larvae	No. of larvae/100 florets	No. of adults emerged/panicle	Midge damage (% chaffy florets)
DJ 6514	23(28)[a]	37(6)[b]	7(14)[a]	8(2)[b]	15(3)[b]	15(22)[a]
AF 28	17(23)	21(4)	43(40)	6(7)	24(4)	33(34)
TAM 2566	18(24)	37(5)	31(34)	41(6)	33(6)	30(33)
IS 15107	23(27)	38(6)	47(42)	59(7)	71(8)	39(38)
CSH 1(S)	54(47)	153(12)	81(65)	142(12)	404(19)	81(65)
Swarna(S)	50(44)	141(11)	74(60)	127(11)	318(18)	83(66)
S.E. (±)	(2.9)	(0.9)	(3.2)	(1.2)	(1.1)	(4.1)
L.S.D. (0.05)	8.0	2.5	8.8	3.3	3.0	11.3

Figures in parentheses are a = Arcsin $\sqrt{\%}$ transformed values and b = Square root transformed values.
S = Susceptible check.

Results

Numbers of eggs, larvae and emerging adults. The percentage of florets with eggs and the number of eggs/100 florets were significantly higher in the susceptible cultivars, CSH 1 and Swarna (Table 1). AF 28 and TAM 2566 had a lower percentage of florets with eggs, followed

Table 2. *Length (L) and breadth (B) of floral parts[a], rate of grain development, and tannin content in six cultivars (mean of 4 seasons)*

	Glume		Lemma		Lodicule		Anther		Palea	Rate of grain[b] development			Tannins % (10-day-old grain)	Tannins % (matured grain)
	g1	g2	l1	l2										
Cultivar	L	L	L	L	L	B	L	B	L	G1	G2	G3		
DJ 6514	139	142	128	70	55	25	83	34	95	0.77	1.47	0.47	0.063	0.03
AF 28	137	139	130	110	51	23	90	32	99	0.75	1.87	0.97	13.800	7.00
TAM 2566	122	125	115	98	59	26	83	32	84	0.67	1.03	0.83	10.700	1.00
IS 15107	154	151	136	107	55	30	99	29	91	1.03	1.52	0.94	10.250	3.00
CSH 1	181	180	149	123	71	27	120	34	103	0.47	0.93	0.31	0.240	0.03
Swarna	188	192	163	137	59	32	108	30	105	0.47	0.85	0.55	5.930	0.03
SE(±)	2.5	2.6	2.1	2.0	1.2	0.7	1.3	0.7	3.4	0.1	0.1	0.1	2.7	0.2
LSD(0.05)	6.9	7.3	5.8	5.5	3.4	1.9	3.6	2.0	9.3	0.3	0.3	0.3	7.5	0.4

a. Linear measurements are in occular scale units (40 occular scale units = 1mm)
b. G1, G2, and G3 = Rates of grain development based on size, fresh weight, and dry weight, respectively. See text.

Table 3. *Correlation coefficients between characters for midge resistance and length (L) of floral parts, rate of grain development (G), and tannin content of grain.*

Character	Florets with eggs(%)	Eggs/ 100 florets	Florets with larvae(%)	Larvae/ 100 florets	Adults emerged/ panicle	Grain damage (%)
Glume g1 L	0.73**	0.69**	0.87**	0.75**	0.81**	0.79**
Glume g2 L	0.77**	0.73**	0.89**	0.74**	0.81**	0.80**
Lemma L1 L	0.67**	0.70**	0.82**	0.71**	0.78**	0.74**
Lemma L2 L	0.59**	0.60**	0.78**	0.88**	0.85**	0.79**
Palea L	0.56**	0.56**	0.56**	0.63**	0.67**	0.49**
Lodicule L	0.58**	0.51**	0.68**	0.50*	0.60**	0.59**
Ovary L	0.21	0.19	0.32	0.35	0.38	0.33
Anther L	0.72**	0.65**	0.89**	0.84**	0.89**	0.82**
Style L	0.68**	0.68**	0.80**	0.50*	0.59**	0.63**
Stigma L	0.32	0.26	0.26	0.25	0.31	0.24
G1	−0.20	−0.21	−0.35	−0.12	−0.25	−0.36
G2	−0.36	−0.54**	−0.50**	−0.33	−0.41*	−0.49*
G3	−0.49*	−0.53**	−0.37	−0.17	−0.31	−0.24
Tannins (10-day-old grain)	−0.62**	−0.52**	−0.51**	−0.33	−0.52**	−0.32
Tannins (matured grain)	−0.47*	−0.45*	−0.47	−0.23	−0.45*	−0.32

L = Length.
*, ** = Significant at $P < 0.05$, and $P < 0.01$, respectively.
G1, G2, and G3 = See text.

by DJ 6514 and IS 15107. The percentage of florets with midge larvae and the number of larvae/100 florets were lowest in DJ 6514 followed by TAM 2566, AF 28 and IS 15107. Fewer adults emerged in the midge-resistant cultivars than in the susceptible checks, CSH 1 and Swarna.

Grain damage. Grain damage was least in DJ 6514, closely followed by TAM 2566, AF 28, and IS 15107. In the midge-susceptible cultivars, grain damage (> 81%) was significantly higher ($P < 0.05$) than in the resistant ones (< 39%) (Table 1).

Floral morphology, rate of grain development and tannin content of grain. There were significant differences in linear measurements of the floral parts, rates of grain development and the tannin contents of the grain (Table 2). Floral parts of midge-resistant genotypes were significantly shorter than the susceptible checks. Rates of grain development in midge-resistant cultivars were higher than in the susceptible ones. Also, midge-resistant genotypes, except DJ 6514, had higher tannin content than the susceptible ones.

The rate of grain development was negatively associated with susceptibility to sorghum midge (Table 3). Glume g1 and g2, lemma L1 and L2, palea, lodicule, anther, style and stigma length were positively associated with susceptibility to sorghum midge. Tannin content of grain was also negatively correlated with susceptibility to midge, although there were distinct exceptions (e.g. DJ 6514 is highly resistant but has a low tannin content).

Discussion

Resistance to sorghum midge mainly consists of cultivar non-preference to adults, reduced oviposition and/or antibiosis (Sharma, 1985*b*). Cultivar non-preference to adults is an important component of resistance to sorghum midge (Wiseman & McMillian, 1968; Sharma *et al.*, 1990), but fails in the absence of a favourable host (Harris, 1961; Passlow, 1965; Sharma *et al.*, 1990). Visual and chemical stimuli from the host-plant influence the host finding and oviposition by the sorghum midge (Sharma *et al.*, 1990). A detailed study may help elucidate the factors that account for such differences in cultivar preference to adults. Cultivar non-preference can be used in conjunction with other mechanisms to strengthen and diversify the levels of resistance to this insect.

Under no-choice conditions in the headcage, the success in oviposition determined the differences in genotypic resistance to sorghum midge. This seems to be by far the most important component of resistance. Apparently, reduced oviposition is associated with short florets or floral parts, high rates of grain development and higher tannin content of grain (except in DJ 6514). Short glumes (Ball & Hastings, 1912) and nature of glume coupling (Rossetto *et al.*, 1975) have been reported to be associated with resistance to sorghum midge. Amongst resistant cultivars, adult emergence was relatively lower than the number of larvae/100 florets in DJ 6514, AF 28 and TAM 2566 but not in IS 15107. Larval mortality during development suggest that antibiosis contributes to resistance in some lines. The size of glumes in relation to that of grain and the rate of grain development may account for this by limiting the space for development between glumes and grain. In some resistant genotypes (e.g. TAM 2566), midge larvae have been observed to come out of glumes (H. C. Sharma, unpublished data).

The tannin content of grain may act as an antifeedant or antibiotic to the developing larvae (Rossetto, 1985). This may lead to extended period of development and/or lower survival of the larvae. Post-embryonic development was extended by 5-8 days on IS 10712, IS 19474, IS 19512 and TAM 2566 (H. C. Sharma, unpublished data). A correlation between tannins and resistance to sorghum midge has been suggested by Santos & Carmo (1974) and Sharma *et al.* (1990). Johnson (1977) reported that sorghum lines with the highest level of midge resistance have a testa, and such lines have a high tannin content (Kofoid, Maranville & Ross, 1982). Since resistance to sorghum midge is mainly influenced by the extent of oviposition, a high correlation between midge resistance and tannins cannot be established (Rossetto, 1985). This aspect can be properly understood by developing isolines for tannin content. The tannin content of grain varies both qualitatively and quantitatively during the grain development. Further studies are in progress to pinpoint the exact role of these components in the survival and development of sorghum midge.

Resistance to sorghum midge is mainly comprised of cultivar non-preference to adults, less oviposition and antibiosis. Short floral parts, faster rate of grain development and high tannin content of grain are apparently associated with resistance. However, there may be distinct exceptions to this trend. Sorghum midge resistant cultivars have different levels and/or combinations of the components associated with resistance, and there is a distinct possibility of increasing resistance levels and broadening the basis of resistance by hybridisation amongst the diverse sources.

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